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A special issue celebrating the opening of the Rose Center for Earth and Space

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COVER A full Moon shines over the Frederick Phineas and Sandra Priest Rose Center for Earth and Space on December 22, 1999.
STORIES BEGIN ON PAGE 46
PHOTOGRAPH BY DENIS FINNIN AND ROD NICKENS; AMNH
As this issue of Natural History goes to press, we here at the American Museum of Natural History are putting the final touches on one of the most spectacular and ambitious projects in the Museum's 130-year history—the new Frederick Phineas and Sandra Priest Rose Center for Earth and Space. This facility embodies a new vision of what it means to be a museum in the twenty-first century. To put it simply, we seek to perpetuate and extend dramatically the role of the Museum in communicating science to the public and advancing science literacy throughout the nation.

The Rose Center consists of a completely rebuilt and reimagined Hayden Planetarium, as well as the new Cullman Hall of the Universe and the Gottesman Hall of Planet Earth (which opened to great public and critical acclaim in June 1999). It addresses areas of science—astronomy and astrophysics—that are experiencing a true “golden age” of discovery.

When the first Hayden Planetarium was built in 1935, we had not seen quasars, pulsars, or black holes, nor did we even know that such curious objects could exist. In 1935 we had only fuzzy photographs of the planets of our Solar System; since then, we have walked on the Moon, sent robot probes to planets in the outer reaches of the Solar System, and discovered more than two dozen extrasolar planets. With the Rose Center, we seek to make astrophysics and cosmology—exceedingly complex, abstract areas of science—accessible and comprehensible to the public, and to bring the frontiers of outer space and discovery to the people. By taking our visitors on a journey that reveals the universe around us, we hope to illuminate the magnitude, majesty, and mystery of the cosmos and, ultimately, humanity's place in it.

Outfitted with a one-of-a-kind Hayden Edition Zeiss Projector, as well as with a revolutionary new digital map of our galaxy that will allow museumgoers to travel to the stars, the new Rose Center will also receive feeds from NASA, allowing us to learn of events and discoveries in space as they occur. In turn, the Rose Center will be able to transmit these images, along with our scientists’ interpretations of them, to classrooms, homes, and community centers across the city and the nation.

Together with our beloved existing exhibition halls, the Rose Center will enable the Museum to take visitors on a grand and all-encompassing journey that tells a coherent, comprehensive story of life, from the outer reaches of the universe to the planet’s inner core and through the extraordinary diversity of life and culture on Earth. Our extensive collections have long provided materials for retrospective scientific analysis, and now our cutting-edge technological capacities and research can produce up-to-the-minute observations through dramatic live images and contemporaneous explanation. We look forward to welcoming you to the new Rose Center for Earth and Space and to the Museum for the new millennium.

Ellen V. Futter, President
American Museum of Natural History
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TO THE EDITOR

A Tiny, Brainy Bird
In “The Cost of a Brain” (12/99–1/00), Göran E. Nilsson discusses absolute and relative brain size and cites squirrel monkeys and some bats as having the most impressive brain-to-body-weight ratio (5 percent) of all mammals, including humans.

Birds also provide a useful perspective on brain size. The common passerine (perching) bird is the largest passerine bird and reputedly one of the most intelligent, has a brain volume of 17 cc. The golden-crowned kinglet, weighing in at about 5 grams, is probably the smallest passerine. The volume of its brain is only 0.34 cc (one-fiftieth that of the raven’s). Relatively speaking, however, the golden-crowned kinglet’s brain is huge: 6.8 percent (as compared with the raven’s 1.3 percent) of body mass.

In general, the larger the brain, the more information-processing potential it has. But I speculate that being a passerine bird—perhaps like being a primate—requires a certain minimum amount of information-processing capacity, regardless of body size: hence the kinglet’s relatively large brain.

Incidentally, just because a bird is large doesn’t mean it has a big brain, even in absolute terms. A Rhode Island red has a pea-sized brain of only 3.1 cc (0.11 percent of body mass), even though it weighs twice as much a raven.

Bernd Heinrich
Burlington, Vermont

Golden-crowned kinglet

The Future of Vultures
I enjoyed “Cultureless Vultures,” by Richard Milner (12/99–1/00). However, it is probably not possible for a species that learns, shares, and transmits information to be without culture. The condors will succeed to the extent their new culture allows. We’ll just have to see what they teach their offspring.

While we can’t have cultureless vultures, it is possible to have vultureless cultures. My thanks to those taking steps to prevent such an outcome.

Kent Hanson
Everett, Washington

Pre-Adamite Pooh-Bah
As I read Stephen Jay Gould’s “Pre-Adamite in a Nutshell” (11/99), I looked forward to what I thought would be his inevitable allusion to Gilbert and Sullivan’s Mikado. I was disappointed to find that Gould had not somehow worked in the lines in which Pooh-Bah declares, “I am, in point of fact, a particularly haughty and exclusive person, of pre-Adamite ancestral descent. You will understand this when I tell you that I can trace my ancestry back to a protoplasmal primordial atomic globule.”

Danel Roberts
via e-mail

Duchamp’s Deckchairs
Even after reading “Boats & Deckchairs,” by Stephen Jay Gould and Rhonda Roland Shearer (12/99–1/00), I must admit that I would not have recognized the three objects in Marcel Duchamp’s painting as rowboats if they hadn’t been so labeled. And although I am usually good at seeing what is in an ambiguous image, try as I might, I couldn’t see deckchairs in the picture from any perspective.

Do I lack the imagination to follow where Duchamp, Gould, and Shearer lead, or are Gould and Shearer defining “plausible” more broadly than I would?

Harold Bailey
North Bend, Oregon

ECOLOGY

Kings (and Queens) of the Flooded Forest
The aquatic lowlands of the Amazon are home to a rebounding population of black caiman. Scientists explore the small, remote “nursery” lakes of Brazil’s Mamirauá Reserve, where these top predators nest.

GENETICS

Asthma and the Genome
The search for this common affliction’s controlling gene is turning up multifarious possibilities.
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For ten years, Merrill Lynch and the American Museum of Natural History have worked together to create a successful partnership built on a mutual belief in the importance of science and education, both today and in the next millennium.

A Partnership in Motion

Merrill Lynch
Science,” on view at the Museum from October 26, 1996 through January 1, 1997. This exhibition of a rare manuscript by Leonardo da Vinci offered an in-depth view of the scientific thinking of one of the greatest geniuses in the history of the Western world. The Codex Leicester, written between 1506 and 1510, opens a window into the mind of the awe-inspiring Renaissance artist, scientist, and thinker while illuminating both the scientific and creative process. This enlightening exhibition included an innovative demonstration room, lectures, and children’s workshops.

An additional grant from the Merrill Lynch Foundation in support of education programs to complement the exhibition allowed over 6,000 children from New York City public schools (grades 6-12) to attend the exhibition with a guide and to participate in special pre-and post-viewing programs.

The tremendous success of this partnership has led to an enduring relationship between the Museum and Merrill Lynch, and in 1996 Chairman and Chief Executive Officer David Komansky joined the Board of Trustees of the Museum.

“The American Museum of Natural History has been a source of inspiration, fun, and knowledge throughout my life,” says Komansky. “I’m pleased that, as a trustee of the Museum, I’m able to support the vital role this institution plays—not only in the metropolitan area, but wherever knowledge is highly valued.”

THE MOVEABLE MUSEUM

In July 1997, Merrill Lynch made a $1 million, three-year gift targeted to the Museum’s educational outreach programs. As part of the gift, Merrill Lynch purchased and outfitted a new “Moveable Museum,” a recreational vehicle converted into a mobile exhibition space. The Moveable Museum now travels to schools, community centers, parks, street fairs and other neighborhood organizations throughout the five boroughs of New York City.

The Merrill Lynch vehicle features an exhibition called “Structures and Culture,” which invites visitors to explore the traditional homes of nomadic people in Africa, Asia, the Middle East and North America and to discover what architecture and artifacts tell us about each culture.

“With our new ‘Structures and Culture’ Moveable Museum, we can bring thousands of school kids on a virtual, round-the-world expedition of cultural discovery,” says Jeff Rodgers, Director of the Moveable Museum Program. “Merrill Lynch helped us create a new way for kids to learn about their world without ever leaving their neighborhood.”

“I’m especially proud that Merrill Lynch will be honored for helping the Museum fulfill its growing mission. The truth is, it’s very easy to support an institution that appeals to all people and is characterized by excellence at every turn.”

David Komansky

year’s program was so rich. Not only did I learn earth science in the Hall of Planet Earth, but I also learned about myself by interacting with such a diverse group of people.”

THE PARTNERSHIP

In 2000, the American Museum of Natural History will honor David Komansky and Merrill Lynch for their generous support of the institution and of science and education in general. “David Komansky and Merrill Lynch have been generous both with the Museum and the entire New York City community. David is a valued trustee and member of the business community and we look forward to acknowledging his and Merrill Lynch’s tremendous support and vision as we enter the new millennium,” says Ellen V. Futter, President of the American Museum of Natural History.

For information on the many programs that the American Museum of Natural History offers, please call 212-769-5100.
Allan Sandage ("Twinkle Twinkle," page 64) has made lasting contributions to two of the defining pursuits of twentieth-century astronomy. During his student days at the California Institute of Technology, his talents in determining the parallaxes and motions of stars brought him to the attention of Edwin Hubble. When Hubble died, in 1953, Sandage inherited the great astronomer's long-term project to find Hubble's constant, a number astronomers would later use to determine the age of the universe (which Sandage now estimates to be about 15 billion years). Yet Sandage has never wavered from his first love, the stars. He codiscovered quasars and has gone a long way toward fulfilling his dream of learning "everything about everything"—at least in the realm of astronomy.

Henry S. F. Cooper Jr. ("Sphere of Influence," page 50) remembers sitting in a cavity inside a gigantic meteorite when he visited the Hayden Planetarium in 1937. He was four years old. At fourteen, he reviewed Jules Verne's From the Earth to the Moon for his high school newspaper. Ten years later, after he had graduated from Yale, this same book inspired his first piece as a staff writer for the New Yorker, on the transformation of science fiction into science fact. The exploration of space remains a fascination of Cooper's; he has published eight books on the subject, including Thirteen: The Apollo Flight That Failed (Johns Hopkins University Press, 1995) and The Evening Star: Venus Observed (Farrar, Straus and Giroux, 1993).

Since January 1996, R. Paul Butler ("Prospecting for Planets," page 67), an astrophysicist at Carnegie Institution of Washington’s Department of Terrestrial Magnetism, has detected—working with fellow planet-hunter Geoffrey Marcy—more than two-thirds of the twenty-eight known planets outside our Solar System. So efficient is the technique he's helped perfect—deducing the presence of a planet from the gravitational wobble of its parent star—that Butler himself sometimes struggles to remember the official tally of the planets. In early November, after a two-night observation run on one of the 10-meter Keck telescopes on Mauna Kea in Hawaii, Butler e-mailed Natural History, "When I wrote this piece, there were 22 extrasolar planets, but I used the number 25 so it wouldn't be out of date by February. Strangely, we just discovered 6 more, so the number now stands at 28.”

Before becoming director of special projects at the Hayden Planetarium, James S. Sweitzer ("Theater of the Stars," page 60) was assistant director of Chicago’s Adler Planetarium. Already enthralled with electronic devices in his childhood, Sweitzer built an electrostatic generator. He worked his way through his undergraduate years at the University of Notre Dame as a nuclear physics technician on particle accelerators. For five years, Sweitzer was assistant director of the Center for Astrophysical Research in Antarctica, overseeing the building of an observatory telescope to detect radiation from the big bang. "Building the Rose Center," he says, "is just a continuation of working on science projects, only on the largest scale and involving a simulation of the entire universe.”

Michael Shara ("Cannibals of the Cosmos," page 70) is curator-in-charge of the Museum’s Department of Astrophysics. As an undergraduate at the University of Toronto, Shara read an illustrated article explaining that a head-on collision between two Sun-like stars could lead to either a gentle merging or a catastrophic destruction of both stars, depending on the impact speed. "That a computer could produce such breathtaking simulated pictures of an event no human has ever witnessed seemed magical to me," he says. "I was determined to advance that field of research." After earning a Ph.D. in 1978 from Tel Aviv University, he went to work at the Space Telescope Science Institute, eventually leading the committees that allocate observing time on the Hubble Space Telescope. He regrets having too little time for scuba diving and squash.
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At the Harvard-Smithsonian Center for Astrophysics, Margaret J. Geller ("The Big Picture," page 74) has worked since the early 1980s with colleagues and students to map the universe and understand its structure. She became a MacArthur Fellow in 1990 and has also received awards for her work in physics and astronomy. As a child, Geller was the family navigator during vacations, never dreaming she would "one day make maps on such a grand scale." Combining her interests in astronomy and the visual arts, she has made two documentary films—Where the Galaxies Are and So Many Galaxies... So Little Time—and is at work on another one, about Cecilia Payne-Gaposchkin, the woman who discovered that stars are made of hydrogen.

Mordecai-Mark Mac Low ("The Virtual Universe," page 88) grew up in the South Bronx and first visited the Hayden Planetarium as a child. He now is a member of the Museum's newly founded Department of Astrophysics and, for his research, uses the supercomputers at the Hayden Planetarium. After completing his doctorate in physics at the University of Colorado at Boulder, he held postdoctoral fellowships at the NASA Ames Research Center (near San Francisco) and the University of Chicago. He then moved to Heidelberg, Germany, to the Max-Planck-Institut für Astronomie. "Having lived in every time zone in the lower forty-eight, and having lived in Europe as well," he says, "I admit to being quite surprised and pleased to find myself back in my hometown."

In 1979 Alan H. Guth ("Genesis: The Sequel," page 77) worked out the equations for what he would come to call the inflationary era of the universe. This concept has thoroughly revolutionized cosmology over the past two decades, by answering many of the questions about the origins of the universe that the standard big bang theory couldn't. Guth's primary interest was originally particle physics, but after almost serendipitously hearing talks about the early universe by Robert Dicke and Steven Weinberg, he realized that in the extreme high-energy conditions of the big bang, cosmology and particle physics were essentially one and the same. Guth, a professor at MIT, tells the story in The Inflationary Universe: The Quest for a New Theory of Cosmic Origins (Perseus Books, 1998).

Except for two brief periods, David J. Helfand ("Seeing the Whole Symphony," page 84) has been at Columbia University and its Astrophysics Laboratory for his entire career. "Unlike most astronomers," says Helfand, who earned his M.S. in physics and his Ph.D. in astronomy at the University of Massachusetts, "I did not have a telescope when I was nine years old and indeed was a theater major at Amherst College. Whereas I was statistically unlikely to work regularly as an actor, I discovered I could give ninety-minute monologues to customers willing to pay very high prices for seats in an astronomy class." Helfand has now found a considerably bigger theater of operations: his team's current cosmic survey of radio waves will provide precise information about the geometry of the universe.

Brian Greene ("The Heart of Matter," page 80), a professor of both physics and mathematics at Columbia University, has been working on superstring theory for more than a decade. Greene's research focuses on the new features of space and time that emerge from unifying the laws of physics. He is the codiscoverer of mirror symmetry (the recognition that distinct geometrical forms of space can yield physically identical universes) and of smooth topology change (which shows that the fabric of space can not only stretch but also tear). Greene "enjoys finding entertaining ways to communicate cutting-edge physics to those without technical training." His book on the subject—The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory (W. W. Norton, 1999)—explains to the layperson the behavior of the universe on both cosmological and subatomic scales.
A new light on our horizon.
Con Edison congratulates the
American Museum of Natural History
as the Rose Center for Earth and Space
opens its doors to the minds and
imaginations of the next generation.
A Show of Planets

By Joe Rao

Mercury appears as a rather conspicuous evening "star" for the first three weeks of February, shining at magnitude -1 to 0. By February 6, it sets about an hour and fifteen minutes after sunset. On that same evening, you will find it just 2.5° to the right of and slightly above a very thin crescent Moon. Mercury's greatest elongation (or maximum angular distance from the Sun) comes on February 14, when and the Sun (inferior conjunction) on March 1. Mercury has an undeserved reputation for being hard to see: you just have to look in the right place at the right time. In short, this is a good month to join the small number of people who have laid eyes on the innermost planet.

Venus becomes visible as the night nears an end. It is still brilliant the planet is positioned only 18° away from the Sun in the twilight sky but will appear almost directly above it as both descend in the west. The Sun keeps a tight rein on Mercury this month because the planet's greatest elongation falls on the day before its perihelion, when it is physically closest to the Sun. This circumstance offers a very favorable opportunity to see Mercury. Later in the month, as its crescent rapidly thins, the planet plunges back into the Sun's glare and quickly fades. It passes between Earth (magnitude -4) in the morning sky, although it is not as high or as prominent as it has been in recent months. At the beginning of the month it rises with the first light of dawn 90 minutes or so before the Sun and is still very low in the southeast as dawn grows bright. It sinks lower and lower as the month wears on, and by month's end it is rising only an hour before the Sun. A waning crescent Moon will be about 2° above and slightly to the right of Venus on the morning of February 2.

Mars now appears as a moderately bright yellowish-orange star of magnitude +1.2. It sits low in the southwest sky at dusk and sets about 8:30 P.M. local time all through the month. The waxing crescent Moon passes about 5° to the left of Mars at dusk on February 8.

Jupiter, in the constellation Aries, is below and to the right of Saturn during the early evening hours. The king of the planets shines brilliantly at magnitude -2.3 and appears nearly a dozen times brighter than Saturn. These two giant planets slowly edge closer together all month: 12° separate them on the 1st, 10° on the 28th. A fat crescent Moon will pass about 5° below and to the left of Jupiter during the late evening hours of February 10.

Saturn shines at magnitude +0.3 and is also found in Aries. It remains about 18° southwest of the Pleiades and well to the northeast of Jupiter and is visible until about midnight. A telescope will reveal its beautiful ring system, now tilted some 21° to our line of sight, with the south face visible. The Moon will lie about 4° to the left of and slightly below Saturn late on the evening of February 11.

The Moon is at new phase on February 5 at 8:03 A.M. First quarter occurs on February 12 at 6:21 P.M., full Moon on February 19 at 11:26 A.M., and last quarter on February 26 at 10:53 P.M.

Unless otherwise noted, all times are given in Eastern Standard Time.

Joe Rao is a lecturer at the American Museum–Hayden Planetarium.
Recipe for a Universe

Mathematical laws drive not only the microworld of atoms—and the forces linking them together—but the whole fabric of the cosmos.

REVIEW
By Jeremiah P. Ostriker

Cosmology is a subject that no culture has done without. For most of Western history, placing the observable world in the context of time and space has been a speculative, philosophical endeavor—not a field of quantitative reasoning.

When I received my Ph.D. in astrophysics in 1964, some aspects of the subject had entered the modern era, but the flavor of speculative ideology was still strong. At that time, galaxies essentially defined the objects to be observed, and the properties to be discussed were their number, their apparent brightness, their distance from us, and the velocity at which they were speeding away. Such information was combined and manipulated to answer two questions raised by Einstein’s general theory of relativity: What is the age of the universe (following the big bang)? Will the universe expand forever, or will it stop expanding, reverse course, and recollapse?

Since that time, our knowledge has grown enormously, as has the complexity of the questions. The features of big bang cosmology have been so well confirmed, both by the distribution of the light chemical elements cooked up in that early furnace and by direct measurements of cosmic background radiation, that the majority of cosmologists have no doubt about the basic accuracy of the model.

But now we recognize that the galaxies are not eternal and unchanging and that to use them in empirical studies, we need to understand their formation and evolution. We also know that ten times more dark matter of a mysterious nature exists than does normal matter, which is detectable by the radiation it emits or absorbs. What we know as normal matter (on the basis of measured gravitational forces) accounts for perhaps only 10 percent of what’s out there.

Martin Rees, England’s astronomer royal, addresses these questions at the level of fundamental physics. Starting with Earth, other Solar System planets, and nearby stars, he carries us through our galaxy and out into the cosmos on its grandest scale. Although this is a brief, clear, wise, and witty book, it is challenging to read. Translating the fundamental laws of physics into accessible language, Rees explains why the chemistry necessary for life is possible; why nuclear-powered stars can exist in equilibrium; why structure developed at all (as opposed to the universe’s evolving in a featureless void); and why there may exist a repulsive force (unlike gravity, which makes all matter attract all other matter) that causes the universe to expand at an ever accelerating rate. Rees does not directly address the so-called anthropic principle—that the universe had to be just so to allow complex life to form—but leaves it for the reader to discover (or rediscover) unaided.

The story is presented in terms of dimensionless numbers (those whose values are independent of the units used). One of these is π, familiar to us all as the ratio of the circumference of a circle to its diameter. Another is c/√(GMₑ)—the ratio of the electrostatic forces pushing apart two electrons to the gravitational forces pulling them together—one of the famous “big numbers” of physics, roughly ten followed by forty zeroes. (Gravity, although it dominates at cosmic scales, is extraordinarily weak compared with atomic forces.) Rees shows, without using any mathematics, how such numbers determine the structure of our universe.

It is all here, with the tale told—for once—by someone who understands the story.

Jeremiah P. Ostriker, a professor of astrophysics and provost at Princeton University, is a trustee of the American Museum of Natural History.
Racing To The Moon.

Instinct and moonlight guide them to the ocean. For newborn sea turtles, it is a run for survival. They must quickly move past predators to the safety of deep water. That’s why people working in partnership on Thevenard Island conceal the light from their oil and gas operations. So the turtles won’t be drawn off-course. Which helps protect a threatened species by making certain the only light visible is the one that leads home.

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The Moon’s Violent Birth

About 4.5 billion years ago, somewhere between the present orbits of Earth and Mars, a planet about the size of Mars probably struck the embryonic Earth in a collision that ultimately created Earth’s only satellite. Known as the giant impact theory, this scenario largely accounts for the particular chemical composition of both bodies, explaining, for instance, why the Moon has only a tiny metallic core and Earth has a considerable one. It also accounts for the amount of angular momentum in the Earth-Moon system. (Angular momentum is the measure of motion of objects in curved paths. In this case, it means the spin of each body plus the orbital motion of the Moon around Earth.) As shown here, the young Earth was probably almost completely molten during this process.

A Mars-size impactor smacks the embryonic Earth, heating and deforming both bodies and spewing ejecta into space.

The impactor rebounds and hits Earth again. Its metallic core gets incorporated into Earth’s core.

An orbiting ring of very hot ejecta, very little of it metallic, eventually cools and condenses into discrete particles.

As particles accrete, they sweep up the disk of ejecta. Within about ten years, the largest body sweeps up the remaining debris to become our Moon.
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Here Be Dragons: The Scientific Quest for Extraterrestrial Life, by David W. Koerner and Simon LeVay (Oxford University Press, 2000; $27.50; 256 pp.)

The authors—a planetary scientist and a neuroanatomist—describe the exciting, provocative work of such scientists as NASA Ames Research Center's Chris McKay, who is investigating cold, dry environments that might offer clues to life in the cosmos, and Carnegie Mellon University's Hans Moravec, a "roboticist, futurologist, and general out-of-the-box thinker." Whoever predicted the end of science was dead wrong.

The Invisible Universe, by David M. Draper (Bulfinch Press/Little, Brown, 1999; $60; 176 pp.; illus.)

Amid the avalanche of late-twentieth-century discoveries in astronomy and astrophysics, Goldsmith traces the key steps that led to the vindication of Einstein's nonzero "cosmological constant" and the further recognition that the universe appears to be expanding at an accelerating pace.

The Search for Life on Mars, by Malcolm Walter (Perseus/Helix, 1999; $25; 170 pp.; illus.)

The more we investigate Earth's earliest life forms, the more we recognize the similarities between our planet and Mars. Walter, an Australian paleobiologist, astrobiologist, and longtime NASA adviser, surveys the strategies and possible results of future explorations of the red planet.

The Runaway Universe: The Race to Find the Future of the Cosmos, by Donald Goldsmith (Perseus/Helix, 2000; $25; 256 pp.; illus.)

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Astrobiology

Water has been found in the soils of the polar craters of the Moon. One of the missions of the failed Mars Polar Lander was to look for signs of frozen water in the soil of the red planet. Investigating the watery, methane-rich atmosphere of Saturn’s moon Titan and the suspected liquid ocean beneath the icy surface of Jupiter’s moon Europa is a major goal for future exploration. Water being one of the prerequisites for life, these efforts are part of a larger astrobiological NASA mission to probe the origin and distribution of life in the universe.

A rather broad discipline, astrobiology is barely five years old, yet it has become the umbrella under which a great deal of space science is conducted. To get an idea of how much is encompassed by this branch of science, visit the Astrobiology Web (www.astrobiology.arc.nasa.gov/). In addition to posting the latest research news from the field, the site has an impressive listing of astrobiology-related articles and Web pages; subjects range from the first animals to leave Earth (canine cosmonaut Laika and primate cosmonaut Ham) to terraformation (the engineering of planetary environments).

Life in Extreme Environments, for example, profiles a number of interesting (and tenacious) organisms that could conceivably move between planetary systems on space voyages of a million years or more. I was intrigued by the superbacterium Deinococcus radiodurans (in the Radiation Tolerance section), discovered in a can of beef that went bad despite sterilizing radiation. It can apparently survive a radiation dose of 1.5 million rads (about 3,000 times the level needed to kill most organisms—from microbes to humans) and has a knack for rapidly repairing its DNA. Another bug, Staphylococcus mitis (in the Life at Varied Pressures section), supposedly survived for almost three years on the Moon aboard Surveyor 3 in the late 1960s.

A related and perhaps broader subject is astrochemistry, the study of the chemical reactions that lead to the evolution of life. How do inorganic molecules assemble to start life? And how easily does it happen? See NASA’s astrobiology site (astrobiology.arc.nasa.gov/index.cfm) for an overview of current research—from microbial mats to the complex organic molecules that form on comets. In the near future, this site will also have a section called Astrobiology for Kids, which will answer questions about how common life is among the stars and how rare Earth-like planets really are.

Robert Anderson is a freelance science writer based in Los Angeles.
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Thirty years ago, people were walking on the moon. Back then, everyone assumed that Neil Armstrong’s “one small step” was the first on a great journey that would soon take us to Mars and the satellites of Jupiter and Saturn. We had grand dreams of discovering other worlds, landing with our spaceships and tramping proudly over the ground. None of that happened. Instead, the emphasis shifted to unmanned vehicles, because they were able to go farther and see more than people could. And so we sat in front of our television sets watching Star Trek, while our marvelous instruments in space—the Hubble Space Telescope and the Voyager and Galileo spacecraft—did the job of exploring for us. In this manner, the dreams of the 1960s died and, with them, our vision of why we had wanted to explore space in the first place.

Human nature has often led us along this path of boom and bust. We dream great dreams, invest in great engineering projects—enormous dams and nuclear power stations—and then let them die. But each of these cycles leaves behind something of permanent value—a residue of knowledge, a new science or industry, a stepping-stone toward the dreams of the next generation.

Sooner or later, there will be new dreams of the exploration of the universe by humans. Fulfilling these dreams will require new and drastically cheaper technologies, based on biology rather than on massive engineering. We will need inexpensive ways of traveling to new worlds and staying alive once we are there. Bioengineering and biotechnology will allow us to grow new species of plants, microbes, and animals adapted to living in harsh environments. The trick will be to breed plants that generate their own greenhouses to sustain warmth, moisture, and air. This kind of ecosystem could be created on Mars, Saturn, and places even farther from the Sun.

Such dreams make sense only for worlds with no life of their own. If we find life on Mars, for example, we should leave the planet alone and move on to some of the billions of lifeless worlds where, with a little help from humans, terrestrial life might flourish. Even as far away as Pluto, plants could be warm and cozy in greenhouses that had big mirrors around them to collect sunlight. (The same plants that make use of biotechnology to make the greenhouses could produce the mirrors as well.) Life, once it has made the big jump away from Earth, could adapt itself to take root almost anywhere, since its necessary ingredients—sunlight, a supply of common chemicals, and water—are found in abundance throughout the universe. We will have to tread lightly, though, just as we must do on Earth, if we are not to destroy the newly created ecosystems.

We are a restless species. After another century or two, when life and human settlements have spread widely in space, we will dream again of giant engineering projects. Technologies based on resources drawn from all over the Solar System will make interstellar trips affordable. The dream of spreading life as we know it throughout the Galaxy might come true—unless, as the poet Robinson Jeffers warned, the day comes “when the earth will scratch herself and smile and rub off humanity.” That future is also possible, if we behave foolishly. The choice is ours.

By Freeman J. Dyson

Freeman J. Dyson is professor emeritus in the School of Natural Sciences at the Institute for Advanced Study in Princeton, New Jersey. His latest book is The Sun, the Genome, and the Internet: Tools of Scientific Revolutions (Oxford University Press, 1999).
What does the dreaded “E”

A reverie for the opening of the new Hayden Planetarium

By Stephen Jay Gould

Evolution posed no terrors in the liberal constituency of New York City when I studied biology at Jamaica High School in 1956. But our textbooks didn’t utter the word either—a legacy of the statutes that had brought William Jennings Bryan and Clarence Darrow to legal blows at Tennessee’s trial of John Scopes in 1925. The subject remained doubly hidden within my textbook—covered only in chapter 63 (of 66) and described in euphemism as “the hypothesis of racial development.”

The antievolution laws of the Scopes era, passed during the early 1920s in several southern and border states, remained on the books until 1968, when the Supreme Court declared them unconstitutional. The laws were never strictly enforced, but their existence cast a pall over American education, as textbook publishers capitulated to produce “least common denominator” versions acceptable in all states—so schoolkids in New York got short shrift because the statutes of some distant states had labeled evolution dangerous and unteachable.

Ironically, at the very end of this millennium (I am writing this essay in late November 1999), demotions, warnings, and anathemas have again come into vogue in several regions of our nation. The Kansas school board has reduced evolution, the central and unifying concept of the life sciences, to an optional subject within the state’s biology curriculum—an educational ruling akin to stating that English will still be taught but that grammar may henceforth be regarded as a peripheral frill, permitted but not mandated as a classroom subject. Two states now require that warning labels be pasted (literally) into all biology textbooks, alerting students that they might wish to consider alternatives to evolution (although no other well-documented scientific concept evokes similar caution). Finally, at least two states have retained all their Darwinian material in official pamphlets and
word mean, anyway?
curricula but have replaced the dreaded "e" word with a circumlocution, thus reviving the old strategy of my high school text.

As our fight for good (and politically untrammeled) public education in science must include our forceful defense of a key word—for inquisitors have always understood that an idea can be extinguished most effectively by suppressing all memory of a defining word or an inspirational person—we might consider an interesting historical irony that, properly elucidated, might even aid us in our battle. We must not compromise our showcasing of the "e" word, for we give up the game before we start if we grant our opponents control over basic terms. But we should also note that Darwin himself never used the word "evolution" in his epochal book of 1859. In Origin of Species, he calls this fundamental biological process "descent with modification." Darwin, needless to say, did not shun "evolution" from motives of fear, conciliation, or political savvy but rather for an opposite and principled reason that can help us appreciate the depth of the intellectual revolution that he inspired and some of the reasons (understandable if indefensible) for the persistent public unease.

Pre-Darwinian terminology for evolution—a widely discussed, if unorthodox, view of life in early nineteenth-century biology—generally used such names as transformation, transmutation, or the development hypothesis. In choosing a label for his own, very different account of genealogical change, Darwin would never have considered "evolution" as a descriptor, because that vernacular English word implied a set of consequences contrary to the most distinctive features of his proposed revolutionary mechanism of change.

"Evolution," from the Latin evolvere, literally means "an unrolling"—and clearly implies an unfolding in time of a predictable or prepackaged sequence in an inherently progressive, or at least directional, manner (the "fiddlehead" of a fern unrolls and expands to bring forth the adult plant—a true evolution of preformed parts). The Oxford English Dictionary traces the word "evolution" to seventeenth-century English poetry. Here the word's key meaning—the sequential exposure of prepackaged potential—inspired the first recorded usages in our language. For example, Henry
More (1614–87), the British philosopher responsible for several of the seventeenth-century citations in the OED entry, stated in 1664, “I have not yet evolved all the intangling superstitions that may be wrap up.”

The few pre-Darwinian English citations of genealogical change as “evolution” all employ the word as a synonym for predictable progress. For example, in describing Lamarck’s theory for British readers (in the second volume of his Principles of Geology, 1832), Charles Lyell generally uses the neutral term “transmutation”—except in one passage, where he wishes to highlight a claim for progress: “The testacea of the ocean existed first, until some of them by gradual evolution were improved into those inhabiting the land.”

Although the word “evolution” does not appear in the first edition of Origin of Species, Darwin does use the verbal form “evolved,” clearly in the vernacular sense and in an especially crucial spot: the very last word of the book! Most students have failed to appreciate the incisive and intended “gotcha” of these closing lines, which have generally been read as a poetic reverie, a harmless linguistic flourish essentially devoid of content, however rich in imagery. In fact, the canny Darwin used this maximally effective location to make a telling point about the absolute glory and comparative importance of natural history as a calling.

We usually regard planetary physics as the paragon of rigorous science, while dismissing natural history as a lightweight exercise in dull, descriptive cataloging that any person with sufficient patience might accomplish. But Darwin, in his closing passage, identified the primary phenomenon of planetary physics as a dull and simple cycling to nowhere, in sharp contrast with life’s history, depicted as a dynamic and upwardly growing tree. The Earth evolves in uninteresting sameness, but life evolves by unfolding its potential for ever expanding diversity along admittedly unpredictable, but wonderfully various, branchings:

Whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved.

But Darwin could not have described the process regulated by his mechanism of natural selection as “evolution” in the vernacular meaning then conveyed by the word. For the mechanism of natural selection yields only increasing adaptation to changing local environments, not predictable progress in the usual sense of cosmic or general betterment expressed as growing complexity, augmented mentality, or whatever. In Darwin’s causal world, an anatomically degenerate parasite, reduced to a formless clump of feeding and reproductive cells within the body of a host, may be just as well adapted to its surroundings, and just as well endowed with prospects for evolutionary persistence, as is the most intricate creature, exquisitely adapted in all parts to a complex and dangerous external environment. Moreover, since natural selection can adapt organisms only to local circumstances, and since local circumstances change in an effectively random manner through geological time, the pathways of adaptive evolution cannot be predicted.

Thus, on these two fundamental grounds—lack of inherent directionality and lack of predictability—the process regulated by natural selection could scarcely have suggested, to Darwin, the label “evolution,” an ordinary English word for sequences of predictable and directional unfolding. We must then, and obviously, ask how “evolution” achieved its coup in becoming the name for Darwin’s process—a takeover so complete that the word has now almost (but not quite, as we shall soon see) lost its original English meaning of “unfolding” and has transmuted (or should we say “evolved”? ) into an effective synonym for biological change through time.

This interesting shift, despite Darwin’s own reticence, occurred primarily because a great majority of his contemporaries, while granting the overwhelming evidence for evolution’s factuality, could not accept Darwin’s radical views about the causes and patterns of biological change. Most important, they could not bear to surrender the comforting and traditional view that human consciousness must represent a predictable (if not a divinely intended) summit of biological existence. If scientific discoveries enjoined an evolutionary reading of human superiority, then one must bow to the evidence. But Darwin’s contemporaries (and many people today as well) would not surrender their traditional view of human domination, and therefore could conceptualize genealogical transmutation only as a process defined by predictable progress toward a human acme—in short, as a process well described by the term “evolution” in its vernacular meaning of “unfolding an inherent potential.”

Herbert Spencer’s progressivist view of natural change probably exerted the greatest influence in estab-
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lishing “evolution” as the general name for Darwin’s process, for Spencer held a dominating status as Victorian pundit and grand panjohn-drum of nearly everything conceptual. In any case, Darwin had too many other fish to fry and didn’t choose to fight a battle about words rather than things. He felt confident that his views would eventually prevail, even over the contrary etymology of a word imposed upon his process by popular will. (He knew, after all, that meanings of words can transmute within new climates of immediate utility, just as species transform under new local environments of life and ecology!) Darwin never used the “e” suspected a basic biological determinism behind our opposite choices. Carl was tall and looked up toward the heavens; I am shorter than average and tend to look down at the ground.)

My essays may be known for their tactic of selecting odd little tidbits as illustrations of general themes. But why, to mark the reopening of the Hayden Planetarium, would I highlight such a quirky and apparently irrelevant subject as the odyssey of the term “evolution” in scientific, and primarily biological, use—thus seeming, once again, to reject the cosmos in favor of the dinosaurs? Method does inhere in my apparent madness.

Darwin himself never uses the word “evolution” in Origin of Species. He calls the process “descent with modification.”

word extensively in his writings, but he did capitulate to a developing consensus by referring to his process as evolution for the first time in Descent of Man, published in 1871. (Still, Darwin never used the word “evolution” in the title of any book—and he chose, in his book on human history, to emphasize the genealogical “descent” of our species, not our “ascent” to higher levels of consciousness.)

When I was a young boy, growing up on the streets of New York City, the American Museum of Natural History became my second home and inspiration. I loved two exhibits most of all—the Tyrannosaurus skeleton on the fourth floor and the star show at the adjacent Hayden Planetarium. I juggled these two passions for many years and eventually became a paleontologist; Carl Sagan, my near-contemporary from the neighboring newland of Brooklyn (I grew up in Queens) weighed the same two interests in the same building but opted for astronomy as a calling. (I have always (whether or not I succeed in conveying this reasoning to my readers). I am writing about the term “evolution” in the domain I know in order to explicate its strikingly different meaning in the profession that I put aside but still love avocationally. A discussion of the contrasts between biological evolution and cosmological evolution might offer some utility as a commentary about alternative worldviews and as a reminder that many supposed debates in science arise from confusion engendered by differing uses of words and not from deep conceptual muddles about the nature of things.

Interdisciplinary unification represents a grand and worthy goal of intellectual life, but greater understanding can often be won by principled separation and mutual respect, based on clear definitions and distinctions among truly disparate processes, rather than by false unions forged with superficial similarities and papered over by a common terminology. In our understandable desire to unify the sci-
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nces of temporal change, we have too often followed the Procrustean strategy of enforcing a common set of causes and explanations upon the history of a species and the life of a star—partly, at least, for the very bad reason that both professions use the term “evolution” to denote change through time. In this case, the fundamental differences trump the superficial similarities—and true unity will be achieved only when we acknowledge the disparate substrates that, taken together, probe the range of possibilities for theories of historical order.

The Darwinian principle of natural selection yields temporal change—evolution in the biological definition—by the twofold process of producing copious and undirected variation within a population and then passing along only a biased (selected) portion of this variation to the next generation. In this manner, the variation within a population at any moment can be converted into differences in mean values (average size, average braininess) among successive populations through time. For this fundamental reason, we call such theories of change variational as opposed to the more conventional, and more direct, models of transformational change imposed by natural laws that mandate a particular trajectory based on inherent (and therefore predictable) properties of substances and environments. (A ball rolling down an inclined plane does not reach the bottom because selection has favored the differential propagation of moving versus stable elements of its totality but because gravity dictates this result when round balls roll down smooth planes.)

To illustrate the peculiar properties of variational theories like Darwin’s in an obviously caricatured, but not inaccurate, description: Suppose that a population of elephants inhabits Siberia during a warm interval before the advance of an ice sheet. The elephants vary, at random and in all directions, in their amount of body hair. As the ice advances and local conditions become colder, elephants with more hair will tend to cope better, by the sheer good fortune of their superior adaptation to changing climates—and they will leave more surviving offspring on average. (This

**"W**hile this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved.”—**Charles Darwin**

differential reproductive success must be conceived as broadly statistical and not guaranteed in every case: in any generation, the hairiest elephant of all may fall into a crevasse and die.) Because offspring inherit their parents’ degree of hairiness, the next generation will contain a higher proportion of more densely clad elephants (who will continue to be favored by natural selection as the climate becomes still colder). This process of increasing average hairiness may continue for many generations, leading to the evolution of woolly mammoths.

This little fable can help us understand how peculiar and how contrary to all traditions of Western thought and explanation the Darwinian theory of evolution, and variational theories of historical change in general, must sound to the common ear. All the odd and fascinating properties of Darwinian evolution—the sensible and explainable but quite unpre-
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dictable nature of the outcome (dependent upon complex and contingent changes in local environments), the nonprogressive character of the alteration (adaptive only to these unpredictable local circumstances and not inevitably building a “better” elephant in any cosmic or general sense)—flow from the variational basis of natural selection.

Transformational theories work in a much simpler and more direct manner. If I want to go from A to B, I will have so much less conceptual (and actual) trouble if I can postulate a mechanism that will just push me there directly than if I must rely upon the meaning to our lives cannot be accomplished by scientific study in any case, then Darwin’s variational mechanism will no longer seem threatening and may even become liberating in teaching us to look within ourselves for answers to these questions and to abandon a chimerical search for the purpose of our lives, and for the source of our ethical values, in the external workings of nature.)

These difficulties in grasping Darwin’s great insight became exacerbated when our Victorian forebears made their unfortunate choice of a defining word—“evolution”—with its vernacular meaning of “directed unfolding.”

Many people cling to the comforting view that human consciousness must represent a predictable (if not a divinely intended) summit of biological existence.

We would not face this additional problem today if “evolution” had undergone a complete transformation to become a strict and exclusive definition of biological change—with earlier and etymologically more appropriate usages then abandoned and forgotten. But important words rarely undergo such a clean switch of meaning, and “evolution” still maintains its original definition of “predictable unfolding” in several nonbiological disciplines—including astronomy.

When astronomers talk about the evolution of a star, they clearly do not have a variational theory like Darwin’s in mind. Stars do not change through time because mama and papa stars generate broods of varying daughter stars, followed by the differential survival of daughters best adapted to their particular region of the cosmos. Rather, theories of stellar “evolution” could not be more relentlessly transformational in positing a definite and predictable sequence of changes unfolding as simple consequences of physical laws. (No biological process operates in exactly the same manner, but the life cycle of an organism certainly works better than the evolution of a species as a source of analogy.)

Ironically, astronomy undeniably trumps biology in faithfulness to the etymology and the vernacular definition of “evolution”—even though the term now holds far wider currency under the radically altered definition of the biological sciences. In fact, astronomers have been so true to the original definition that they confine “evolution” to historical sequences of predictable unfolding and resolutely shun the word when describing cosmic changes exhibiting the key features of biological evolution—unpredictability and lack of inherent directionality.

As an illustration of this astronomical usage, consider the most standard and conventional of all sources—the Encyclopaedia Britannica article “Stars and Star Clusters” (15th edition, 1990 printing). The section entitled “Star Formation and Evolution” begins by analogizing stellar “evolution” to a preprogrammed life cycle, with the degree of evolution defined as the position along the predictable trajectory:

Throughout the Milky Way Galaxy . . . astronomers have discovered stars that are well evolved or even approaching extinction, or both, as well as occasional stars that must be very young or still in the process of formation. Evolutionary effects on these stars are not negligible.

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The spread of luminosities and colors of stars within the main sequence can be understood as a consequence of evolution. As the stars evolve, they adjust to the increase in the helium-to-hydrogen ratio in their cores. When the core fuel is exhausted, the internal structure of the star changes rapidly; it quickly leaves the main sequence and moves towards the region of giants and supergiants.

The same basic sequence unfolds through stellar lives, but the rate of change (evolution, to astronomers) varies as a predictable consequence of differences in mass:

Like the rate of formation of a star, the subsequent rate of evolution on the main sequence is proportional to the mass of the star; the greater the mass, the more rapid the evolution.

More complex factors may determine variation in some stages of the life cycle, but the basic directionality (evolution, to astronomers) does not alter, and predictability from natural law remains precise and complete:

The great spread in luminosities and colors of giant, supergiant, and subgiant stars is also understood to result from evolutionary events. When a star leaves the main sequence, its future evolution is precisely determined by its mass, rate of rotation (or angular momentum), chemical composition, and whether or not it is a member of a close binary system.

In the most revealing verbal clue of all, the discourse of this particular scientific culture seems to shun the word “evolution” when historical sequences become too meandering, too nondirectional, or too complex to explain as simple consequences of controlling laws—even though the end result may be markedly different from the beginning state, thus illustrating significant change through time. For example, the same Britannica article on stellar evolution notes that one can often reach conclusions about the origin of a star or a planet from the relative abundance of chemical elements in its present composition.

Earth, however, has become so modified during its geological history that we cannot use this inferential method to reconstruct the initial state of our own planet. Because the current configuration of Earth’s surface developed through complex contingencies and could not have been predicted from simple laws, this style of change apparently does not rank as evolution—but only, in astronomical parlance, as being “affected”:

The relative abundances of the chemical elements provide significant clues regarding their origin. The Earth’s crust has been affected severely by erosion, fractionation, and other geologic events, so that its present varied composition offers few clues as to its early stages.

I don’t mention these differences to lament, to complain, or to criticize astronomers in any way. After all, their use of “evolution” remains more faithful to etymology and the original English definition, whereas our Darwinian reconstruction has virtually reversed the original meaning. In this case, since neither side will or should give up its understanding of “evolution” (astronomers because they have retained an original and etymologically correct meaning, and evolutionists because their redefinition expresses the very heart of their central and revolutionary concept of life’s history), our best solution lies simply in exposing the legitimate differences and explaining the good reasons behind the disparity in usage.

In this way, at least, we may avoid confusion and also the special frustration generated when prolonged wran-
gles arise from misunderstandings of words rather than from genuine disputes about things and causes in nature. We evolutionary biologists must remain especially sensitive to this issue, because we still face consider-

We now know that certain mesozoaans are descended from more complex animals and have become simplified by adaptation to their parasitic lifestyle.

Two studies published within the past month led me to this topic, because each discovery confirms the biological, variational, and Darwinian "take" on evolution while also, and quite explicitly, refuting a previous, transformational interpretation—rooted in our culturally established prejudices for the more comforting, astronomical view—that had blocked our understanding and skewed our thoughts about an important episode in life's history:

1. Vertebrates "all the way down." In one of the most crucial and enigmatic episodes in the history of life—and a challenge to the older, more congenial idea that life has progressed in a basically stately, linear manner through the ages—nearly all animal phyla made their first appearance in the fossil record at essentially the same time, an interval of some 5 million years (about 525 million to 530 million years ago) called the Cambrian explosion. (Geological firecrackers have long fuses when measured by the inappropriate scale of human time.) Only one major phylum with prominent and fossilizable hard parts did not appear in this incident or during the Cambrian period at all—the Bryozoa, a group of colonial marine organisms unknown to most nonspecialists today (although still relatively common in shallow oceanic waters) but prominent in the
One other group, until last month, also had no record within the Cambrian explosion, although late Cambrian representatives (well after the explosion itself) have been known for some time. Whereas popular texts have virtually ignored the Bryozoa, the absence of this other group has been prominently showcased and proclaimed highly significant. No vertebrates had ever been recovered from deposits of the Cambrian explosion, although close relatives within our phylum (the Chordata), if not technically vertebrates, had been collected (the Chordata includes three major subgroups: the tunicates, *Amphioxus* and its relatives, and the vertebrates proper). This absence of vertebrates from strata bearing nearly all other fossilizable animal phyla provided a strong ray of hope for people who wished to view our own group as “higher” or more evolved in a predictable direction. If evolution implies linear progression, then later is better—and uniquely later (or almost uniquely, given those pesky bryozoans) can only enhance the distinction. But the November 4, 1999, issue of *Nature* includes a persuasive article ("Lower Cambrian Vertebrates from South China," by D-G. Shu, H-L. Luo, S. Conway Morris, X-L. Zhang, S-X. Hu, L. Chen, J. Han, M. Zhu, Y. Li, and L-Z. Chen) reporting the discovery of two vertebrate genera within the Lower Cambrian Chengjiang formation of southern China, right within the temporal heart of the Cambrian explosion. (The Burgess Shale of western Canada, the celebrated site for most previous knowledge of early Cambrian animals, postdates the actual explosion by several million years. The recently discovered Chengjiang fauna, with equally exquisite preservation of soft anatomy, has been yielding comparable or even greater treasures for more than a decade. See “On Embryos
We must contrast the good fortune of our own evolution with the inexorable evolution of our nurturing Sun toward a spectacular climax that might make our further evolution impossible.

The two Chengjiang genera possess all the defining features of vertebrates: the stiff dorsal supporting rod, or notochord (subsequently lost in adults after the vertebral column evolved); the arrangement of flank musculature in a series of zigzag elements from front to back; the set of paired openings piercing the pharynx (operating primarily as respiratory gills in later fishes but used mostly for filter feeding in ancestral vertebrates). In fact, the best reconstruction of branching order on the vertebrate tree places the origin of these two new genera after the inferred ancestors of modern hagfishes but before the presumed forebears of lampreys. If this inference holds, then vertebrates already existed in substantial diversity within the Cambrian explosion. In any case, we now have two distinct and concrete examples of vertebrates “all the way down”—that is, in the very same strata that include the first known fossils of nearly all phyla of modern multicellular animals. We vertebrates do not stand higher and later than our invertebrate cousins, for all “advanced” animal phyla made their first appearance in the fossil record at essentially the same time. The vaunted complexity of vertebrates did not require a special delay to accommodate a slow series of progres-
did not require a special delay to accommodate a slow series of progressive steps, predictable from the general principles of evolution.

2. An ultimate parasite, or “how are the mighty fallen.” The phyla of complex multicellular animals enjoy a collective designation as Metazoa (literally, “higher animals”). Mobile, single-celled creatures bear the name Protozoa (“first animals”—actually a misnomer, since many of these creatures, in terms of genealogical branching, rank as close to multicellular plants and fungi as to multicellular animals). In a verbal in-between stand the Mesozoa (“middle animals”). Many taxonomic and evolutionary schemes for the organization of life rank the Mesozoa by the literal implication of their name—that is, as a persistently primitive group, intermediate between the single-celled and the multicellular animals and illustrating a necessary transitional step in a progressivist reading of life’s history.

But the Mesozoa have always been viewed as enigmatic, primarily because they live as parasites within truly multicellular animals, and parasites often adapt to their protected surroundings by evolving an extremely simplified anatomy, sometimes little more than a glob of absorptive and reproductive tissue cocooned within the body of a host. Thus, the extreme simplicity of parasitic anatomy could represent the evolutionary degeneration of a complex, free-living ancestor rather than the maintenance of a primitive state.

The major group of mesozoans, the Dicyemida, live as microscopic parasites in the renal organs of squid and octopuses. Their adult anatomy could hardly be simpler: a single axial cell (which generates the reproductive cells) in the center, enveloped by a single layer of ciliated outer cells (some ten to forty in number) arranged in a spiral around the axial cell, except at the front end, where two
the tissues of the host. The zoological status of the dicyemids has always been controversial. Some scientists, including Libbie H. Hyman, who wrote the definitive, multivolume text on invertebrate anatomy for her generation, regarded their simplicity as primitive and their evolutionary status as intermediate in the rising complexity of evolution. As she noted in 1940, "Their characters are in the main primitive and not the result of parasitic degeneration." But even those researchers who viewed the dicyemids as parasitic descendants of more complex free-living ancestors never dared to derive these ultimately simple multicellular creatures from a very complex metazoan. For example, Horace W. Stunkard, the leading student of dicyemids in the generation of my teachers, thought that these mesozoa had descended from the simplest of all Metazoa above the grade of sponges and corals—the plathyhelminth flatworms.

Unfortunately, the anatomy of dicyemids has become so regressed and specialized that no evidence remains to link them firmly with other animal groups, so the controversy of persistently primitive versus degeneratively parasitic could never be settled until now. But newer methods of gene sequencing can solve this dilemma, because even though visible anatomy may fade or transform into something unrecognizable, evolution can hardly erase all traces of complex gene sequences. If genes known only from advanced Metazoa—and known to operate only in the context of organs and functions unique to Metazoa—also exist in dicyemids, then these creatures are probably degenerated metazoans. But if, after extensive search, no sign of distinctive metazoon genomes can be detected in dicyemids, then the Mesozoa may well be intermediate between single and multicelled life after all.

In the October 21, 1999, issue of Nature, M. Kobayashi, H. Furuya, and P. W. H. Holland present an elegant solution to this old problem ("Dicyemids Are Higher Animals"). These researchers located a Hox gene—a member of a distinctive subset known only from metazoans and operating in the differentiation of body structures along the antero-posterior (front to back) axis—in Dicyema orientale. These particular Hox genes occur only in triploblastic, or "higher," metazoans with body cavities and three cell layers, and not in any of the groups (such as the Porifera, sponges, and the Cnidaria, or corals and their relatives) traditionally placed "below" triploblasts. Thus, the dicyemids are descended from "higher," triploblastic animals and have become maximally simplified in their parasitic lifestyle. They do not represent primitive vestiges of an early
stage in the linear progress of life.

In short, if the traditionally “highest” of all triploblasts—the vertebrate line, including our exalted selves—appears in the fossil record at the same time as all other triploblastic phyla in the Cambrian explosion, and if the most anatomically simplified of all parasites can evolve (as an adaptation to local ecology) from a free-living lineage within the “higher,” triploblastic phyla, then the biological, variational, and Darwinian meaning of “evolution” as unpredictable and nondirectional gains powerful support from two cases that, in a former and now disproven interpretation, once bolstered an opposite set of transformational prejudices.

As a final thought to contrast the predictable unfolding of stellar evolution with the contingent nondirectionality of biological evolution, I should note that Darwin’s closing line about “this planet . . . cycling on according to the fixed law of gravity,” while adequate for now, cannot hold for all time. Stellar evolution will, one day, enjoy a predictable end, at least to life on Earth. Quoting one more time from Britannica:

The Sun is destined to perish as a white dwarf. But before that happens, it will evolve into a red giant, engulfing Mercury and Venus in the process. At the same time, it will blow away the earth’s atmosphere and boil its oceans, making the planet uninhabitable.

The same predictability also allows us to specify the timing of this catastrophe—about 5 billion years from now! A tolerably distant future, to be sure, but consider the issue another way, in comparison with the very different style of change known as biological evolution. Earth originated about 4.6 billion years ago. Thus, half of our planet’s potential history unfolded before contingent biological evolution produced even a single species with consciousness sufficient to muse over such matters. Moreover, this single lineage arose within a marginal group of mammals—the primates, which include about 200 of the 4,000 or so mammalian species. By contrast, the world holds at least half a million species of beetles. If a meandering process consumed half of all available time to build such an adaptation even once, then mentality at a human level certainly doesn’t seem to rank among the “sure bets,” or even the mild probabilities, of history.

We must therefore contrast the good fortune of our own evolution with the inexorable evolution of our nurturing Sun toward a spectacular climax that might make our further evolution impossible. True, the time may be too distant to inspire any practical concern, but we humans do like to muse and to wonder. The contingency of our evolution offers no guarantees against the certainties of the Sun’s evolution. We shall probably be long gone by then, perhaps taking a good deal of life with us and perhaps leaving those previously indestructible bacteria as the highest mute witnesses to a stellar expansion that will finally unleash a unicellular Armageddon. Or perhaps we, or our successors, will have colonized the universe by then and will shed only a brief tear for the destruction of a little cosmic exhibit entitled “the museum of our geographic origins.” Somehow I prefer the excitement of wondering and cogitation—not to mention the power inherent in acting upon things that can be changed—to the certainty of distant dissolution.

Stephen Jay Gould teaches biology, geology, and the history of science at Harvard University. He is also Frederick P. Rose Honorary Curator in Invertebrates at the American Museum of Natural History.
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TO KNOW TH

"The scanty conceptions to which we can attain more pleasure than all our knowledge of
of celestial things give us, from their excellence, the world in which we live."  Aristotle
TELLING THE STORY

By Neil de Grasse Tyson

All parts of the known universe reflect the same basic laws of nature we observe and test here on Earth. Our universe is thus a deceptively simple place. In detail, things may look complicated, but in general, cosmic complexity derives from only a few fundamental physical laws.

Energy is perhaps the most useful scientific concept ever developed. The consumption and control of energy on Earth is the foundation of what we now call civilization, and the transformation of this energy from one form to another establishes a direct link between us and the greater universe. Let's start with the calorie content of last night's T-bone steak. It derives from the flesh of a cud-chewing cow. The energy content of the plants eaten by the cow derives from the photosynthesis of sunlight. And the energy content of sunlight derives from the fusion of hydrogen into helium deep within the Sun's core. Furthermore, the basic chemical elements for life as we know it—including carbon, oxygen, nitrogen, and iron—were forged within distant, high-mass stars whose explosive death throes spread their enriched gases across the galaxy.

Yes, we are all powered by thermonuclear fusion—and we are stardust.

Gravity is pretty useful too. The moons and planets of our Solar System and the stars of our Milky Way galaxy move through space as though they were performers in a cosmic ballet. Their paths are choreographed by the forces of gravity and the energy with which gravity endows all objects. Throughout the universe, the principles of gravity and energy also conspire to force large moons, planets, and stars to assume the shape of a sphere. Related principles of physics account for why water droplets and soap bubbles want to be

Previous spread: Gases and stars in the Large Magellanic Cloud, a nearby galaxy, are a backdrop for Supernova 1987A (center of image), a massive star that exploded 12 million years ago. Its light reached Earth in 1987. At right: Artist's impression of a nuclear particle consisting of three quarks.

"For the mind wants to discover by reasoning..."
spheres. This commonality of geometric form is yet another reminder that the laws of nature are at work everywhere and on every scale.

Astronomy distinguishes itself from most disciplines in many ways, but especially by the mind-stretching scales it invokes to describe space, time, and the sizes of objects in the universe: If the Sun were a black hole, it would be no larger than a child’s marble, yet if the Sun were a red giant, it would be large enough to engulf the entire orbits of Mercury, Venus, Earth, and Mars. And if the events that span the 15-billion-year time line of the universe were laid along the length of a football field, then all of human history would span the thickness of a single blade of grass in the end zone.

We built the Museum’s new Rose Center for Earth and Space to emphasize cosmic unity on all scales—not simply because this idea is beautiful to contemplate but also because it explains how the universe actually works. What a rewarding challenge it has been to work with my scientific colleagues—alongside architects, exhibit designers, and, yes, administrators—to craft a venue that thematically marries cosmic space to architectural space.

Besides being a monument to the cosmos, the Rose Center is an educational organism whose concept, design, and execution embody the physical principles that enable us all to get a little closer to the rest of the universe. And the sphere that houses the new Hayden Planetarium is both beautiful and astrophysically relevant—something that cannot be said of pyramids, cubes, or other polyhedral forms.

By treating the universe as an interconnected system of cosmic objects and phenomena, we can do more than just show pretty pictures; we can tell scientific stories. The protagonists are the laws of physics. The plotline is the effect of these laws on the natural world. The love interest is the unending quest of the human mind to discover the unknown. The dramatic scenes are the evolutionary stages of the planets, stars, and galaxies. And the denouement is the still-uncertain ultimate fate of the universe.

Neil de Grasse Tyson is the Frederick P. Rose Director of New York City’s Hayden Planetarium and a member of the newly launched Department of Astrophysics at the American Museum of Natural History. His recent book One Universe: At Home in the Cosmos, coauthored with Charles Liu and Robert Irion (Joseph Henry Press, 2000), is the companion volume to the Museum’s new Rose Center for Earth and Space.
SPHERE OF INFLUENCE

The reborn Hayden Planetarium, in the new Rose Center for Earth and Space, mirrors astronomy’s radical reinterpretation of outer space.

By Henry S. F. Cooper Jr.

Over the past several months, a sphere 87 feet in diameter—standing on a tripod inside a 120-foot cube made partly of glass—has taken shape on 81st Street near Central Park West in New York City. At night, under soft lights, it glows enigmatically. Is it a massive Christmas ornament inside a transparent box, or a Pop Art lightbulb in its container? Perhaps it’s a model of the Sun: those round balls orbiting it seem to suggest as much. But when you enter the cube and look up from its first-floor balcony, you might, for all the world, be gazing at a spaceship surrounded by a multilevel gantry.

The sphere is, in fact, the home of the new Hayden Planetarium, centerpiece of the Frederick Phineas and Sandra Priest Rose Center for Earth and Space, the Museum’s newest addition. Its upper hemisphere is a much upgraded planetarium renamed the Space Theater (to distinguish it from its predecessor, the Sky Theater), while its lower hemisphere contains a searingly dramatic, you-are-there laser recreation of the big bang. Together with other elements of the Rose Center, the sphere was designed to illuminate aspects of and answers to cosmic questions: Where are we in space and time? How did we get here?

Everyone concerned with the new, $210 million Rose Center—including astrophysicist Neil de Grasse Tyson, director of the planetarium; James Stewart Polshek, the architect; and Ralph Appelbaum, the exhibition designer—agrees that the sphere symbolizes a revitalization of the Museum that began in 1993, when its trustees picked a new president, Ellen V. Futter, then president of Barnard College.

To Futter, the center is an intellectual launching pad into the rest of the Museum. “From there,” she says, “you might go across the ground-floor lobby of the main Museum to the spectacular new Hall of Biodiversity or the magnificent Northwest Coast Indians or go up to see the ever popular dinosaurs. Now we can take our visitors on a sweeping, exotic journey from the origins of the universe and the formation of galaxies, stars, and planets to the core of our own planet and on to an investigation of all life on Earth, its various ecosystems and habitats and range of species, including our own species and culture. I think we are the only museum in the world that can tell the comprehensive story of life in such a seamless way.”

Throughout the planning, Tyson, Polshek, and Appelbaum have worked so interdependently that it is often hard to tell who thought of what. Despite the stresses and hard
SIZE AND SCALE

Visitors who follow the Scaling Walk around the sphere can consider the relative magnitude of objects in the universe (architect’s rendering).

“Whole World does not become Astronomers.” Thomas Wright
For architect James Polshek, the sphere inside the cube is a salute to I.M. Pei’s glass pyramid at the entrance to the Louvre.

work that go with any large project, they had a very good time, and this is evident in the result. (They are quick to point out that many others, such as Polshek’s partner Todd Schliemann, were vital to the creation of the Rose Center.)

The old Hayden Planetarium, which opened on October 3, 1935, has become a venerable New York icon in need of redefinition. To scientific purists, the last straw was a 1993 exhibition about the Star Trek television series that included a prominent display of Mr. Spock’s pointy ears. As the fourth-oldest planetarium in the United States—after the Adler in Chicago (1930), the Fels in Philadelphia (1934), and the Griffith in Los Angeles (1935, just four and a half months before the Hayden)—the Hayden had become outmoded in many ways. Like the other, older planetariums, it was designed to specifications by the German company Carl Zeiss and was intended basically to house projectors; apart from their domes, these Art Deco buildings consisted mainly of corridors for getting people in and out of the big attraction: the sky theater showing views of the stars as seen from Earth. And the Hayden—in terms of its shows, at least—was stuck in a geocentric vision of the universe. It was as if the scientific revolution triggered by Copernicus’s proposal in 1543 that the Sun, not the Earth, was at the center of the Solar System had never occurred. An even bigger problem was that after the old Hayden was built, there were enormous advances in astrophysics and in our understanding of the universe, not to mention the advent of the space age and manned space travel.
The Museum’s newest addition is respectful of the institution’s history. Its centerpiece is the new Hayden Planetarium sphere, which is about the same diameter as the dome of the old planetarium and is centered on the same spot (architect’s rendering).

A visiting committee of scientists, chaired by J. Richard Gott III, an astrophysicist from Princeton, had already been organized in the early 1990s to consider the planetarium’s options. The first idea was to retrofit the building so that it could deal better with such matters as the big bang, star formation, and quasars, but the dark corridors of the Hayden did not lend themselves to exhibition spaces any more readily than the old Zeiss Mark VI projector housed within it lent itself to intergalactic displays.

Polshek, who joined the project at the retrofitting stage, toyed with the idea of completing the circle of the old Hayden dome, thus turning it into a sphere. The idea was to accomplish this without disturbing the dome’s original supports, a series of columns that held it up like a table. “But when we drew it up as a sphere, it looked a little clunky,” he says. The idea was shelved. Once Futter became president of the Museum in November 1993, planning began to heat up.

when I was a child?” Thomas Carlyle
SPACE THEATER
The Hayden's new Zeiss Mark IX—the most modern star and planet projector in existence—can be programmed to display the sky as seen from any planet in the Solar System (architect's rendering).
By the time Tyson joined the planetarium staff in July 1994, several proposals for retrofitting were on the table. Futter then asked the scientists, architects, and designers what they would do if they had a blank slate. It was a seminal question. Conceptually whisking away the old building, Polshek lifted the sphere high into the air and onto a pedestal. Tyson had doubts. “It looked like a golf ball on a tee,” he says.

Soon the golf tee, too, was swept away and replaced with a tripod of rounded beams attached to the armature of the sphere below its equator. Placing the beams at the side made them largely imperceptible. Suddenly the sphere appeared to be un tethered and levitating—floating, bubblelike, as if it were a planet or a star.

The Museum’s trustees fell in love with the un tethered sphere. One entranced trustee was Frederick P. Rose, chairman of the construction firm Rose Associates, which had built many New York apartment houses. A wry, energetic seventy-five-year-old who always wore his enthusiasm on his sleeve, Rose donated $20 million to the project and supervised the construction until his death this past September. Two other trustees, Dorothy Cullman and David S. Gottesman, also gave important gifts to the project.

The Rose Center is the most ambitious not-for-profit project to have been built in Manhattan since Lincoln Center. Although the Metropolitan Museum’s additions since the 1960s are bigger in aggregate, no single element is as large. And although there are other examples of spheres in architecture (Wallace K. Harrison’s Perisphere at the 1939 World’s Fair, for example), the new Hayden Planetarium sphere is unique in being encapsulated in a cube. Another feature is that the cube’s two glass walls (west and north) are the only ones in the United States that are built without frames or mullions to hold the panes, each of which measures ten feet by five and a half feet and is half an inch thick. These panes—separated by less than half an inch—are bolted to clamps attached to a system of tension rods, allowing for the stresses caused by wind or movements of the earth; the space between the panes is caulked with a translucent silicon sealant so that the two glass facades, each as high as a twelve-story building, look like single plates.

Polshek, who regards the sphere inside the cube as his salute to I.M. Pei’s glass pyramid at the entrance to the Louvre, says the Rose Center is respectful of the Museum’s history. The sphere is centered on the same spot as the dome of the old Hayden and has about the same diameter. It also fits neatly into a space that was designated as a courtyard in the Museum’s 1871 master plan. Moreover, the Rose Center makes liberal use of the same brick, granite, limestone, and patinated copper roofing that are used throughout the rest of the Museum.

Having been skeptical of the planetarium sphere during its clunky, multilegged early stage and then in its golf-tee stage, Tyson, who in May 1996 became Frederick P. Rose Director of the Hayden Planetarium, loved it when it levitated. “It’s now floating out there in full view, serving as a scientific icon,” Tyson says of the floating ball. “Spheres are common in the universe. I can work with a visible, levitating sphere.”

Tyson and his associates quickly decided to use the sphere as a reference for the size and scale of objects in the universe. At the building’s second level (positioned below the equator of the sphere, which looms above you) is the
Scaling Walk. “Trying to explain the scale of things in space is the nightmare in which we live,” says James Sweitzer, an astrophysicist who worked with Tyson on the Rose Center’s technology. The solution was to have the sphere represent—at various points in your walk around it—the Sun, a giant star, and the universe itself. Seen as the Sun, the 87-foot sphere helps you get a feel for the relative size of the planets—8 feet 11½ inches for Jupiter, 9½ inches for Earth, 5 inches for Mars, 3½ inches for Mercury, and so on—that float above the walk. As you circumnavigate the sphere, the frame of reference keeps changing; “Walk a little further around,” says Tyson, “and now the Sun fits in your two hands, while the sphere represents the blue supergiant star Rigel, in the constellation Orion. Walk around a little more, and the sphere becomes our galaxy’s halo. Then you can fit the whole solar neighborhood in a tiny cup.”

The other elements of the Rose Center must reckon with the sheer immensity of the sphere: they wind around it or lie under it or escape from it altogether into the Museum proper. From the Scaling Walk, you can exit down a long ramp named the Harriet and Robert Heilbrunn Cosmic Pathway, which swirls under the sphere and deposits you, 350 feet and one and a half revolutions later, at the first level. With more than 300 images and diagrams mounted along the railing, the pathway takes you through 13 billion years of evolution in a time line that unfolds at about 3 million years per inch. Dinosaurs go extinct a mere two feet from the end, where all of human history is represented by the width of a human hair.

From there, a flight of stairs carries you down to the Lewis B. and Dorothy Cullman Hall of the Universe, directly beneath the sphere, and as you look down at some of the images of celestial objects reproduced in the floor’s brilliant mosaics, the sphere seems to float above you, “confronting your idea of up and down,” as Tyson puts it. A free-standing wall of twenty video screens collectively called the AstroBulletin plugs visitors into real-time events in space through direct feeds from large terrestrial observatories, the orbiting Hubble Space Telescope, and spacecraft visiting planets, comets, and asteroids. The AstroBulletin also shows videos that take you through the evolution of stars, planets, and the universe itself or that portray the search for extraterrestrial life and planetary landscapes. Adding substance to all the video displays, the 16.1-ton Willamette meteorite seems about to blast a crater in the concrete floor.

But even the Willamette meteorite is dwarfed by the giant sphere, which may make you feel as nervous as if you had an elephant in your living room. There is, however, an escape route. Back upstairs on the first level, at the foot of the Cosmic Pathway, a big blue-and-white model of Earth beckons you through a corridor and into the David S. and
Ruth L. Gottesman Hall of Planet Earth. This section of the Rose Center, which opened last June, looks inward at Earth and its geological history, giving you a foundation for all of life to come—and, incidentally, a springboard to the forty-plus galleries that make up the rest of the Museum.

The big-ticket item—indeed, the only one for which you actually need a ticket other than your entrance contribution to the Museum—is the Space Theater, situated in the top half of the sphere. Here is where the Ptolemaic, geocentric constraints are finally broken. No more looking at the night sky solely from Earth: the technology used in the theater enables you to see the stars projected accurately from any point in the Solar System (and from anywhere else in the universe).
When you enter the Space Theater, the new Zeiss Mark IX projector, unlike the Mark VI, which in the old Hayden loomed above you like a giant ant, is nowhere to be seen. As the lights dim, the squat little projector—strongly reminiscent of R2D2, the technologically savvy Star Wars robot—rises from beneath the floor to carry you into space. The new Zeiss is to the old one what a spacecraft is to a Model A Ford. It takes you from one planet to another (something the old projectors couldn’t do), all the way to the outer edges of the Solar System. Many significant advances in astrophysics during the past sixty years, however, have involved our own Milky Way galaxy, as well as our local supercluster of galaxies and the structure of the universe as a whole. In order to lift you out of the Solar System and its neighborhood of stars, digital technology—a Digital Universe computer—takes over where the Mark IX projec-
tor leaves off (see “Theater of the Stars,” page 60). The computers in the Space Theater and elsewhere in the Rose Center allow exhibits to be updated in light of new discoveries. “The database is malleable,” Tyson says. “In astronomy, if you design only for what you know, you’re dead.”

One result of all this high technology, sensory zapping, and hypergalactic velocity is that the shows in the Space Theater are a lot shorter: twenty minutes as opposed to forty-five minutes a decade ago, or an hour when the Hayden first opened. More than once in the old planetarium, Tyson turned up the lights at the end of a forty-five-minute show to find much of the audience asleep. The MTV generation’s attention span may be short, but perhaps young people also have an increased capacity for the rapid absorption of information, especially if it comes through several senses at once. (In the Space Theater, while pixels bombard the eye, sounds ripple from multiple speakers in the dome, and seats shake to simulate space-shuttle launches.) The show’s twenty-minute duration also allows the Space Theater to be filled and emptied twice per hour. And the audience, far from falling asleep, will probably reel from the theater in a state of sensory shock.

For additional sensory zapping, visitors can then take the escalator down to the Big Bang Theater, in the belly of the planetarium sphere, where they can be visually pounded by

*Leaving the Big Bang Theater, the audience will blink in the brilliant light from the reflective panels covering the sphere.*

a re-creation of the first three minutes of the very origins of the universe. Leaving the theater, the dark-adapted audience will blink in the flood of brilliant natural light created by the reflective white aluminum panels that cover the sphere.

Light is what virtually all the exhibits consist of: buckets of it splashed from projectors onto the Space Theater’s dome; streams of it on computer and video screens; zillions of photons of it hurtling through the big windows, direct from the nearest star, eight light-minutes away. Light, notes Tyson, is what astronomers study. “One of our missions is to alert the public to how important the analysis of light is,” he says. “It’s at the foundation of most cosmic discoveries. By analyzing light spectra, we discovered the planets outside our own Solar System, and we discovered the expanding universe. We learned that the ingredients of the stars are the same as those found in the human body and in the rest of life on Earth, which leads to the legitimate claim that we are stardust.” Light is also something that architects and designers can play with; exhibition designer Appelbaum points out that most galleries in most museums are dark—paradoxically, the result of the invention of the electric light. In many places on the Rose Center’s glass-curtain walls, he attached defraction gratings that act as prisms, casting spectra—tiny rainbows—that twinkle across the white sphere, across the planets, and onto the back wall, moving slowly with the Sun. Most designers like to control light; Appelbaum, Polshek, and Tyson are content to let light happen.

The Rose Center, say all three, is a celebration of light. □

 Arthur Stanley Eddington
THEATER OF THE STARS

Planetariums have come a long way in the past 300 years.

By James B. Sweitzer

Within the globe of the new Hayden Planetarium, advanced projectors are fed by some of the most powerful computers ever used to advance the public understanding of science. This cutting-edge technology makes it easy to forget that the planetarium descends from a lineage that is more than 300 years old.

In the mid-1600s, Adam Olearius, court mathematician and librarian to the duke of Holstein-Schleswig-Gottorp, designed a hollow, ten-foot-diameter, water-powered rotating sphere into which people could climb to see gilded constellations illuminated by centrally placed oil lamps. At best, the Gottorp globe was a crude depiction of the celestial sphere, but it could not adequately represent the planets of our Solar System.

For that, one would have to wait for the mechanical tabletop orreries of the eighteenth century. Orreries were simulation devices based on one of the most advanced technologies of the time, that of the gear-driven clock. They allowed students of astronomy to move miniature planets round and round a small brass ball that represented the Sun. The orrery was ideal for displaying the Copernican model of the planets in our Solar System, but, like the Gottorp globe, it failed to provide an integrated view of the universe.

The next leap did not come until the 1920s, when the firm of Carl Zeiss in Jena, Germany, invented an electro-optical projector that cast images of the stars, Sun, Moon, and planets onto a large hemispheric screen. The positions and motions of these celestial bodies could be realistically re-created from any perspective on Earth and for any date up to 26,000 years in the past or the future.

From the time it opened in 1935, the old Hayden Planetarium relied on the brilliant Zeiss invention. Advanced as the electro-optical planetarium was, however, its perspective remained geocentric. To offset this limitation, the Hayden installed a large overhead orrery (with a lightbulb as the Sun and motorized planets circling around it on electrified orbit rails) that operated until the early 1980s in a gallery below the Sky Theater.

But even the best mechanically driven projectors and orreries are incapable of depicting the universe as we now understand it. Astrophysicists of the twentieth century demonstrated that far from living in the center of a gently rotating, unvarying clockwork world, we humans inhabit instead an expanding, constantly evolving universe. The stars and galaxies are organized in hundred-million-light-
The Sun, Moon, and planets course through the sky, steered by special computers, and the sky can be displayed not just from Earth but from any planet in the Solar System.

For deep space travel, the task falls to the digital-dome simulator, a one-of-a-kind system integrated by SEOS Trimension of Great Britain. Seven powerful video projectors blend together to display on the huge dome a single image of more than 7.2 million pixels. Fed by a Silicon GraphicsOnyx 2 InfiniteReality Engine computer, the system is similar to those used by the film industry for special effects. But the Space Theater’s effects are based on data from NASA and the European Space Agency, as well as on supercomputer models of the universe. The result is a digital model of the galaxy, featuring billions of stars.

In the Space Theater’s signature program, the audience will take a grand tour from Earth into deep space. Voyaging through the Milky Way, they will stop off at a fantastic nebular region. Shifting to a higher speed, they will—in one continuous movement—take a turn, head out the southern side of the disk of the galaxy, fly past Earth’s nearest extragalactic neighbors, and then hurdle a billion light-years from home, journeying trillions of times farther than NASA’s most remote space probe.

The new planetarium also treats an aspect of cosmic history that was all but unknown in the 1930s. The Big Bang Theater, located in the bottom of the planetarium orb, is, in effect, a giant time machine. As though suspended over the abyss of the early universe, visitors will stand on a doughnut-shaped glass floor lying over a deep, wide projection screen. A high-powered laser beam and dozens of computer-controlled lights will immerse viewers in an accurate re-creation of the most important epoch of the early cosmos.

Unique in the universe of planetariums, the new Hayden, with its capacity to accurately simulate the universe in extraordinary three-dimensional detail, will launch visitors on one-of-a-kind expeditions into deep space and time.

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**NIGHT VISION**

How a city boy grew up with stars in his eyes

By Neil de Grasse Tyson

It was a dark and starry night.

The air was calm and mild. I felt as though I could see forever. Too numerous to count, the stars of the autumn sky and the constellations they trace were rising slowly in the east while the waxing crescent Moon was descending at the western horizon. The Big Dipper and Little Dipper were just where they were supposed to be, afloat in the northern sky. The planets Jupiter and Saturn were up there, too—one in the east, the other in the west.

One of the stars, I don’t remember which, seemed to fall toward the horizon. It was a meteor streaking through the atmosphere. I saw a long, skinny cloud that stretched across the sky. But it wasn’t a cloud. It was the Milky Way, with its varying bright and dark patches giving the appearance of structure and the illusion of depth. Before that night I had never seen the Milky Way or the constellations with such clarity.

Forty-five minutes of my suspended disbelief swiftly passed before the house lights came back on in the Hayden Planetarium Sky Theater.

That was the night. The night the universe poured down from the sky and flowed into my body. I had been called. The study of the cosmos would be my career, and no force on Earth would stop me. I was just nine years old, but I now had an answer for that perennially annoying question all adults ask: “What do you want to be when you grow up?” Although I could barely pronounce the word, I would tell them, “I want to be an astrophysicist.”

From that moment onward, one question lingered within me: Was the planetarium sky an accurate portrayal of the real celestial sphere, or was it a hoax? Surely there were too many stars. I had proof. I had seen the night sky from the rooftop of my apartment building in the Bronx. Built on the highest hill of the borough, it was one of a set of three named the Skyview Apartments.

From New York City on a good night, you might see a hundred stars. But the first time I was away from the city—at a special astronomy camp in the Mojave Desert—I saw bezillions. Apparently my first sky show, six years earlier, had not been a hoax after all. In the near-zero humidity on that cloudless desert night, I couldn’t help thinking to myself, as I gazed upon that glorious natural canopy, “It reminds me of the Hayden Planetarium.”

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*‘He Heavens, and now they are his owne.’* John Donne
Cosmos 2000

A special section produced and edited by Richard Panek

The Hayden Planetarium at the American Museum of Natural History happened to open just as the prevailing conception of the cosmos was undergoing its first major shift since Copernicus and Galileo removed Earth from the center of the universe. The year was 1935. Only ten years earlier, the astronomer Edwin Hubble had announced that some of the faint, fuzzy spirals at the farthest limits of the most powerful telescopes of the time seemed to be external to our own galaxy and, indeed, seemed to be galaxies equal in size and magnitude to the Milky Way. Then, in 1929, Hubble outdid himself with the revelation that these galaxies appear to be racing away from us, and from one another, at rates proportional to their distances—the farther away they are, the faster they seem to be receding. In other words, the universe is expanding.

A universe that’s expanding must be expanding from something, but in 1935 Hubble’s finding was still so new that no physicist had yet followed its implications to their ultimate conclusion. To a great extent, astronomers (and everyone else) were still inhabiting the pre-Hubble universe—one that moved, its planets and stars and galaxies following the predictable paths of Newtonian gravitation, but not one that changed. In the sixty-five years since then, however, the primary focus of astronomy and astrophysics has moved toward understanding and explaining an ever-changing universe: an organism that evolves over time.

This is the universe that the Museum’s new Rose Center for Earth and Space describes. To commemorate its opening, Natural History has commissioned six prominent astronomers and astrophysicists—some of them the very scientists who made the breakthroughs that redefined the cosmos in the past six and a half decades—to tell the story of this new universe.

The narrative begins close to home, in our own galaxy, with an account of how individual stars in our night sky evolve and the discovery that planets are orbiting at least some, and maybe most, of these stars. The story then moves away from the Milky Way and goes across space and back in time to other galaxies, members of a celestial species with its own evolutionary narrative and its own underlying organization of neblike superstructures stretching to the ends of the “visible” universe. Eventually the story leaves the visible universe and enters the realm of the big bang (and beyond), where macrocosmic structures find their origins in the microcosmic physics of subatomic particles.

Our tale ends there for now—February 2000—but it hardly ends there, period. Surely this story will change over the next sixty-five years. And in a sense, the question that has kept sky watchers returning to their vigils since the dawn of our species may be the question that visitors to the reborn Hayden Planetarium, as well as readers of the articles in the following pages, will come to value most: What don’t we know?

Richard Panek writes Natural History’s “Celestial Events” column and is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens (Penguin, 1999).
The Horsehead Nebula in the constellation Orion

"Receding horizons." Edwin Hubble
Twinkle Twinkle

Also explode, collapse, nucleosynthesize. It turns out that our nightly companions do more than just sparkle—and therein lies the tale of our own origins.

By Allan Sandage

Historians of science a hundred years hence will remember twentieth-century astronomy for two main accomplishments. One is the development of a cosmology of the early universe, from creation through consequent expansion. The other is the understanding of stellar evolution.

Although not as well known among nonscientists as the big bang is, the notion of the evolution of stars provided the foundation upon which astronomers built the grand synthesis of cosmological origins. The idea that stars change as they age and that these changes in turn alter their local environment and the chemical makeup of their parent galaxy—an idea that has developed only within the past fifty years—stands in the same relation to astronomy as the Darwinian revolution does to biology. It is a conceptual breakthrough that makes possible the modern understanding of the origin, evolution, and fate of the universe and that influences even questions of life and eschatology.

The theory of stellar evolution had its beginnings when the American physicist Jonathan Homer Lane, in 1869, and the German physicist A. Ritter, from 1878 to 1883, derived equations that described gaseous spheres, or stars, as chemical configurations held together by their own gravity and obeying the known gas laws of thermodynamics. The German mathematician Robert Emden published a remarkable book on the subject—Gasugeln (Gas Spheres)—in 1907, summarizing the work of Lane and Ritter and adding much to the early theory. Well into the 1950s, the so-called Lane-Emden equation was the starting point for much of the the-
oretical work on the structure of stars: their central temperatures and pressures, their masses, and their equilibria.

But did the stars actually do what the equations said? Yes—and the fact that we can determine what the conditions are in the deep interior of the Sun and other stars with far greater precision than we can manage for most other regions of the visible universe still amazes most of us.

In the early years of the twentieth century, the Danish astronomer Ejnar Hertzsprung, working in the Netherlands, and the U.S. astronomer Henry Norris Russell, working at Princeton, invented a graph that would turn out to be the Rosetta stone of stellar evolution. When you plot the temperatures of stars (which can be inferred from their colors) against their absolute luminosities (which can be calculated from their distances and apparent brightnesses), a striking pattern emerges. Figure out why that pattern should exist at all, and you have the life history of the stars.

As stellar astronomers filled in the so-called Hertzsprung-Russell (HR) diagram with observational data during the first half of the twentieth century, two dense collections of data points emerged. The main sequence shows stellar luminosities ranging from 10,000 times greater than to 10,000 times less than the intrinsic brightness of the Sun. In this thin, wavy, highly populated region of the graph, the corresponding surface temperatures of the stars range from 100,000° Kelvin to cooler than 3,000°. The other principal branch on the HR diagram is occupied by stars that are all 10 times more luminous than the Sun yet cooler than 4,000° Kelvin. It is easy to use fundamental equations of physics to show that stars such as those in the second group must have enormous radii, exceeding that of the Sun by more than a hundredfold, and, in addition, are of exceedingly low density.

The stars in this second group are now called giants, while stars on the main sequence (which include the Sun), with radii that range from only one-fifth to ten times that of the Sun, are appropriately named dwarfs.

But while this diagram showed that stars clearly belonged to certain distinct types, astronomers still didn’t understand

A star is stillborn: This detail from the Trifid Nebula vividly depicts the ongoing struggle of a protostellar object (hidden behind the clouds of dust and gas) to come to life and begin to burn hydrogen into helium. According to astronomers, the aspiring star won’t make it.

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a. Reber begins construction of backyard radio telescope, with which he makes first radio map of Milky Way

1938

Fritz Zwicky suggests galaxy clusters are basic building blocks of universe

Hans Bethe and Carl-Friedrich von Weizsäcker independently work out theory of nucleosynthesis in interior of stars

1942. Radio waves from Sun first detected
how the types corresponded to one another or how (and even whether) stars changed. Then, in 1938, Hans Bethe in the United States and, independently, Carl-Friedrich von Weizsäcker in Germany wrote down the nuclear reactions by which hydrogen converts to helium in the high-temperature, high-density realm of deep stellar interiors. With that discovery, nuclear astrophysics was born and, with it, the understanding that hydrogen’s burning into helium is the first stage of an evolutionary process.

Over the next two decades, physicists described the way in which other elements are newly created from atomic reactions within stars. In this process, called nucleosynthesis, first hydrogen burns into helium, then helium turns into carbon, carbon into nitrogen, nitrogen into oxygen, and so on through all the other heavy elements, up to and including iron. At each stage, mass is lost, the stellar structure changes, and the star recycles chemical elements into space. Sometimes this process ends in the catastrophic explosion of a supernova and, with it, the formation and expulsion into space of iron and all the heavier elements.

The development of nuclear astrophysics not only provided much more sophisticated science for use in computing detailed stellar models and nuclear burnings than did the Lane-Emden equation and its later extensions; it also explained all parts of the HR diagram. By the 1960s, astronomers could follow the chemical history of the galaxy, and indeed of the entire universe, from the birth of the first stars, through the buildup of the abundance of heavy elements in the interstellar medium out of which new stars are being continuously formed, and finally to their demise, when the stars become either stable white dwarfs, neutron stars, black holes, or unstable exploding supernovas.

This synthesis of nuclear physics and stellar astronomy has led us to four significant conclusions. The first is that the earliest stars were formed from a reservoir of protogalactic gas that had not been enriched by a previous generation of nuclear burners; indeed, these first-generation stars have turned out to be deficient in the heavy chemical elements by a factor of more than a thousand. Second, because new generations of stars are made in part from the gases of older stars, we can date types of stars according to their “metallicity”—their relative abundance of elements heavier than hydrogen or helium. Third, by examining its metallicity, we have determined that the Sun is a third-generation star made from several supernova episodes that enriched the local interstellar gas some 5 billion years ago. (The age of the Sun and our Solar System has in fact been calculated at 4.6 billion years, considerably less than the age of the approximately 13-billion-year-old clusters of stars at the heart of the galaxy.)

Finally, because all elements heavier than helium have been nucleosynthesized in the deep interiors of stars, the ninety-three stable chemical elements that are the raw materials of life were all present at one time inside at least one star. We are all made from the same cosmic stuff and, indeed, were all once inside the same star. Life as we know it, depending as it does on the interlocking details of the intricate biochemistry that keeps living things in equilibrium, would be fundamentally different if the Sun had been born earlier in the history of the galaxy, when the mean abundance of the elements that are heavier than helium and necessary for life (such as carbon and oxygen) was much lower. Our biochemical feedback systems would have been considerably different—if they had existed at all.

We are the product of the stars. This is one of the most profound insights to have arisen out of twentieth-century astronomy. Life is clearly a property of the evolving universe, made possible by stellar evolution.

"Then felt I like some watcher of the skies, When heaven-led and heart-foreseeing, "
Prospecting for Planets

Astronomers are finding new worlds by the dozen—settling one ancient debate and sparking a multitude of others.

By R. Paul Butler

Do other worlds exist? This question predates not just UFO sightings and Star Trek but science and probably written history as well. Epicurus and Aristotle each debated the issue more than 2,000 years ago. Exactly 400 years ago this month, on February 1, 1600, in a public plaza in Rome, Giordano Bruno was burned at the stake for—among his other heresies—advancing the notion that there were other worlds. But it’s only within the past decade that astronomers have overcome the enormous technical challenges of probing the vicinity of stars other than the Sun to look for unknown planets. In the process, they have not only answered the question of whether other worlds exist but also realized that planets are probably at least as common as stars themselves.

Planets are extremely hard to see, emitting no light of their own and shining only in the reflected light of their host stars. To a hypothetical alien astronomer looking toward our Solar System from a planet orbiting even a relatively nearby star, Jupiter would be an impossibly faint dot, lost in the overpowering glare of the billion-times-brighter Sun. The other planets, including Earth, would be fainter still.

We can’t simply point a telescope at a star and see its orbiting planets directly, but we can attempt to detect them indirectly. The same principle applies to the detection of electrons. They’ve never been directly observed but were discovered a century ago by virtue of their electric charge. For extrasolar planets, it’s a planet’s gravitational field acting on its host star that provides the telltale evidence. Like an unruly poodle yanking its more massive owner on a leash, an orbiting planet gravitationally tugs the host star around in a small counter-orbit.

A star locked in an orbital embrace with a Jupiter-mass planet will regularly move from side to side as well as wobble back and forth. The side-to-side motion can (in theory) be detected by precisely measuring the position of a star relative to more distant background stars, but it’s the back-and-forth wobble on which astronomers have so far concentrated their efforts. Specifically, they use the Doppler effect—an apparent change in the frequency of light (or sound) waves that is caused by motion, similar to the distortion of a train whistle’s sound waves once they leave their source. By employing the Doppler effect to measure minute shifts in light waves from a wobbling star, astronomers have, to date, discovered twenty-eight extrasolar planets.

Prior to these discoveries, theorists had assumed that most planetary systems would be similar to our Solar System: massive Jupiter-like planets at great distances from the host star, with ten- to hundred-year orbital periods, and small Earth-like planets in smaller orbits of a few months to a few years, all traveling in stably near-circles. The twenty-eight planets that have been located since 1995, however, have delightfully confounded these expectations.

While current technology can detect only giant planets with the approximate mass of Jupiter, about half these planets have been found to have orbits that, within our own Solar System, would lie between the Sun and its closest planet, blistering-hot Mercury. Michel Mayor, who along with Didier Queloz discovered the first of these close-in planets around the star 51 Pegasi in 1995, has dubbed them Hot Jupiters. Nearly all the other planets discovered thus far, although not so shockingly close to their host stars, move in highly eccentric, egg-shaped orbits. These deeply surprising findings have stimulated theorists to generate new models of planetary formation and evolution.

We already knew that planets form in the disks of gas and dust that surround young protostars. (Such formations have now been directly observed around most of the nearby

new planet swims into his ken.” —John Keats
young stars by ground-based telescopes and by the Hubble Space Telescope.) The disk swaddles the protostar for its first few million years of existence and is then shed like a cocoon when the newly “turned on” star emerges, its nuclear furnace igniting and literally blowing away the remaining gas and dust. But now, new theoretical models show that an embedded protoplanet within the disk might be driven toward, rather than away from, the star. If conditions are right, the planet will end up in a stable orbit “parked” just outside the star, although in many cases the planet may fall all the way in and be cannibalized by its parent.

Planets that survive the disk phase of formation and evolution face another danger: interactions with other planets.

In a system of multiple Jupiter-mass planets, many might survive in stable orbits for millions or even billions of years but then chaotically, violently interact. At that point, some planets would be thrown into tighter orbits and others would be thrown out. The resulting orbits would all be eccentric and egg-shaped. Something like this would have happened in the Solar System if Saturn had ended up being twice as massive as it is. A Jupiter–Saturn interaction, like an encounter of billiard balls on a gravitationally warped pool table, would have disrupted the orbital stability of the “little worlds” of the inner Solar System and devastated the possibility of higher life’s emergence on Earth.

The first twenty extrasolar planets were all found in
single-planet systems—not surprising, given the adolescent state of current planet-hunting technology. At this stage, we can find these Jupiter-mass planets only by observing their repeating orbits at least twice. Since the oldest survey of extrasolar planets has been underway for only twelve years, we can at present detect planets with orbital periods of, at most, six years. The discovery of a multiple-planet system requires some luck: we’d have to chance upon a system of two or more Jupiter-mass planets, all relatively close to their central star and moving in fortuitously stable orbits.

Amazingly, one such system has emerged. Upsilon Andromedae (see “Strange New Worlds,” Natural History, September 1999), a star visible to the naked eye in clear, dark skies far from city lights, has three planets with masses of roughly one, two, and four times that of Jupiter and respective orbits of 4.6 days, 8 months, and 3.5 years. The innermost planet in the system travels in a circular orbit, as do all the Hot Jupiters. In contrast, the outer two planets are in extremely eccentric orbits, suggesting that gravitational scattering may have played an important role in shaping this system. Since the Upsilon Andromedae system includes both a Hot Jupiter and eccentric planets, it may serve as a key to our understanding of planet formation and evolution.

While Upsilon Andromedae reassures us that systems of multiple planets are probably common, we still yearn to find planet systems that remind us of home, of our own Solar System. We want to know whether such systems are common or rare. Is the Milky Way galaxy littered with analogs of the Solar System, or is our little band of planets improbably fortunate to be moving in stable, life-protecting, nearly circular orbits? Since a Jupiter-mass planet at Jupiter’s distance from its parent star takes about twelve years to complete a single orbit, and since we need to observe at least two orbits to determine with certainty that what we’re monitoring is a planet, the current Doppler-effect surveys won’t complete a preliminary search for a true analog of our Solar System until at least 2010.

The indirect, Doppler-effect detection of back-and-forth wobbling will continue to account for most of the next decade’s extrasolar planet discoveries. Planet-hunting astronomers in the United States, Europe, and Australia are now surveying the nearest 2,000 stars from telescopes in the Northern and Southern Hemispheres. By decade’s end, these surveys will have provided hints about the proportion of planetary systems in our galaxy that are similar to our Solar System.

But teams of scientists and engineers are also developing technologies that allow direct detection of a planet-hosting star’s side-to-side motion against the celestial backdrop. Foremost among these is optical interferometry, a method of combining beams from two or more telescopes to produce an unprecedentedly precise measurement of a star’s position. The first of these optical combiners should be working at the two 10-meter Keck telescopes in Hawaii within the next year, and soon afterward at the four 8-meter telescopes of the European Southern Observatory in Chile. These systems should be able to detect intermediate-mass planets (those with a mass similar to that of Uranus, Neptune, and Saturn).

Interferometric observations made above the blurring effect of Earth’s atmosphere would allow even more precise measurements. NASA’s Space Interferometry Mission (SIM), due to begin within seven years, would be able to detect planets with masses as small as five to ten Earths and with orbital periods of five years or less. Next-generation space interferometers, such as the proposed NASA Terrestrial Planet Finder and the European DARWIN Mission, are tentatively scheduled to launch within fifteen years. These are projects designed to allow scientists to directly “see” Earth-like planets orbiting nearby stars and to search for evidence of water and life on these worlds.

For centuries, the primary goal of extrasolar planet research was simply to find one example. Now we’ve found twenty-eight, and our questions continue to race ahead of our primitive technologies. We want to find analogs to the Solar System, with Saturn- to Jupiter-mass planets in circular orbits the diameter of Jupiter’s. We want to find the intermediate-mass, Neptune-like planets and also the small, Earth-mass planets. We want a broad understanding of the formation and evolution of planetary systems.

Ultimately, though, we want to know how often we can expect to find stars with elegantly arranged systems of planets in mutually stable, circular orbits that might support small, blue-water worlds. By 2020, we may have the first glimmer of an answer.

"With moons to wait upon them as has our own Sun?" Christiaan Huygens
Cannibals of the Cosmos

Galaxies have to fight for survival, just like everything else in the universe. And now they have their own theory of evolution.

By Michael Shara

As with snowflakes, no two galaxies are identical. Even in 1935, when the Hayden Planetarium opened in New York City only a decade after astronomer Edwin Hubble had determined exactly what galaxies are, astronomers appreciated this basic fact. What they didn’t understand was how galaxies come to differ—the evolutionary processes that change them over billions of years.

Since then, three generations of observational and theoretical astrophysicists have succeeded in demonstrating that the appearance and evolution of galaxies are largely driven by collisions; that a collision between two galaxies lasts about 100 million years; that about a billion pairs of galaxies are colliding right now; and that these collisions were even more common 5 billion to 10 billion years ago, when the universe was much more dense.

In the eighteenth and nineteenth centuries, observations made with increasingly powerful telescopes led many astronomers to suggest that faint, fuzzy, spiral-shaped patches of light all over the sky might be “island universes”—galaxies equal in magnificence to our own Milky Way. In 1925 Hubble proved that these objects were made of billions of stars, at distances of millions of light-years from Earth.

In effect, galaxies became the flora and fauna of the cosmos. Just as biologists began early on to group plants and animals into families, seeking to classify the vast diversity of living creatures (and hoping these efforts would ultimately lead to discerning an order in nature), so astronomers of the early and mid-twentieth century proposed galaxy classifications based on shape, luminosity, and stellar content.

One of the first and most influential of these attempts was Hubble’s “tuning-fork diagram,” so called because he traced two distinct evolutionary paths that galaxies might follow out
red-rooster importance: let him count the star-swirls.”  Robinson Jeffers
of a common developmental “handle.” Although the diagram continues to appear in introductory astronomy texts, many of its specifics are now obsolete. Still, it established the general categories into which virtually every galaxy fits: pin-wheel (spiral), round, elliptical, or chaotically shapeless.

Yet it wasn’t until 1972 and the Astrophysical Journal’s publication of the monumental paper “Galactic Bridges and Tails,” by two astrophysicist brothers working at the Massachusetts Institute of Technology, that galaxy-evolution theory got its own Origin of Species. Just as Charles Darwin’s theory accounted for vast numbers of observations by thousands of naturalists, so the conclusions of Alar and Juri Toomre provided a comprehensive new way of looking at the data on galaxies that had accumulated over the course of the century. What the Toomre brothers simply and elegantly demonstrated, through both hypotheses and computer simulations, was that a close encounter between two galaxies—whether a near miss or a direct hit—usually has profoundly disruptive effects on both. To appreciate why this is true, a brief detour into the packed dormitories of galaxies and the spacious estates of stars is necessary.

The universe is far more crowded with galaxies, relatively speaking, than galaxies are crowded with stars. For example, to reach our nearest star (after the Sun), Proxima Centauri, you would need to string together 100 million Suns. By contrast, to reach our nearest galactic neighbor, the Andromeda galaxy, you’d need only twenty-five Milky Ways. Isolated stars similar to our Sun move through space for billions of years with no chance of encountering other stars. But many (and perhaps most) galaxies have passed close to or collided with other galaxies during the 15-bilion-year history of the universe.

As the universe continues to expand from its early, high-density state, galaxies become, on average, farther and farther apart (although they also tend to gather more often in rich clusters). In the distant past, when galaxies were closer together than they are today, collisions would probably have been very common, and galaxies residing in dense clusters would have been even more likely to suffer encounters. Recent Hubble Space Telescope observations of distant galaxy clusters (whose light began its journey to us when the universe was about half its present age) strongly support these hypotheses.

What happens when two galaxies collide? Gravitationally, the outcome can depend on several factors, including
the relative masses, sizes, and types of galaxies; their direction of spin; and how close they get to each other. But galactic collisions also can have generative effects as the gases from one galaxy come into contact with the gases from the other, leading to a baby boom of stars and star clusters. Many thousands of types of galactic interactions are possible, and their outcomes can range from benign to catastrophic. Fortunately for astrophysicists, only a few simple rules govern much of what happens during a close encounter.

Every one of the billions of stars in a galaxy is gravitationally attracted toward all the stars in its own and all other galaxies. The stars that are nearest to one another in two convergent galaxies, however, experience the strongest attractions and accelerations. The result is that both galaxies “stretch” as stars are diverted by varying degrees in different parts of the colliding system. The longer that stars are exposed to these stretching forces, the greater will be the upheaval in star orbits and galaxy shapes.

The Toomre brothers’ computer simulations showed that two galaxies slowly sweeping by each other and rotating in opposite directions (a hypothetical case that maximizes interaction time) can strip large numbers of stars out of each galaxy. This stripping process creates the long bridges and tails (the evidence of stars escaping both systems) that had already been observed but had, only a few years earlier, seemed inexplicable to astrophysicists. The match between long-standing observations and the Toomre brothers’ theory was exquisite—far too close to be coincidence. The simulation clearly explained how a close encounter dramatically distorted both galaxies.

A very close passage (with a distance of just a few galaxy diameters) can yield gravitationally mated, binary galaxies. Within a few hundred million years, the galaxies fall in on each other, thoroughly mixing their stars and emerging as a single massive galaxy. One of these more massive galaxies can exert a larger gravitational pull on nearby objects than would either of its lighter-weight predecessors. Astrophysicists speculate that a single supermassive galaxy within a rich cluster of galaxies can grow by cannibalizing its neighbors—and, in fact, observations reveal that at the core of many populous galaxy clusters is one monster elliptical galaxy. The evolution and eventual dissolution of galaxy clusters may be largely driven by collisions.

Head-on collisions are less probable than near misses but produce some spectacular results. The ring galaxy shown on the facing page is almost certainly the debris of a direct passage of one galaxy through the center of another. This freeze-frame image of a cosmic bull’s-eye is fleeting; the ring structure is unstable and will disintegrate in a “mere” 50 million years.

The effects of a collision between two galaxies go beyond gravitation, though. Computer simulations show that when spiral galaxies collide, many of their star-forming gas clouds are compressed by collisions with other gas clouds. As these clouds condense, they can yield clusters of hundreds of thousands of massive stars. The beautifully symmetrical patterns we see in many spirals are due partly to the clusters of births of massive stars. When these short-lived stars die as supernovas, the material they eject at high speeds triggers the compression of more gas clouds and another wave of star formation. After losing the raw material needed for creating more supernovas, postcollision spiral galaxies become populated with aging stars, as are elliptical galaxies.

These observed and theoretical collisions aren’t the only evolutionary factors affecting galaxies. Others are at work even in isolated galaxies; in particular, hydrogen is being fused into heavier elements and ejected by dying stars in every galaxy (see “Twinkle Twinkle,” page 64). This process continuously changes the chemical makeup of successive generations of stars and may also change the relative numbers of very massive stars and double stars. Finally, surrounding every galaxy is a massive component of dark matter that is detectable only through its gravitational exertions; how this mysterious matter affects the evolution of star orbits is still only partly understood.

There are other, even more subtle, effects we are aware of, as well as many we have yet to discover. Still, it’s clear today, as never before, that galaxies aren’t just the stately swirls seen through nineteenth-century instruments—or even the orderly cosmic companions that Hubble began classifying only three generations ago. They are individual organisms that have been undergoing dramatic, often violent evolution right from the start, shortly after the big bang some 15 billion years ago.

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**ace terrifies me.** Blaise Pascal
The Big Picture

Mapping galaxies gives the night sky something that simply looking at it won't provide: the third dimension.

By Margaret J. Geller

On April 26, 1920, two astronomers, Heber D. Curtis and Harlow Shapley, formally debated whether the fuzzy objects then called spiral nebulae were outside our own Milky Way. Curtis said they were external galaxies; Shapley said they weren't. Their debate marked the end of an era in our perception of our grandest environment. By 1929, Edwin Hubble and others, ironically including Shapley himself, had shown that the universe extends well beyond the boundaries of the Milky Way.

Today we know that our universe may well be infinite and that the farthest reaches of the visible portion—the part we can explore—are 15 billion light-years away. The quest for a map of this dauntingly large universe began promptly, once astronomers understood what to map.

By the time the American Museum—Hayden Planetarium opened its doors, on October 3, 1935, Shapley was engaged in a new debate, this time with Hubble. The subject was the arrangement of galaxies in the universe. Hubble, with access to the 2.5-meter telescope on Mount Wilson, outside Los Angeles, probed deep into the universe over small areas of the sky. He counted faint galaxies and argued that on large scales, the universe is remarkably uniform. Shapley, limited to smaller telescopes, worked with Adelaide Ames to construct a shallow catalog, extending over the entire sky, of the few thousand galaxies nearest the Milky Way. Whereas Hubble emphasized regularity, Shapley focused on irregularity. He noticed that in his catalog, clumps of galaxies covered large regions of the sky. He was ignored.

In 1938 Fritz Zwicky, an inspired maverick, picked up Shapley's thread. He suggested that clusters of galaxies—collections of hundreds to thousands of galaxies like the Milky Way—are the fundamental building blocks of the universe. Zwicky, like Shapley before him, used a fairly small telescope to photograph the entire northern sky. He then measured the two-dimensional positions on the sky—the latitudes and longitudes—for 30,000 individual nearby galaxies in these photographs. Zwicky's catalog, published in the

A slice of the universe: Galaxies clump together, with enormous voids in between the clumps. In this image, blue indicates spirals like the Milky Way, and red indicates elliptical galaxies.
1960s, was the launching pad for the transition from a two-dimensional to a three-dimensional view of the universe.

The 1970s ushered in a revolution in our ability to calculate the distances to galaxies and thus to map the universe in three dimensions. Instead of photographic plates, which register at best a few percent of the light striking them, astronomers began to use detectors similar to the ones in digital cameras today. These more sensitive solid-state charge-coupled device (CCD) detectors are crucial for analyzing the spectra of distant galaxies. To record a spectrum, we spread the galaxy light out into its colors, just as a prism does for sunlight.

Hubble first showed that the more distant a galaxy is, the greater the shift of features in its spectrum toward longer, redder wavelengths. This “redshift,” or stretching, of light occurs because of the expansion of the universe. The redshift is proportional to the distance to the galaxy.

Today Hubble’s relation between redshift and distance is the fundamental tool we use to make the transition from two-dimensional to three-dimensional maps of the universe. To derive the third dimension, we record the spectrum for each galaxy in a two-dimensional map like Zwicky’s. When Hubble and his collaborators measured redshifts for very nearby bright galaxies, it took all night on a 2.5-meter telescope. Today the same measurement takes less than a minute on a smaller telescope. Technological advances have made ours the age of mapping the universe.

Two-dimensional maps of the positions of galaxies across the sky hide the rich three-dimensional texture of the universe uncovered by systematic redshift measurements. Teams of astronomers have now mapped about .001 percent of the volume of the visible universe—about the fraction of Earth that is covered by the state of Rhode Island. Although the coverage is small, the obvious patterns in these maps are surprising.

“Tis a million universes.” —Walt Whitman
In 1986 my work at Harvard with my colleague John Huchra and graduate student Valérie de Lapparent provided unequivocal evidence that there are very large and well-defined patterns in the distribution of galaxies. The pattern of galaxies in our three-dimensional slice of the universe suggested that sheets, or walls, containing thousands of galaxies mark the boundaries of vast dark regions nearly devoid of galaxies. Some of these walls extend for hundreds of millions of light-years. The patterns in the universe are similar to a household sponge or to bubbles in the kitchen sink enlarged about a thousand trillion trillion times.

Maps are changing our picture of the nearby universe. Astronomers are beginning to define its “continents” and “oceans.” But even with these maps we cannot yet say that we have seen the largest patterns in nature. Several ambitious projects to map larger portions of the nearby universe are under way. These maps may tell us how galaxies mark the distribution of matter in the universe, but they will not tell us how galaxies or the patterns they make originated.

Theory asserts that the enormous, rich patterns we observe today originated as gravity caused the growth of very small lumps and bumps in the matter distributed through the early universe. During the past 15 billion years or so, galaxies and the network of structures they inhabit developed from the smooth early sea of matter and radiation.

Computer models produce spectacular images of the evolution of the universe, but there is no model as subtly beautiful as the natural world we observe directly. Today we are in the process of making the “real universe” movie, a journey in space and in time. When we look out in space, we look back in time. Nearly the entire history of the universe is there for us to see and record.

All the information we have about the universe is carried to us by ancient light. These photons travel to us for hundreds of millions, even billions, of years without hitting anything. They end their journey in our detectors and answer age-old questions. Large telescopes on the ground, coupled with space observatories such as the Hubble Space Telescope, will slowly give us the frames of our movie. Observers have already seen that when the universe was only a few billion years old, there were walls of galaxies—walls similar to the nearby ones. Of course, maps of the distant universe are now limited to very small regions and may be a deceptive guide to our history.

Our children’s grandchildren will probably have a picture of the entire universe. That we ask questions about the universe—that we are driven to explore it and understand it—is an awesome part of being human. That we can answer these questions is even more remarkable.

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*A deep view: In 1998 the Hubble Space Telescope peered down a 12-billion-light-year corridor, revealing a dazzling assortment of never-before-seen galaxies in the Southern Hemisphere sky.*

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“I offer the modest proposal that the universe is simply one of those...”
Genesis: The Sequel

In the beginning was the big bang. But what exactly banged? How did it bang? And what happened before it banged? Inflation theory offers some answers.

By Alan H. Guth

Although the study of the origin of the universe is in some sense one of the oldest sciences, cosmology as we know it today—a branch of astronomy dealing with the origin and structure of the universe—was in its infancy in 1935, when the Hayden Planetarium first opened. Just six years earlier, Edwin Hubble had discovered the expansion of the universe. Not only did this revolutionary insight overturn the age-old assumption of a static universe, but it initiated an effort among physicists and astronomers to trace this newfound expansion to its beginning—to what we would today call “the big bang.”

Over the decades, the big bang theory has become the framework of contemporary cosmology. It elegantly describes how the early universe expanded and cooled and how matter clumped to form galaxies and stars. While there’s never any guarantee that a scientific theory is correct, the big bang theory has passed a number of persuasive tests, including the 1965 discovery, by American physicists Arno A. Penzias and Robert W. Wilson, of a microwave hiss that matched predictions for the afterglow of the heat of the big bang. In 1993 the COBE (Cosmic Background Explorer) satellite made far more precise measurements of this radiation, verifying that its properties are just what scientists expected. Yet for all its striking successes, the big bang theory in its traditional form remained incomplete.

In fact, the big bang theory has never really been the theory of a bang at all. It describes the aftermath of a bang—the ongoing ballooning of space itself as the matter of the universe flies apart. But the theory says nothing about what caused this spectacular expansion. It gives not even a clue about what banged, what caused it to bang, or what happened before it banged.

In other words, the theory sheds no light on the underlying physics of the primordial fireball—and with good reason. Not until the 1970s did physicists develop an accurate enough theory of elementary particles to justify extrapolation to the extraordinary temperatures and pressures of the early universe. At about this same time, the evidence for the big bang theory became convincing enough for the scientific community to take it seriously. Thus, in the study of the first fraction of a second of the universe’s existence, particle physicists and cosmologists reached common ground. Their combined efforts led to what we now know as inflation theory—a description of the driving force behind the expansion of the universe and a source of plausible answers to the questions of what banged, how it banged, and more.

According to inflation theory, cosmic expansion was propelled by a peculiar material that turned gravity on its head, generating a repulsive, rather than an attractive, gravitational force. The proposal that the laws of physics should allow such a material is not a blind hypothesis but rather a prediction that arises from the combining of modern particle theory with things which happen from time to time.” Edward Tryon
general relativity. A patch of the early universe may have become filled with this repulsive-gravity material in a number of ways, but they would all have led to the same result. Inflation is like a wildfire taking over a forest: whether the fire was started by a match, a candle, or lightning, the outcome is much the same. The inflating patch would grow exponentially, doubling and redoubling. During the first trillionth of a trillionth of a trillionth of a second of the universe’s existence, the volume of the universe grew by at least a factor of $10^{75}$—about as much as it did during the next million years.

After a hundred or more doublings, the repulsive-gravity material would decay, much like a radioactive substance. The energy released would produce a hot, uniform soup of particles—the assumed starting point of traditional big bang theory. Here inflation theory joins the big bang theory, leaving all the successful big bang predictions intact. If inflation theory is right, essentially all the matter in the universe was created during the inflationary expansion. The universe is the ultimate free lunch.

Because inflation theory describes the bang itself, it can explain a number of previously mysterious features of the cosmos. One is the extreme uniformity of the universe on very large scales. If we divided space into cubes of 300 million light-years or more on each side, we would find that each cube closely resembled the others in all its average properties—mass density, galaxy density, light output, and so on. This large-scale uniformity is seen in galaxy surveys, but the cosmic background radiation provides the most dramatic evidence, showing that the temperature of the early universe was uniform to better than one part in 100,000.

Aside from inflation, no known mechanism can explain this uniformity. Before inflation theory was proposed, cosmologists had no choice but to postulate that the universe somehow began with an almost perfectly uniform temperature. Inflation theory changes this picture, inserting an enormous growth spurt into cosmic history. Prior to this spurt, when the region we are currently observing was less than $\frac{1}{10^5}$ the size that traditional big bang theory had assigned it, there was plenty of time for it to come to a uniform temperature, just as a slice of pizza cools to room temperature after being taken from the oven. Once this tiny region became uniform, inflation stretched it so much that it now encompasses everything we can see.

While the universe on the grandest scale may be remarkably uniform, it’s not entirely uniform. Just look at galaxies and galactic clusters and sheets of galactic clusters (see “The Big Picture,” page 74); inflation theory, it turns out, can explain these nonuniformities, too. According to quantum mechanics, the duration of the inflationary era would have varied slightly from place to place, and these variations manifested themselves in faint but crucial ripples in the matter density of the early universe—the seeds, in effect, that eventually would sprout into galaxies. Today we can observe these ripples indirectly, in the extremely fine variations they produced in the cosmic microwave background. Data from the COBE satellite and ongoing terrestrial experiments have so far been consistent with the predictions, which will be tested more precisely by upcoming space missions: the Microwave Anisotropy Probe (MAP), set for 2000, and the Planck Surveyor, tentatively scheduled for 2007.

Finally, the simplest versions of inflation theory make a prediction for the overall mass density of the universe—an important quantity that has recently acquired additional relevance. Within the past several years, the foundations of cosmology have been shaken by new observations of how the universe’s expansion rate has been changing. By using distant supernovas as distance indicators, two groups of astronomers have found that the rate at which galaxies were receding from one another 5 billion years ago appears to have been lower than it is today. Thus it seems likely, although still uncertain, that the cosmic expansion is accelerating. This suggests that the vacuum—empty space—has the same repulsive-gravity property that inflation theory attributes to the material of the early universe.

The idea that repulsive gravity is generated by a vacuum was introduced in 1917 by Einstein, who called it the cosmological constant. He used this idea to explain why his static-universe model would not collapse under the force of normal gravity but abandoned it when Hubble’s observations showed that the universe is expanding. The reemergence of the concept of a cosmological constant comes as a surprise to most cosmologists, although in many ways it is a welcome one.

"Not only does God definitely play dice, but He sometimes confuse
A cosmological constant would be particularly good news for enthusiasts of inflation theory. First of all, it would demonstrate that repulsive gravity—the hallmark of inflation—is not just a theoretical possibility but a reality. More important, it would help resolve a discrepancy: the simplest versions of inflation theory predict that the universe should contain three to four times more mass than astronomers have so far been able to find. A cosmological constant would lead to the surprising conclusion that empty space has a mass density, and the supernova observations indicate that this density is just right (within uncertainties) to bring the total up to the predicted value. This value is also in accord with a mass-density estimate based on cosmic background radiation experiments. While the implications of the supernova data and the cosmic background data are debatable, the agreement of these measurements with each other and with inflation theory leads to a persuasive picture.

In the next millennium, I think, inflation theory will continue to play a major role in shaping our understanding of how the universe got to be the way it is. This does not mean, however, that the most important problems have been solved. The concept of inflation is really a paradigm, not a detailed theory. Many versions of it have been put forth, and no doubt many more will appear. We still cannot identify the dark matter that makes up more than 90 percent of the mass of galaxies, and the physics that might underlie a cosmological constant remains a total mystery. Meanwhile, observational cosmology is becoming a precision science, rapidly accumulating data on the cosmic background radiation, the distribution of matter, and the composition of the universe. While I feel confident that inflation theory is basically correct, I suspect the final version will differ in many ways from anything so far proposed—and maybe even anything we can at present imagine.
The Heart of Matter

Physicists are still asking, What’s the universe made of? String theorists think they may know, and their new discipline is zeroing in on a theory of everything.

By Brian Greene

Nearly 2,500 years ago, the ancient Greeks asked a seemingly simple question that has wended its way through the ages and is still very much with us: What is the universe made of? That is, what are the fundamental ingredients out of which everything in the heavens and on Earth is composed? Or, to put the question another way, if you take any object whatsoever—a block of wood, a chunk of iron—and you cut it in half and then cut that half in half again, and keep cutting on and on, what is the most basic constituent you will ultimately come upon?

Democritus proclaimed that you would come upon what he called atoms, from the Greek for “uncuttable.” By the late 1800s, scientists had realized that substances such as oxygen and carbon did in fact have a smallest recognizable constituent, which (taking their cue from Democritus) they christened atoms. Yet over the next few decades, experiments revealed that atoms, contrary to the ancient Greek conception, surely must be cuttable, since they were an agglomeration of smaller particles: a swarm of electrons orbiting a central nucleus containing protons and neutrons. Moreover, in the early part of the twentieth century, physicists showed that understanding the behavior of these constituents meant replacing nineteenth-century ideas about matter and energy with the strange new laws of quantum mechanics. And by the early 1930s, physicists studying quantum mechanics realized that it required one of the most dramatic upheavals science has ever experienced. Science could no longer be expected to predict with certainty the outcome of experiments. In the microscopic realm, quantum mechanics showed that science could only predict the probability that a particular outcome might occur.

Although Albert Einstein contributed significantly to the early development of quantum mechanics, he focused much of his attention on gravity, a force that has its greatest relevance in the vastly larger realm of stars and galaxies. His general theory of relativity, proposed in 1916, correctly predicted the bending of starlight by the Sun and explained Edwin Hubble’s 1929 measurements indicating that the universe is expanding. But Einstein had even bigger plans. Perhaps, he mused, the universe could be explained by a “unified theory”—a single master framework that would describe physics out to the farthest reaches of the cosmos and down to the smallest speck of matter. Einstein relentlessly pursued a unified theory, but he ultimately came up empty-handed. To some extent, Einstein “failed” because many things about the workings of the universe were either still unknown or, at best, poorly understood during his lifetime.

For example, the first particle accelerators for studying the microscopic architecture of matter were built in the late 1920s. By the late 1960s, the resolving power of these machines had increased enormously, allowing physicists to reveal another layer of matter’s substructure: each proton and neutron, it was shown, is composed of three smaller particles, dubbed quarks. The proton consists of two “up” quarks and one “down” quark, while the neutron consists of two downs and one up. The detailed study of subnuclear interactions also established convincingly that two other forces besides gravity and electromagnetism are at work in nature: the weak nuclear force, which is responsible for radioactive decay, and the strong nuclear force, which is responsible for tightly binding quarks inside protons and neutrons and for cramming protons and neutrons inside the nuclei of atoms. Increasingly powerful atom smashers (today’s accelerators are more than a million times more powerful than those of...
possible, but not simpler.”  Albert Einstein
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...The framework taurus). the and Abdus Glashow, who in the 1960s proposed that the familiar electromagnetic force and the comparatively less well known weak nuclear force are inter-

mately related. These physicists argued that although the weak and the electromagnetic forces have vastly different characteristics in the world around us, if the cosmic clock were rolled back to an early stage in the universe—less than a millionth of a millionth of a second after the big bang, when the temperature was some million billion degrees Celsius—these two forces would combine into a single

force, somewhat the way a bouillon cube and water will form a homogenous broth when brought to a vigorous boil. By the mid-1980s, a central prediction of this proposed electroweak theory—the existence of certain crucial particles, known as Ws and Zs, that would perform the same force-carrying function in weak interactions that photons do in electromagnetic interactions—had been confirmed by the accelerator at the European Laboratory for Particle Physics (CERN) in Geneva, Switzerland. This represented a major step forward in the quest for unification.

The standard model of particle physics today encompasses both the electroweak theory and the theory of the strong nuclear force (known as quantum chromodynamics). Virtually all data recorded by particle accelerators the world over can be explained with this model; its creation has truly been a monumental achievement. There are, nevertheless, two main reasons physicists still aren’t satisfied.

First, the gravitational force is completely left out of the standard model. This omission creates a terribly thorny issue. The standard model, being a theory that describes microscopic processes, embraces quantum mechanics. But the problem of merging quantum mechanics with general relativity (a theory that describes macroscopic processes) has stumped physicists for more than half a century. Second, the standard model utilizes twenty or so numbers that have been established through decades of fastidious research—numbers such as the comparative strengths of the strong, weak, and electromagnetic forces, as well as the masses of the fundamental particles—but as a theory it offers no insight whatsoever into why these key parameters take the values they do. This marks a profound gap in our understanding, for if the value of some of these parameters had been even slightly different, the nuclear processes that power stars would likely have been disrupted, and without stars the universe would be a very different place.

These objections to the standard model are hard to counter, and many physicists believe that progress requires a radically new approach. During the past decade, the most promising possibility has been based on the notion of “superstrings.” Superstring theory abandons the previous conception of particles as being pointlike—that is, having no spatial extent. Instead the theory envisages the elementary constituents to be tiny, one-dimensional threadlike loops or snippets, which for want of a more clever name are called

"What we know is insignificant. What we a
strings. According to the theory, every elementary particle, if examined with a precision many orders of magnitude greater than what we are able to muster today, would be seen to contain one of these dancing, vibrating strings. And just as a violin’s string can vibrate in different patterns, thus producing different musical notes, string theory’s fundamental strings can also vibrate in different patterns. But instead of producing various tones, these patterns give rise to the distinct elementary particles. An electron is a string vibrating in one pattern, a quark is a string vibrating in another, and so on for all the other particles. The vibrational pattern of a string encodes the properties of the corresponding particle (its mass, its electric charge, its spin) and so may be thought of as the particle’s “fingerprint.”

Thus the universe, rather than being built from a long list of different particles, according to string theory has one fundamental ingredient—strings—and the rich variety of observed particles reflects nothing more than the various vibrational patterns that strings can execute. Moreover, even the four forces of nature, including gravity, are associated with strings vibrating in yet other patterns, and hence everything—all the particles of matter and all the forces by which they interact—is unified under the same rubric: vibrating strings.

However compelling a framework for a unified theory, superstring theory at the turn of the millennium is still very much a work in progress. For example, the theory’s equations are so involved that physicists have as yet been unable to determine whether the repertoire of vibrational patterns precisely accounts for the known particles and forces. The inability to clear this hurdle is due in part to another strange feature of the theory: it requires the universe to have more than the three spatial dimensions of common experience (left/right, back/forth, up/down). Since we don’t see the others, they must be hidden away.

One approach pictures these other dimensions as being curled up like a piece of paper that has been rolled into a thin tube. The more tightly the tube is rolled up, the harder it becomes to see that it has a circular cross section, since this circular dimension gets smaller and smaller. Physicists imagine that the extra space dimensions required by superstring theory are so tightly curled up that equipment powerful enough to detect them has not yet been built.

Although these extra dimensions are minuscule, they have a profound effect on the physics of string theory. The strings themselves are so small that they are able to vibrate in both the familiar “big” dimensions and the tiny, curled-up dimensions. The precise size and shape of these dimensions affect the ways a string can vibrate, much as the twists and turns of a French horn affect the ways that forced air streams can vibrate through its interior. And since the string’s vibrational patterns determine such things as particle masses and force strengths, the detailed geometry of the extra dimensions may one day explain why the aforementioned twenty numbers that animate the standard model of particle physics would have the values they do—in essence, why the universe is as it is.

The experimental verification of superstring theory in the near future poses quite a challenge. Since strings are thought to be less than a billionth of a billionth the size of an atom, we can’t use current technology to detect them directly. An indirect test, however, will be carried out within the next decade or so by a huge atom smasher called the Large Hadron Collider, which is now being built by CERN. Through enormously powerful collisions, physicists hope to produce a number of particle species (collectively called sparticles) that have never before been seen but are believed to be an essential part of the superstring framework. Another indirect test is now being carried out at Stanford University and the University of Colorado at Boulder, where researchers are looking for evidence of the required extra dimensions by trying to ascertain their influence on specific properties of the gravitational force.

Evidence for assessing this theory may also one day be found through increasingly refined astronomical observations, since superstring theory shows its true colors in extreme environments such as those associated with black holes and the big bang. It would surely be a wonderfully poetic emblem of unification if the theory describing the most microscopic properties of matter—a theory answering that prescient question raised by the ancient Greeks—were one day confirmed by turning powerful telescopes toward the sky and examining the grand expanse of the cosmos.

"But know is immense." Pierre Simon de Laplace
Seeing the Whole Symphony

For four millennia, astronomers were color-blind to most of the universe's energy spectrum.

By David J. Helfand

luck a hair from your head and hold it taut at arms' length. That fine line, bisecting the background and reflecting a little light directly to your eyes, represents the smallest dimension your eyes can perceive unaided. If you don't believe this, reduce the hair's apparent width by having someone carry it ten times farther away—across the room—and watch it disappear.

Why does it vanish?

The limits on human vision were set eons ago by just two physical parameters, neither of which might at first seem relevant: the temperature of the surface of the Sun and the force of gravity on the surface of Earth. These two parameters, accidents of the Solar System's formation 4.6 billion years ago, not only limit the dimensions our eyes can resolve but also dramatically restrict the range of colors we can perceive. With a surface temperature of 5,800°C, the Sun emits most of its energy as yellow-green light, with smaller amounts of red and blue. Earth's gravitational pull—is insufficient for the planet to hold on to its primordial hydrogen and helium atmosphere but strong enough for it to retain oxygen and nitrogen—defines the atmospheric filter through which radiant energy must pass before reaching the planet's surface. The Sun's blue light gets scattered around a lot (which is why the sky is blue), and some of the reddest rays get absorbed by molecules in the air, but most of the wavelengths from the Sun make it through. These colors, having bathed Earth for billions of years, are what our eyes have evolved to see.

Putting a big telescope in front of our eyes can compensate for our inability to perceive details at great distances, but it does nothing for our more profound color blindness. Human vision, a marvel of evolutionary adaptation and the most precious of our senses, turns out to be a rather poor instrument for observing the universe.

An aural analogy may explain the problem. The human ear is sensitive to a full ten octaves of sound-wave frequencies—from about 20 oscillations per second (roughly one octave below the lowest note on a piano) to 20,000 oscillations per second (the highest squeak of the audiologist's tone generator). Our instant recognition of the timbre of a familiar voice and our appreciation for the rich texture of an orchestra bringing to life the storm in Beethoven's Pastoral Symphony rely on the ear's ability to register a wide range of frequencies. The human eye, however, is sensitive to barely one “octave” of the electromagnetic spectrum. Trying to understand the universe equipped with only this very limited instrument is like trying to do justice to the “Ode to Joy” on a ukulele.

Yet when the Hayden Planetarium first opened its doors in New York City, in October 1935, this was the astronomer's lot. Over the course of four millennia, astronomers (and eventually) astrophysicists, working first with the unaided eye and then with ever more powerful telescopes, had closely examined the Sun, Moon, planets, stars, and finally galaxies. They had conducted extraordinarily precise studies of the motions of celestial objects, arrived at a model of the Solar System, and determined the distances to the stars. They had computed the ages and masses of stars and had broken down their light to reveal their chemical composition. They had demonstrated that distant aggregations of stars were indeed galaxies distinct from our own Milky Way. Perhaps most remarkable, they had shown that the universe appears to be expanding in all directions. Not bad for explorers almost totally blind to their surroundings.

But what had astronomers missed over the millennia? Quasars and pulsars. Black holes and neutron stars. Vast clouds of cold organic molecules and the 100-million-degree gas that can not only sufluse an entire galaxy cluster but actually outweigh it. The afterglow of the big bang itself. They missed most of the matter in the universe, most of the sweep of space-time, the coldest parts, the hottest parts, the densest parts, and the remotest parts—most of what constitutes astronomy today.

Everything in the universe radiates energy in the form of electromagnetic waves that move through space at 300,000 kilometers per second. The temperature of objects—or, more precisely, the energies of their constituent particles—determines the frequencies of these waves. Nothing can get colder than absolute zero (0° K, or -273.15° C), and no particles can travel faster than light, but everything in between is allowed; the result is a spectrum of electromagnetic-wave frequencies that spans more than 100 octaves. Radio waves and infrared radiation, ultraviolet rays, X rays, and gamma rays—entities we think of as unrelated to vision—are in fact just labels applied to different octaves in the variegated spectrum of electromagnetic radiation. Our multicolored rain-

Opposite page: The Milky Way, seen in eight different wavelengths
Radio waves provided the first image of the universe outside the narrow band of visible light.

bow fits into just one octave in the middle of this broad spectrum—the octave we call light.

This single octave is no more special than the octave of sound waves from the F sharp below middle C to the F sharp above it—its boundaries are no less arbitrary, and its relationship with the adjacent higher and lower frequencies is no less continuous. It is simply that conditions determined by the Sun and Earth have conspired to produce living electromagnetic sensors blind to all the other octaves.

Even the Sun produces energy in parts of the spectrum invisible to us: just above the apparent surface of the Sun, the temperature climbs to tens of thousands of degrees, producing primarily ultraviolet radiation. Even farther from the surface, giant loops of magnetic fields collide, raising the temperature to millions of degrees and producing X rays, while charged particles race through the loops, generating bursts of radio-wave emission. To these and other phenomena we remained blind—until we began opening windows to other octaves in the electromagnetic spectrum.

In 1890, just two years after the discovery of radio waves, Thomas Edison proposed the first experiment to search for cosmic sources, although no records of the experiment’s execution have been found. A few years later, Oliver Lodge attempted to detect the Sun in radio waves but discovered instead the ever-present bane of the radio astronomer’s existence—man-made interference (in Lodge’s case, from the surrounding city of Liverpool). Numerous other experiments in the first decades of the twentieth century also failed, and it wasn’t until May 5, 1933, that the New York Times carried the first report of invisible radiation from the universe, under the headline “New Radio Waves Traced to Center of Milky Way.”

The article described the work of a young Bell Telephone Laboratories engineer, Karl G. Jansky, who had been systematically identifying sources of radio static in order to improve ship-to-shore and transatlantic communications. In addition to lightning and man-made sources, there was, he discovered, a signal apparently fixed with respect to the stars that was coming from the general direction of the center of the Milky Way. Although he published his results in Popular Astronomy as well as in a radio engineering journal, virtually every astronomer ignored his work, and Jansky was soon reassigned to another project at Bell Labs.

One person who did pay attention to Jansky was Grote Reber, a radio engineer and amateur astronomer who in 1937 devoted $700 (one-third of his annual salary) plus many nights and weekends to constructing a “radio telescope” in his backyard in Wheaton, Illinois. Within six years, he had completed the first systematic survey of the sky that was based on radio waves. The results, published in the Astrophysical Journal under the title “Cosmic Static,” identified several regions of
enhanced radio emission along the plane of the Milky Way and, more important, provided the first image of the universe outside the narrow band of the visible spectrum. Astronomy would never be the same.

It was not an accident that the radio portion of the spectrum was the first to be exploited by astronomers; it's the only set of frequencies besides visible light that can penetrate Earth's atmosphere. To view the universe in other frequencies—with X-ray, ultraviolet, or infrared eyes—we must get above the absorbing blanket of air. Thus, astronomy's newer disciplines couldn’t develop until we had access to space. In 1962 a small rocket carried a detector aloft for a five-minute glimpse of the X-ray universe. Contrary to theoretical expectations, a brilliant X-ray “star” was seen. Even more extraordinary, the whole night sky was aglow with X rays, suggesting multitudes of X-ray sources awaiting discovery. Within a decade, rockets and satellites had been launched to scan the skies for objects emitting infrared, ultraviolet, and gamma radiation. None of the experimenters was disappointed.

The astronomical explorations of the second half of the twentieth century confirmed some of physics' more remarkable predictions of the first half, turning the entire cosmos into a vast experimental facility for testing extreme states of matter and energies unattainable in earthbound laboratories. Neutron stars with a density of a billion tons per teaspoon help us assess the behavior of particles in the atomic nucleus. Black holes allow us to probe the structure of space and time itself, while the afterglow of the big bang allows us to set constraints on the fundamental structure of matter.

With a far more complete view of the cosmos, astronomers can expand their understanding of the laws of nature in ways that would have been unimaginable when the old Hayden was built. The impact of opening new windows on the universe is perhaps best illustrated by Martin Harwit’s list of astronomical phenomena in his book Cosmic Discovery. The first 4,000 years of astronomical observations produced twenty-six distinct discoveries that helped define the contents of the universe. All, of necessity, were visible phenomena. Between 1940 and 1980, seventeen additional fundamental discoveries were made. Only two of these were accomplished with visible light; the remaining fifteen came about because we learned to sample the universe on its own terms, instead of limiting our perspective to the evolutionary accident of sight. For an audience confined so long to a single octave, it is a revelation of immense significance to finally see the whole symphony.

An ultraviolet map of the sky based on six months of observations by the Extreme Ultraviolet Explorer (EUV/E) satellite.
The Virtual Universe

In cyberspace, astronomers can boldly go where no one has gone before.

By Mordecai-Mark Mac Low

A half-mile-wide pile of gravel and dirty snow hurtles past Jupiter, barely evading the grasp of its gravity. Still, the comet (for that’s what this pile of debris is) begins to drift apart because of the feather-light difference between Jupiter’s gravitational force on its near and its far sides. This tidal force strews pieces of the comet through space until they span a distance greater than the separation between Earth and the Moon. During the following year, bits of rubble from the ill-fated comet gravitationally reassemble themselves into a chain of twenty smaller objects. As Jupiter's gravity asserts itself once more, drawing the whole chain back toward the planet on an even more perilous orbit, astronomers on Earth finally notice that the comet is on a fatal course.

With the whole world watching, the first object in the chain plunges into Jupiter's atmosphere at more than 100,000 miles per hour, becoming the mother of all meteor strikes. Falling beneath the ammonia clouds that form the visible surface of the planet, the comet fragment vaporizes in the white-hot heat of its shock wave, releasing the energy of thousands of nuclear bombs. On Earth, the resulting fireball would stretch from New York to Chicago. On Jupiter, it blows material clear out of the atmosphere but is nevertheless a mere pinprick to the giant planet.

The once-herculean task of calculating thousands of orbits can now be completed in an hour or two by a single astronomer.

To predict, and eventually to interpret, the violent fate of comet Shoemaker-Levy 9 in July 1994, astronomers turned not just to their traditional tools—mathematical calculations and telescopes—but also to computer models. Computer modeling began just over half a century ago, initially driven forward by the race to design and build atomic weapons. Astonishing increases in computer speed and memory have since made it into a third method of scientific investigation, distinct from mathematical theory and from experiment and observation—yet relying on both.

In June 1993, soon after word of the comet's potentially
catastrophic fate began to circulate among astronomers, Kevin Zahnle, of NASA’s Ames Research Center, called me to suggest that we actually begin a collaboration we’d often discussed, one that would combine his knowledge of asteroid and comet impacts on planets with my expertise in astrophysical shock waves. The first moves were made not by us, however, but by dynamical astronomers, who used one of the most fundamental mathematical descriptions of the physical universe: the law of gravity.

Mathematical computations of the orbits of objects under the influence of both a planet and the Sun draw on a body of work stretching back more than 300 years to Isaac Newton. By the early twentieth century, orbit calculations were already being carried out by computers, although the word “computer” then referred not to a machine but to a member of an arduous profession that, as it happens, offered almost the only way available at the time for women to participate in astronomical research. These human computers could calculate single orbits but not the thousands necessary for constructing a model of a fragmenting and reassembling comet. Now, though, such a herculean task can be completed in an hour or two by a single astronomer, who can then compare many models with the observations so as to find the best match.

Opposite page: The author’s computer simulations show a comet entering Jupiter's atmosphere in a region six miles across. Above: The resulting explosion covers a region 600 miles across.
The programs that compute these orbits use the principles of high-school analytic geometry to represent the motions of thousands of comet fragments. At the beginning of the computation, each fragment is assigned a position in space using three coordinates, along with an initial velocity (in the case of comet Shoemaker-Levy 9, the fragments were initially distributed in a sphere with a diameter of just under a mile). Using the law of gravity, the program next computes the forces acting on each fragment—from Jupiter, from the Sun, and from every other fragment—in order to determine the direction and distance that each will travel over a very short time. The coordinates of the fragments are then changed to their new positions, and the time is advanced. The program then repeats these steps, using the new positions and taking into account the slightly different forces now acting on them because of their motion with respect to one another, to Jupiter, and to the Sun. Repeating this relatively simple procedure thousands or even millions of times allows the computation of the entire comet breakup.

Each of the particles in such a computer program might represent something the size of a boulder, as in the case of comet Shoemaker-Levy 9, but it might just as easily represent a star—or even groups of tens of thousands of stars. Simultaneous computations of the orbits of tens of thousands of such massive particles can demonstrate how galaxies develop their beautiful spiral arms. By initially placing the particles in a uniform, rotating disk and then simulating their interactions, astronomers find that spiral arms form whenever the disk arrangement is even slightly perturbed, as a natural result of the gravitational interactions between the stars. Similarly, but on an even grander scale, computations of collisions between spiral galaxies show that mutual gravitational interactions disrupt the orderly disks and throw stars out in spectacular streamers tens of thousands of light-years long (see “Cannibals of the Cosmos,” page 70), as observed in contorted objects such as the Antenna galaxy.

These same computational techniques have led to a revolution in our understanding of the large-scale structure of the universe and the process of galaxy formation. Models of this process begin with not tens of thousands but tens of millions of particles, distributed through a representative region of the universe almost uniformly, just as matter was distributed in the earliest centuries after the big bang. Each particle in the simulation now represents a mass of millions of stars—still a small fraction of the billions of stars in a galaxy. Modeling the orbits of these particles under the mutual influence of all the other particles in the region reveals that areas of slightly greater density attract more and more mass, eventually forming stars and galaxies, while areas of slightly lesser density empty out, forming cosmic voids that can still be observed today. When the models are started with initial conditions consistent with observations, the resulting cosmic web beautifully reproduces the distribution of galaxies that we observe in the universe today (see “The Big Picture,” page 74).

Gravity alone is sufficient for predicting the behavior of boulders and stars only so long as no other forces become as strong. In the case of comet Shoemaker-Levy 9 on its final plunge, however, the fragments screaming into the wispy outer reaches of Jupiter’s atmosphere entered the realm of hypersonic gas dynamics. The basic laws of gas flow were described 200 years ago by Leonhard Euler, but it was not until the middle of the twentieth century that researchers developing rockets and nuclear bombs first carefully computed the properties of strong shock waves and massive explosions. (To this day, classified U. S. nuclear weapons development centers maintain the largest computers available for such computations, although research centers that are open to all scientists offer strong competition.) When the atmosphere gets dense enough, the pressure forces overwhelm the gravitational forces between particles and must be included in the model.

Before: By following the motions of stars in galaxies that have begun to interact gravitationally, a computer simulation reveals how spiral arms form.
This is where Zahnle and I entered the picture. I had already computed, in other contexts, many models that included pressure forces. Gas pressure varies, so to compute its effects, a coordinate system is set up, and a grid of points is defined throughout the region. At each point on the grid, the local pressure, density, and velocity of the gas are noted. For the comet collision, I used a software package called ZEUS (written by Michael Norman and his colleagues at the National Center for Supercomputing Applications) to set up a grid covering a small region of Jupiter's atmosphere, with a sphere as dense as ice (representing the comet) falling through the grid at many times the speed of sound.

Because gas flows away from regions of high pressure and toward regions of low pressure, the program computes how the gas at each point will move under the influence of gas at neighboring points over a very short time period. These motions are then used to determine how the gas properties stored at each point in the grid change over this short time. By repeating this computation thousands of times, we can follow the gas flow: the comet fragment drives a high-pressure shock wave ahead of it, while the rest of the atmosphere remains undisturbed until the shock wave hits it, heats it, and drives an explosive expansion.

Zahnle and I based our computations of the comet's impact on previous models I had done of the effects of multiple supernova explosions on the gas between stars in the disks of spiral galaxies. Although the distances in these models were tens of trillions of times greater than those in the comet impact, and the explosion energies even more extreme, the physical mechanisms were quite similar. I scaled down the distances from light-years to miles by some thirteen powers of ten (one followed by thirteen zeros), scaled down the explosion energies by even more (a factor of twenty-three powers of ten), and found virtually the same expansion of an explosion in Jupiter's stratified atmosphere that I had found in the galactic models.

When interpreting computational models, we must always keep in mind two questions. The first is, Does the model contain all the important physical processes? Short of including not just every atom but every electron and photon, modeling always involves estimating how strongly different processes contribute to the situation and then deciding which processes can safely be ignored. For example, in my models of the comet impact, I neglected radiative heating of the icy comet fragment by the white-hot shock front below it, because of calculations by colleagues suggesting that radiative heating would be slightly less important than heating from the hot, shocked gas. Including the radiative heating would also have made the problem far more difficult to compute—always a consideration in deciding what to ignore.

The second question is, Does the numerical model actually simulate the physical processes we've decided to include? If the sampling, for example, is too coarse, important features can be missed, but if the sampling is too fine, the time needed for computing the model will be prohibitive. The question of how much sampling is enough arose during my computations of the comet impact. I realized that some of the first published models of the impact did not have fine enough grids to follow the way the comet was torn apart by the pressure forces. Instead, the fragments in these models remained intact and therefore punched much more deeply into the atmosphere, burying their energies and leading to predictions of less spectacular explosions.

Because of these two constraints, computational simulations can never stand on their own, independent of observation. The seeming completeness of simulations can easily seduce us into believing that they give a true picture of reality. Poor approximations or inaccurate numerical methods, however, all too often yield attractive but incorrect models. Only the interplay between model and observation can yield reliable information about the universe around us.

How will astrophysical computer modeling develop in the next decade? Computations of straightforward three-dimensional gas dynamics at moderate resolution are still a recent addition to the computational scientist's tool kit. Now the challenge is twofold: first, to include more of the relevant physical processes, such as the chemical behavior of gas as it is heated to millions of degrees by hypersonic shock

After: The galaxy collision results in something resembling the Antenna galaxy—a celestial oddity. Modeling reveals its history and predicts it will become a massive elliptical galaxy.
waves and then cools down almost to absolute zero; and second, to increase the resolution of the models so that, for example, the formation of individual galaxies can be followed in cosmological simulations.

Only the interplay between model and observation can yield reliable information about the world around us.

The new generation of supercomputers presents its own challenges. Rather than being very fast single processors, they consist of hundreds or even thousands of off-the-shelf microprocessors linked by very fast communications networks. Programming these machines requires that all these individual units be coordinated without their generating the kind of internal traffic jams that clog the Internet. Another direction being pursued for increasing computational speed is the development of specially designed chips that can perform the most time-consuming parts of the simulations rapidly, so that desktop processors can achieve supercomputer speeds for particular types of problems. This technique has already proved particularly fruitful for particle simulations such as those described above.

Finally, the never-ending struggle to win insight from computation will depend not just on better simulations but also on better analysis of the results of those simulations. These analyses will more and more rely on computing how the results would appear if the physical situation simulated were observed through a particular telescope, and then comparing these simulated observations with real observations by that telescope. Increasingly, astrophysicists will attempt to understand complex observations with complex computer models, but always with the ultimate aim of gaining an understanding of the universe that can be confirmed by comparisons with observations of the real world.

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Sky of the Beholder

The Starry Nights series, explains photographer Neil Folberg, “began as an attempt to show the sky as our eyes see it.” While telescopic images can offer us lush color close-ups of galaxies, they put the viewer at a vantage point somewhere in space. Folberg combines constellations, lunar eclipses, and meteor showers with more earthly scenes—desert landscapes, temples, archaeological sites. In the image shown here, entitled simply Cactus, the stellar display is punctuated by the clustered stars of the Pleiades, or Seven Sisters, which brightly crowd in at the far right. But we are rooted in a landscape of shrub and rock in the Judaean hills, not far from Jerusalem.

An ongoing series (a recent entry includes last fall’s Leonid meteor shower), Starry Nights grew out of two very distinct book projects: color landscapes of deserts and images of historic synagogues around the world. Folberg finds a “direct continuity” in his scenes of desert, temple, and sky.

Like all photography, Folberg’s work is about light, sight, and technique. If you look up, particularly in the clarity of a desert night, your human eye drinks in starlight. But stars do not lend themselves to snapshots: point a camera skyward and push a shutter, and the film will record nothing. Prolong the exposure, and arcs of light will appear as the stars trace their way around a fixed point in the heavens. Folberg overcomes this problem by mounting his camera on a motorized base in order to track the stars as the Earth turns. And to reproduce what our eyes see naturally, he also uses “exotic techniques”: infrared film (as for the foreground here), precious-metal toners, and other “manipulations that push the materials to their limits.” In the best photographic tradition, the result is, of course, more than meets the eye.—Judy Rice

Photograph by Neil Folberg
A Forgotten Cosmic Designer

Artist-scientist Howard Russell Butler painted moonscapes and portraits of “Earth’s richest man,” but his plans for a hall of astronomy were eclipsed.

At the age of sixty-two, painter Howard Russell Butler was invited to join a U.S. Naval Observatory expedition to Oregon to chronicle the solar eclipse of June 8, 1918. “As a portrait painter,” he wrote in *Natural History* (“Painting Eclipses and Lunar Landscapes,” July–August 1926), “I generally asked for ten sittings of two hours each. But all the time they would allow me on this occasion was 112½ hours.” His finished painting eventually graced the Hayden Planetarium’s rotunda.

To record color values, Butler relied on a shorthand system he had developed for use in “recording transient effects.” The artist may have perfected his color shorthand while laboring over thirteen portraits of Andrew Carnegie, who reportedly could not sit still for long. Impressed with Butler’s many talents (the painter had also been a professor of physics, a patent lawyer, and an arts administrator), the steel magnate hired him to design a mansion on Fifth Avenue, create an artificial lake at Princeton University, and run the recently built Carnegie Hall. Butler’s gift for creating celestial images (and his friendship with Carnegie) attracted the attention of American Museum of Natural History president Henry Fairfield Osborn, who asked him to design a hall of astronomy. In May 1925, Osborn wrote to the Carnegie Foundation: “I am confident that [it] will be the most inspirational and seductive of all our great Sections and will not only be a unique monument to Mr. Andrew Carnegie but will exert a profound influence on the life and thought of the entire United States, as our Department of Paleontology is now doing.” Carnegie money, however, was not forthcoming.

Butler had placed the hall at the Museum’s center, as “the celestial hub, so to speak—from which all the halls containing terrestrial exhibits will radiate” (“An Ideal Astronomic Hall,” *Natural History*, July–August, 1926). It was to be a dimly lit rotunda ringed with tiers of meteorite exhibits and backlit telescopic photographs. Topping the four-storied hall would be a dome onto which the newly developed Zeiss projector could beam the images of 4,500 fixed stars and various heavenly bodies. By 1927, however, Butler’s ambitious plan for a hall of astronomy was shelved in favor of a freestanding building that would eventually become the Hayden Planetarium.

Ultimately, Butler’s legacy was not the hall design itself but a collection of artwork that was on display in the old Hayden for many years. His meticulous paintings of solar eclipses, of Mars as if viewed from its moons, and of Earth as it would appear to someone standing on our Moon stirred the imaginations of several generations of schoolchildren.

“Many times, while making [the moonscape] painting, I longed to be at the spot and see how it really looked,” Butler recalled. “But when [an astronomer] informed me that the temperature there would be about 70° below zero, I was content to abandon that desire.”—*Jenny Lawrence and Richard Milner*
EVENTS

Rose Center Opening
The Frederick Phineas and Sandra Priest Rose Center for Earth and Space opens February 19, 2000. The Center includes the new Hayden Planetarium, the Lewis B. and Dorothy Cullman Hall of the Universe, and the David S. and Ruth L. Gottesman Hall of Planet Earth (which opened in June 1999).

Our Place in Space, a free astronomy publication for eight- to twelve-year-olds, is available in the Museum’s Cullman Hall of the Universe and at www.amnh.org/explore/ourplace.

FEBRUARY 1 AND 8
In two 7:00 P.M. talks, Johns Hopkins University scientists discuss the impact of climate change on public health. In the first, Jonathan Patz evaluates the human health risks of global warming and El Niño; in the second, Gregory Gurri Glass examines the effects of habitat destruction in Peru and the United States.

FEBRUARY 5
“What Causes Climate and Climate Change?” led by Charles F. Keller, of the Los Alamos National Laboratory, is the fourth of five monthly 1:30 P.M. discussions by geologists and climatologists of issues explored in the Gottesman Hall of Planet Earth.

FEBRUARY 6
Cuban biologist and photographer Alfonso Silva Lee gives a family lecture at 2:00 P.M. about the animals of Puerto Rico. Silva Lee’s talk focuses on Cogni and His Friends, his new book for children.

FEBRUARY 10
The great auk, extinct since 1844, is the subject of a 7:00 P.M. talk by artist and naturalist Errol Fuller, who has published a book on this flightless North Atlantic bird.

FEBRUARY 14
As part of the “Distinguished Authors in Astronomy” series, Ken Croswell, an astronomer from Berkeley, California, gives a talk at 7:30 P.M. entitled “Magnificent Universe,” based on his illustrated book portraying the cosmos.

FEBRUARY 15
At 7:00 P.M., science writer Matt Ridley, author of Genome: The Autobiography of a Species in 23 Chapters, talks about the impact of the Human Genome Project, the massive international effort to map and sequence the genes in human DNA.

FEBRUARY 16
At 7:00 P.M., Sidney Horenstein, the Museum’s coordinator of environmental programs, gives an update on the geology of our Solar System’s planets, moons, meteors, and comets.

FEBRUARY 16 AND 23
In the first two talks in the 7:00 P.M. series “The Primal Feast: Food, Sex, Foraging, and Love,” Susan Allport, author of A Natural History of Parenting, focuses on foraging strategies of animals from howler monkeys to hedgehogs and on the variety of human diets and attitudes toward food.

FEBRUARY 17
James Gleick, author of Faster: The Acceleration of Just About Everything, speaks at 7:00 P.M. about our culture’s obsession with timesaving devices and strategies.

FEBRUARY 19
At 1:00 and 3:00 P.M., sword-dance troups and musicians perform some of the centuries-old English rituals associated with the cycle of the seasons.

FEBRUARY 22
Peter Matthiessen, author of Tigers in the Snow, speaks at 7:00 P.M. about the protection of the Siberian tigers of Russia’s Sikhote-Alin’ coastal mountains. The U.S.-Russian team that undertook the project was led by biologist Maurice Hornocker.

FEBRUARY 24
Drawing on her new book, Mother Nature: A History of Mothers, Infants, and Natural Selection, anthropologist Sarah Blaffer Hrdy gives a talk at 7:00 P.M. on how gender roles, mate choice, sex, reproduction, and parenting motivate behavior.

FEBRUARY 25, 26, AND 27
As part of the series “Body Art in Asian Theater,” Japanese master performer Yoshi Tachibana demonstrates a distinctive form of Kabuki theater developed during the Edo period (1603-1868). For scheduled times, call (212) 769-5315.

FEBRUARY 26
Folklorist Daniel N. Wojcik discusses youth culture’s approaches to self-decoration at 7:00 P.M., in connection with the Museum’s special exhibition on body art.

FEBRUARY 28
At 7:30 P.M., as part of the “Frontiers in Astrophysics” series, Clark Chapman, of the Southwest Research Institute in Boulder, Colorado, gives a talk entitled “Europa: Jupiter’s Enigmatic Moon.”

DURING FEBRUARY
Science Bulletins, the Museum’s regular updates on new developments, can be viewed on video panels and kiosks in the exhibition halls. Or visit biobulletin.amnh.org, earthbulletin.amnh.org, and astrobulletin.amnh.org for the latest news in biodiversity, earth science, and astronomy online.

To celebrate Black History Month, the Leonhardt People Center presents free weekend programs focusing on the traditions of Africa and the African diaspora. For information, call (212) 769-5315.

For a listing of the Hayden Planetarium’s courses, call (212) 759-5900.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100. For tickets, call (212) 769-5200. Visit the Museum’s Web site at www.amnh.org.

Natural History Online
Visit www.naturalhistory.com, Natural History’s Web site, for current articles and accompanying audio and video clips, as well as memorable pieces from earlier issues and additional material not found in the print version of the magazine. (Pictured above is this month’s Mystery Object. Its identity will be revealed next month.)
Born three years before the old Hayden Planetarium, I can remember when the Sunday supplements would carry articles speculating on what the inhabitants of the other planets looked like. We knew that Venus was hot, so the Venusians must be slim and flickering, like salamanders. We knew that Jupiter was a huge ball of gas, so its residents would be squat and splayfooted, like gravity-flattened camels treading the sand. When the imagination moved out to Neptune and Pluto, it became ghostly, conjuring up giant eyes to see in the dark, so far from the Sun. Now, of course, the planets and their satellites have had the benefit of a Voyager flyby or some other robotic close-up, and the stunning photographic images yield no sign of life. Mars is a desert, Europa a ball of ice, Io a giant pizza. The Solar System has become more colorful and less companionable; the stars beyond, too, for all the efforts of cinematic science fiction to domesticate them, are more forbidding for being more numerous, more violent, and more rapidly retreating than was thought sixty years ago. The universe refuses to be held to anything like human measure.

When the Milky Way arched over the nighttime desert like a powdery river and hovered above the Mediterranean like a slowly rotating disk of bright pinpricks, men sought intimacy with this unreachable reality by tracing and naming constellations; the planets, as these wanderers emerged from the dazzling mass, were given the names of deities. Humanity read itself into the heavens. The Christian religion supplanted the theologies of pagan Europe, and the stars were made to adorn the Virgin’s crown, to stand watch over the divine infant’s manger, and to adhere to invisible spheres—as many as twenty-seven—that smoothly turned in concentric homage to God’s glory.

The telescope roughened the picture: the Moon had mountains, Saturn had rings, and Jupiter’s moons rotated around it, puncturing the planet’s crystal sphere. The picture has widened and deepened ever since; fuzzy nebulae were revealed to be other galaxies, as full of stars as our own, and the chemistry of the stars yielded to spectrum analysis. A universal history was deduced, traceable to a monstrous singularity, a big bang in which the vastness of all matter was for an iota of time contained in a volume smaller than a single atom’s. As late as the early 1960s, I remember, the big bang had a hotly defended rival hypothesis—the steady-state universe, where hydrogen atoms emerged one by one to feed the observable expansion—but the discovery in 1965 of the big bang’s radio-wave fossil, the 2.7° Kelvin background radiation uniformly spread in all directions of space, banished the rival to the same realm as the wobbly Ptolemaic spheres.

The Earth’s heavy elements, including the substance of our bodies, were forged in the cataclysms of dying stars: this is our connection with the starry empyrean, this and the mental ingenuity and persistence that chip away at cosmic riddles in which the physics of the inconceivably small merges with that of the inconceivably large.

Perhaps the sky is no less comforting than it ever was. For billions of years into the future, barring an unlucky meteor, it will not intrude into our planetary privacy. Nor, it becomes increasingly clear, will we travel to it; the speed of light is circumvented only in the impracticable overdrives, time warps, and quantum tunnels of light-fingered futuristic fantasy, and even at the speed of light all but a few of the stars are many men’s lifetimes away. What we see, looking up, is a glittering cage, frozen by its impregnable distances. In the Earth-years that the Hayden Planetarium and I have witnessed, the universe has shed the cartoon face it wore in the Sunday supplements; it looms more and more as something utterly alien, unconscious, but for us, of its own triumphant beauty. And yet it has a savor of creation, its indifference scarcely distinguishable from benevolence.

John Updike’s next novel is Gertrude and Claudius (Knopf, 2000).
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54 ASTHMA, ENVIRONMENT, AND THE GENOME
Researchers are constantly adding to the list of substances that trigger asthma. They’re also finding more and more genes that influence susceptibility. But the real problem may be our pampered immune systems.
BY MATT RIDLEY

66 DOING LUNCH
A network of couriers enables workers in a modern Indian metropolis to enjoy meals cooked at home according to traditional dietary rules.
STORY BY DORANNE JACOBSON — PHOTOGRAPHS BY KADIR VAN LOHUIZEN

70 SECRETS OF THE FLOODED FOREST
In the seasonally inundated lands bordering the Amazon in western Brazil, human residents and wildlife go with the flow of the great river. The Mamirauá Reserve was established to preserve the region’s natural richness for all its inhabitants, including the black caiman. Scientists are studying the reptile’s nesting habits in efforts to ensure its continued survival.
STORY BY JOHN THORBJARNARSON AND RONIS DA SILVEIRA
PHOTOGRAPHS BY LUIZ CLAUDIO MARIGO
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Major individual gifts to the Rose Center have been provided by Frederick P. and Sandra P. Rose, Mr. and Mrs. Richard Gilder, Dorothy and Lewis B. Cullman, and David S. and Ruth L. Gottesman. Support for the Hayden Planetarium has been provided by a generous grant from the Charles Hayden Foundation. Public support of the Rose Center has been provided by the State of New York, the City of New York, Office of the Mayor, the Speaker and the Council of the City of New York, and the Office of the Manhattan Borough President. Significant educational and programming support has been provided by The National Aeronautics and Space Administration (NASA). Major support from Eastman Kodak Company.
TO THE EDITOR

Dinosaur Stress
The Deinonychus foot on the cover of the 12/99–1/00 issue is of special interest to an orthopedist—and not only because of the lethal second toe. The swelling above the joint at the third metatarsal (circled in photograph) shows evidence of a classic healed fatigue (or stress) fracture. Such injuries are common in athletes, for example. This one may well indicate that the animal had performed a greater-than-usual amount of walking and running shortly before it died. Perhaps a pack of these hungry predators had been forced to pursue a healthy Tenontosaurus.

Gilbert H. Lang, M.D.
Sacramento, California

Snow Birds
In “Savings in a Snowbank” (12/99–1/00), Peter Marchand notes that ptarmigans and grouse often take refuge under a blanket of snow on cold nights, having “caught on to a trick no others use.”

But while walking in deep snow in Prince George’s County, Maryland, perhaps twenty years ago, I was startled by several meadowlarks, which popped up (one at a time) out of smooth snow near my feet.

I couldn’t say whether they had deliberately buried themselves or had simply allowed the snow to fall on them, but it seemed to me that they were using the snow for cover.

John Krehbiel
via e-mail

For Love of Condors
Richard Milner’s piece on California condors (“Cultureless Vultures,” 12/99–1/00) was nicely done, but it was based on the opinions of a single source, Les Reid. While Reid claims to be an advocate of the condor, his uninformed comments are damaging to the condor recovery project.

Reid claims that protecting habitat was the correct path to preserving the condors. But the birds’ high mortality rate—caused by the ingestion of lead in bullet-tainted carrion and by collisions with power poles, among other things—was an immediate crisis that habitat protection could not have addressed.

Captive breeding is controversial, but without it there would no longer be any condors. Among the twenty-seven wild birds brought into captivity in the mid-1980s, very few were natural breeding pairs. This meant that the potential for reproduction was almost nonexistent. Productivity was a top priority. A breeding pair in the wild raises one chick every two years, but the practice of “puppet rearing” allowed the same pair to produce two, and sometimes three, viable eggs a year.

Yes, because we humans managed to drive these birds to the brink of extinction, no older birds remain to pass on the “culture” that dictates appropriate vulture behaviors. But once the first generation of zoo-raised chicks breeds, we will see an increase in parent-raised chicks and, we hope, an increased possibility that the condors will slowly regain their culture.

Biologists, zoo officials, and condors are all learning by trial and error. We must do everything we can to help the birds survive in the wild, including behavior modification (flushing them from undesirable roosts, such as Les Reid’s home) and publishing balanced articles on the issue.

By the way, some of our staff members want to know where wildlife biologists are “making sixty grand a year.” They want to apply.

John Brooks
California Condor Recovery Program
U. S. Fish and Wildlife Service

Natural History’s e-mail address is nhmag@amnh.org.


Missing Words
Because of a printer’s error, two lines were omitted from the bottom of the column on page 42 in Stephen Jay Gould’s essay “What does the dreaded ‘E’ word mean, anyway?”(2/00). The corrected paragraph follows:

The major group of mesozoa, the Dicyemida, live as microscopic parasites in the renal organs of squid and octopuses. Their adult anatomy could hardly be simpler: a single axial cell (which generates the reproductive cells) in the center, enclosed by a single layer of ciliated outer cells (some ten to forty in number) arranged in a spiral around the axial cell, except at the front end, where two circles of cells (called the calotte) form a rough “mouth” that attaches to the tissues of the host.
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Matt Ridley ("Asthma, Environment, and the Genome") is a British zoologist and science writer. The book on which this article is based is a whistle-stop tour through the human genome, chromosome by chromosome—"rather as Primo Levi told his autobiography element by element in The Periodic Table," as Ridley puts it. Convinced that being able to read the genome is the greatest intellectual moment in history, Ridley says that it "will tell us more about our origins, our evolution, our nature, and our minds than all the efforts of science to date." In his two previous books on evolution, he focused on sex (The Red Queen: Sex and the Evolution of Human Nature, 1995) and on cooperation (The Origins of Virtue: Human Instincts and the Evolution of Cooperation, 1998).

Doranne Jacobson ("Doing Lunch"), who has done research in India over the past thirty years, has not engaged the services of the dabbawalas who deliver home-cooked meals in Mumbai (formerly Bombay), but she loves dining out in that metropolis, where she and her family have enjoyed breaks from her rural fieldwork. An anthropologist, writer, photographer, and lecturer based in Springfield, Illinois, Jacobson (right, with two friends) is the author-photographer of India, Land of Dreams and Fantasy (W. H. Smith, 1992) and coauthor, with Susan S. Wadley, of Women in India: Two Perspectives (South Asia Books, 4th ed., 1999). Her most recent article for Natural History was "A Reverence for Cows" (6/99). Freelance photojournalist Kadir van Lohuizen was introduced to the dabbawalas while covering a story in Mumbai on India's "new rich." Based in Amsterdam, he has worked widely in western, central, and eastern Asia as well as in Africa, Europe, and the Americas, often documenting the plight of peoples caught in the midst of war and social upheaval. Van Lohuizen's numerous publication credits include Der Speigel, Le Monde, the Guardian, the Washington Post, and Time. This February he was invited to serve as a jury member for World Press Photo's annual contest.

John Thorbjarnarson ("Secrets of the Flooded Forest") notes that he may be the only herpetologist of Icelandic descent; Iceland has no native reptiles or amphibians. Thorbjarnarson himself was born in Boston and "never outgrew the universal interest of small boys in reptiles." A conservation zoologist for the Wildlife Conservation Society in New York, he specializes in crocodilians. In addition to his caiman work in Brazil, he is involved in a study of the critically endangered Chinese alligator and works with Cuban colleagues on American crocodiles. Coauthor Ronis Da Silveira, right, is from Brazil's state of São Paulo and lives on a lake with his wife, Barbara, their baby daughter, and thousands of caiman "in whole harmony." A doctoral student at the Instituto Nacional de Pesquisas da Amazônia and a researcher with the Sociedade Civil Mamirauá/Projecto Mamirauá, he has studied, and worked to conserve, black and spectacled caiman for the past ten years. For twenty years, Luiz Claudio Marigo has been photographing the wildlife of his native Brazil. His work appears in two books, on Brazilian butterflies and bromeliads.

When he was seventeen years old and living in the crowded city of Tokyo, Michio Hoshino ("The Natural Moment") became intrigued by an aerial photo of an Eskimo village in the midst of the Alaskan wilderness. Two years later, he traveled to Shishmaref, Alaska, where he found both his spiritual home and his vocation. After completing degrees at Keio University and the University of Alaska, Hoshino taught himself to be a wildlife photographer and soon ranked among the best. His 1987 photo book Grizzly resulted from his pursuit of a family of Alaskan grizzlies over a year's time; in 1989 he documented the migration of caribou herds and the life history of moose. Hoshino's life ended tragically on August 6, 1996, on the Kamchatka peninsula in northeastern Russia, when a brown bear pulled him from his tent and killed him.
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My first glimpse of a snow buttercup flowering beneath a thin pane of ice was not unlike my first experience of watching a monarch butterfly emerge from its cocoon. It seemed a marvel of metamorphosis. From under the granular crust of a subalpine snowfield sprang forth life as tender and fresh as a butterfly’s newly unfolded wings. I had often seen the hardy crocuses of town and country gardens poking their cheerful colors through the fresh white powder of a spring snowstorm, but these buttercups had reached their flowering stage entirely beneath the waning winter snowpack, finally absorbing sufficient sunlight to re-radiate heat and melt a hole through the ice grains around them.

The vivid yellow buttercup’s ability to grow beneath snow is not unique. Seeds germinate, leaves unfurl, flower buds swell as numerous spring
wildflowers—among them the familiar trout lilies, cornflowers, spring beauties, and pasqueflowers—begin preparations for emergence long before the snow cover recedes. Digging into the midwinter snow, I have often found plants that were browned and dead-looking in late autumn already greening at their leaf bases or sprouting new shoots.

Growth of any sort, whether it involves the elongation of tiny root hairs or the unfolding of new leaves, requires energy. With the temperature under the snowpack hovering at about 32°C in late winter and with carbon dioxide levels often elevated (mostly the result of root respiration and decomposition of organic matter during winter), the environment beneath the snow is not inhospitable to plant growth. And there is some evidence to suggest that the wildflowers of early spring can support their growth partly through photosynthesis beneath the snow. The plants’ phytochromes—pigment molecules that are sensitive to slight changes in day length and that control a plant’s growth timetable—may respond to dim light coming through the snow. But while the ability to photosynthesize under snow has been demonstrated in a few evergreen plants, including aquatic plants locked beneath ice, evidence of the process in other plants is difficult to come by. In some early spring flowers, the machinery for capturing radiant energy, although mostly assembled by late winter (even the chlorophyll for photosynthesis may be produced in response to light penetrating the snow), probably isn’t fully activated until immediately after the plant is released from the snowpack.

In the absence of photosynthesis, energy for growth under the snow must come entirely from reserve carbohydrates. Many spring wildflowers have relatively large below-ground storage depots—in the form of tubers and rhizomes—that are stoked with fuel at the end of the previous growing season. As growth resumes under the snow, the weight of these storage organs declines steadily, in direct proportion to the increase in size of new shoots and flower buds. If the arrival of spring is timely, photosynthesis will start before these reserves are depleted.

The earliest—and arguably the most resourceful—of the spring flowers is the skunk cabbage, ubiquitous in the wet places of North America and Eurasia. Its flowering stalk emerges from the soil (and snow) before its leaves do—and often while air temperatures are still below freezing. So high is the cellular respiration of the skunk cabbage at this time of year that the plant (except for one western North American species) generates heat—one of the few in the world to do so. When the air temperature is below freezing, the plant may be as much as 30°C warmer than its surroundings, and the flower stalk is able to melt its way through frozen ground and ice.

But aren’t these early bloomers too precocious for insect pollinators? In fact, a number of insects are available to do the job, although some of the plants have the capacity to self-pollinate as well. It’s not uncommon, for example, to find flies and solitary bees foraging as the snow recedes. And when a flower is the only show in town, there’s a strong likelihood of its attracting attention and being cross-pollinated, even with a few insect species around. As for the skunk cabbage, it leaves less to chance, having evolved an additional lure: a malodorous scent whose dispersal seems to be facilitated by the heat-producing flower. This dung or carrion mimicry attracts flesh flies, rove beetles, and even mosquitoes, all of which have been observed with pollen on them. (Some biologists believe that the heat produced by skunk cabbage flowers may also attract pollinators by providing a warm basking site during cool weather.)

Still, one other question begs for an answer: Why all this effort to be first with a flower? Reduced competition for pollinators may be one advantage of early flowering, but for many of these spring ephemerals, time is the most pressing issue. Most occupy habitats where the growing season is greatly compressed, either because of the short interval between the final spring and the first autumn frosts or because the closure of the overhead tree canopy in early spring smothers them in deep shade. In the race to reproduce, these plants can’t wait for the snow to melt.

Badlands and Oases

Palm trees are an unexpected sight in the California portion of the Sonoran Desert.

**THIS LAND: CALIFORNIA**

*By Robert H. Mohlenbrock*

Four major deserts lie in the long trough between the Rocky Mountains and the Sierra Nevada and Coast Ranges of North America: the Great Basin, the Mojave, the Chihuahuan, and the Sonoran. Occupying elevations of up to about 3,000 feet in much of southeastern California and parts of southwestern Arizona, with extensions into Baja California and other parts of Mexico, the Sonoran has several natural divisions. The westernmost section, in California, is bounded on the east by the Colorado River and is usually referred to as the Colorado Desert. It is watered by gentle winter rains from the Pacific Ocean and more violent summer storms that blow in from the Gulf of Mexico.

Low desert—the sandy flats found in valleys and bordering the many mountains—is the principal habitat in the Colorado Desert. Traversing this landscape are countless washes—waterways that are dry for most of the year but fill up briefly following torrential summer rains. The low desert also has some scattered palm oases, alkaline sinks, desert marshes, and permanent streams. The often steep and rugged lower slopes of the mountains are dominated by cacti, agaves, yuccas, and thorn-bearing shrubs. Farther upland, usually between 3,000 and 5,000 feet, is chaparral, where scrub oaks, manzanitas, and various other shrubs join cacti and yuccas.

One of the best places to explore the Colorado Desert is Anza-Borrego Desert State Park, a 1,500-square-mile preserve that has well-paved roads and miles of primitive jeep trails and hiking trails. Among the paved roads is Highway S22, which passes through typical low desert as well as a severely eroded landscape known as the Borrego Badlands. Thimble Trail, off S22 in the badlands, is an excellent place to see the colorful annual wildflower show that appears (if winter rainfall has been ample) between mid-February and early April. Anywhere a paved road crosses one of the normally dry washes is a good place to study desert-wash vegetation. One such location is Smoke Tree Canyon, which is easily accessible from S22 and has a concentration of smoke tree (*Psorothamnus spinosus*) as well as indigobush (*P. schottii*) and desert lavender. A fine chaparral community can be viewed along S22 as it passes through Culp Valley, southwest of the desert community of Borrego Springs.

The lower slopes of the mountains that rise from the desert floor are often difficult to hike because of the rocky terrain. But a typical (and easily reachable) patch of this kind of desert habitat lies near Ocotillo Flats and can be reached by taking DiGiorgio Road north out of Borrego Springs and continuing along a dirt road. This is a good place to encounter the purple milkweed vine *Sarostemma* and the lavender-flowered spectacle pod, a member of the mustard family.

The goal of many park visitors is to
Beavertail cacti and Washington fan palms in Borrego Palm Canyon
see Washington fan palms, which grow naturally only in California's Colorado Desert and in two isolated spots in western Arizona. The sixty-foot trees live in patches kept wet by underground water sources. Reaching these oases usually requires a hike through rocky ravines; the easiest to get to is Borrego Palm Canyon, just one and a half miles by hiking trail from the nearby campground. Another unusual plant is the elephant tree, named for its swollen gray trunk and limbs. The most accessible ones grow a short distance from the Elephant Tree parking area off Split Mountain Road.

Among Anza-Borrego's wetlands is Coyote Creek, a perennial stream in the northwest corner of the park. Its rugged surroundings may be explored on foot or partway by jeep. Plants that grow along the stream banks include alder, Fremont cottonwood, sycamore, honey mesquite, and Goodding willow. Another wetland is the marshy Senecac Cienega, along San Felipe Creek, near the juncture of Routes 78 and S2. The huge reed _Phragmites_ grows there, along with three-square, a sedge found in wetlands across the United States. Woody plants along the margins include Goodding, narrow-leaved, and arroyo willows; _Baccharis_; desert willow (not a willow but a relative of the catalpa tree); and Fremont cottonwood.

Scattered depressions in the desert fill with water after a rainfall, retaining an alkaline residue as the water evaporates. One of these alkaline sinks is Borrego Sink, about five miles southeast of Borrego Springs. Most of the plants found here can tolerate a high degree of salinity and, apart from the honey mesquite, do not grow elsewhere in the park. Among them are salt grass, pickleweed (also called sapphire, or _Salicornia_), arrowweed (a purplish-flowered perennial related to the marsh fleabane of the southeastern United States), and several species of _Atriplex_, or saltbush.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

For visitor information, write: Anza-Borrego Desert State Park 200 Palm Canyon Drive Borrego Springs, CA 92004 (760) 767-4205 www.anzaborrego.statepark.org

**HABITATS**

Low desert is dominated by creosote bush, with its small yellow flowers and fuzzy fruits, and burroweed, also called bur sage, a shrubby relative of ragweed with spiny, burrlike fruits. Other common plants are dune evening primrose, globemallow, fishhook cactus, and a couple of kinds of prickly pear cacti. Desert annuals include dandelion, Bigelow's monkey flower, brown-eyed evening primrose, ghostflower, Arizona lupine, and slender bladderpod.

Desert washes support small trees such as palo verde, ironwood, and honey mesquite, while the most common shrubs are desert willow, indigobush, desert lavender, desert aster, and cheesebush (burrobush), a plant with obscure greenish flowers and winged fruits. Conspicuous flowers are produced by chuparosa, whose long tubular red flowers are a favorite of hummingbirds; desert aster, a daisylike plant with bright blue flower heads; desert lily, whose white petals have a silver-green stripe; and trixis, with yellow, daisylike flowers.

Lower desert slopes have a dozen or so cacti, including beavertail, prickly pear, Engelmann's hedgehog, teddybear cholla, buckhorn cholla, and desert barrel. Large plants such as desert agave, Mojave yucca, and ocotillo are often present. Other shrubs include desert thorn, indigobush, creosote bush, burroweed, brittlebush, and wishbone bush.

Chaparral has California scrub oak, chamise, greenback ceanothus, manzanita, and three types of sumac— sugar-bush, skunkbrush, and lemonade berry. A yucca with the engaging name of Our Lord's candle is often present, as well as two kinds of cacti, the beavertail and the cane cholla.

Palm oases include Mountain Palm Springs (where for some reason the palms are stunted), Torote Canyon, and Borrego Palm Canyon. Along the trail leading to the latter grow brittlebush, lavender bush, desert _Datona_, ocotillo, indigobush, cheesebush, desert croton, sand verbena, chuparosa, and desert trumpet. More than 800 palms grow at this oasis, along with such moisture-loving plants as honey mesquite, desert willow, three-square sedge, desert rush, and arrowweed.
Storms on the Sun
The sunspot cycle’s peak may bring more than the usual fanfare of iridescent night lights.

CELESTIAL EVENTS
By Richard Panek

Our Sun is nothing more than a nuclear reactor: all it does is continuously convert hydrogen into helium. The same is true of most other stars, as astronomers have known for more than half a century (see “Twinkle Twinkle,” Natural History, 2/00). Still, in the absence of overt reminders, it can be difficult to remember how extraordinarily volatile the Sun actually is. But now we’ve got reminders (in abundance) for anyone who cares to look.

Sunspots, the outward manifestations of the great gas ball’s innermost workings, and an integral part of the solar weather system, have long been the object of aesthetic and scientific fascination for sky watchers.

In recent years, however, sunspots have also come to be viewed as a potential threat to Earth—and never more so than at the most active period in the sunspot cycle.

That time is now, more or less. Over the eleven years of the cycle, the number of these blotches on the Sun each month can vary from zero to hundreds. It’s impossible to know for certain whether the sunspots of a particular cycle have peaked until the numbers start declining, but a panel of experts at a meeting of the American Astronomical Society in Chicago last spring anticipated that the present activity cycle would reach its maximum in March 2000, give or take a month.

It’s actually not the sunspots themselves that concern solar researchers. Sunspots are simply variations on the gas bubbles that are always roiling the surface of the Sun. If a magnetic storm on the Sun hits a patch of gas, the gas temperature drops and the “cool” area appears dark by contrast (although in isolation, an average sunspot would easily outshine the full Moon). Sometimes, however, the magnetic energy near a sunspot builds up, and it finds release in something called a solar flare—an explosion that heats the gases to millions of degrees, generating as much energy as 10 million volcanic eruptions and sending radiation that spans the entire electromagnetic spectrum hurtling earthward.

So far, so good—usually. Earth’s atmosphere and its magnetic field (or magnetosphere) manage to block most of the radiation from solar flares. But if a magnetic storm on the Sun is especially fierce, the result can be a coronal mass ejection (CME)—what one NASA publication calls “the solar equivalent of a hurricane.” In that case, the effect on Earth’s

The aurora borealis, or northern lights, illuminates the twilight sky.
magnetosphere can be profound. Which is not to say that a sunspot maximum need result in a catastrophe—or even an inconvenience—for Earth. Even if a CME broadsides the planet, the impact might merely result in a more picturesque version of the aurora borealis and aurora australis. During a maximum in 1909, in fact, the auroral displays usually seen around the Poles, where Earth's magnetic field is weakest, were visible as far as the equator.

But since 1909, the world has changed in ways that leave us particularly vulnerable to a direct hit. In March 1989, during the last maximum, an extensive magnetic storm on the Sun was responsible for a number of serious disruptions: power in the province of Quebec was knocked out, leaving 6 million people without electricity for six hours; more than 1,500 satellites slowed down or dropped several miles in their orbits; and some folks in Minnesota reported that although they couldn't pick up their local radio stations, they could hear the California Highway Patrol loud and clear. A decade later, our technology has become even more dependent on power grids and satellites. The Space Environment Center in Boulder, Colorado, recently inaugurated the Solar Cycle Project—in part to give electrical providers and communications companies a day's warning about CMEs heading our way during this next sunspot maximum.

To monitor the solar situation yourself, you don't need a telescope or even binoculars, just an appropriate filter; many naked-eye solar observers prefer no. 14 arc welder's glass. A single sunspot might not be discernible, but during a maximum, the Sun often erupts with large sunspot groups. If you do want to use binoculars or a telescope, be sure to attach a full-aperture solar filter of either aluminized glass or aluminized Mylar. (Never ever look at the Sun without using an appropriate filter.) Check out www.sunspotcycle.com for day-by-day sunspot totals as well as links to other sites where the Sun is visible even on a cloudy day.

And speaking of Earth's weather, what's true down here applies up there as well: if you don't like the Sun's weather now, just wait a while and it will change.

Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens (Penguin, 1999).

THE SKY IN MARCH

By Joe Rao

Mercury arrives at inferior conjunction with the Sun on March 1. It will stand 2° above Venus on the morning of March 16, but at magnitude +1.1, it shines only 1/100 as bright. It can be found (with difficulty) late in the month in the predawn sky, and it more than doubles in brightness by month's end. Greatest elongation occurs on March 28, when this little planet is 28° west of the Sun. But at this time of year, the ecliptic (the path of the planets) is at a shallow angle relative to the east-southeast horizon, making this an uninspiring morning apparition.

Venus rises in the dawn twilight all month and becomes increasingly difficult to see. At the start of the month, it comes up in the east-southeast barely an hour before sunrise. Yet it's worth trying to find Venus very early in the month, if for nothing else than to use it as a guide for spotting the planet Uranus. The very faint bluish "star" about half a degree below and to the left of Venus on the 3rd, and above and to its right on the 4th, is Uranus. By month's end, Venus will have moved to within 20° of the Sun, rising about forty minutes before it.

Mars, Jupiter, and Saturn are all slowly converging in the western evening sky during March. At the beginning of the month, the three planets are strung along an imaginary line spanning about 28° (about three clenched fists held at arm's length). By the end of March, the line has shrunk to less than 10°. In early April, the planetary trio will form a spectacular triangle in the western sky, gathering closest together on April 14.

Mars, the lowest and dimmest of the three evening planets, appears as a first-magnitude star with a topaz hue, moving from Pisces to Aries during March. It is low in the west after darkness falls and sets from two to two and a half hours after the Sun.

Jupiter, in Aries, is the middle and brightest of the three evening planets. It is visible low in the west after sunset and sets in the west-northwest three to three and a half hours after the Sun. The giant planet, lagging farther and farther behind Earth in the planetary race around the Sun, is now at magnitude -2.1.

Saturn, in the eastern zone of Aries, appears as a yellowish zero-magnitude star low in the west as twilight fades. It sets four hours after the Sun.

The Moon is at new phase on March 6 at 12:17 A.M. First quarter is on March 13 at 1:59 A.M., full Moon is on March 19 at 11:44 P.M., and last quarter is on March 27 at 7:21 P.M.

The Vernal Equinox occurs on March 20 at 2:35 A.M. Spring arrives in the Northern Hemisphere, and autumn in the Southern Hemisphere.

Unless otherwise noted, all times are given in Eastern Standard Time.
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Calling a Bluff

Thanks to their long windpipes, some birds sound bigger than they are.

*Story by Carl Zimmer ~ Illustration by Sally J. Bensusen*

On the island of New Guinea lives a glossy, bluish black bird called the trumpet manucode (*Manucodia keraudrenii*). It’s about the size of a grackle and not particularly striking in appearance. But on the inside, the male manucode is as extravagant as a peacock: its trachea, or windpipe, is not the six inches long you’d expect for a bird this size but an astonishing thirty-two inches, wrapped up in a giant coil to fit inside the creature’s body. Unrolled, the manucode’s trachea would be three times the length of the entire bird.

The trumpet manucode belongs to a diverse group of about sixty species of birds, including trumpeter swans and whooping cranes, that have dramatically elongated windpipes. And Harvard University evolutionary biologist W. Tecumseh Fitch has an intriguing theory to explain this strange anatomy: it provides a mechanism for birds to sound bigger than they are.

You might think that to sound bigger, a bird would give its calls a lower pitch, but Fitch says that for many animals, pitch is not a reliable clue of body size. Birds produce vocal sounds in basically the same way we do, by making air vibrate through a tube. (There are some important differences, but more on them later.) To speak, you push air out of your lungs and up your trachea. At the top of the trachea, the air passes between the folds of the larynx (the vocal cords). The folds spread apart and then collapse, making the air vibrate, and these vibrations are what we hear as sound. A sound consists of waves, each of which has peaks and troughs of intensity. The distance between peaks is longer in low-frequency than in high-frequency waves.

A big larynx vibrates more slowly than a small one, producing low-frequency waves and thus lower-pitched sounds. But people who are the same size may have larynxes of differing sizes. We’ve all heard big burly men with surprisingly high voices. And when a teenage boy’s voice suddenly drops, it isn’t because his body has suddenly grown bigger but because his larynx has gone through a growth spurt of its own.

Fitch is interested in a subtler and far more reliable indicator of body size: the timbre of a voice. When you speak, your larynx vibrates, producing sound waves in a broad spectrum of frequencies. Each wave travels along your vocal tract, from larynx to lips. When a wave reaches your lips, some of its energy escapes with your exhaled breath, while some gets reflected back down your throat. When this reflected wave hits your larynx, it bounces back up again, traveling alongside newly created sound waves produced as you continue to speak. If the reflected wave’s peaks and troughs line up closely with those of a new wave coming from the larynx, they’ll combine to create a stronger wave. How the waves line up depends on the distance between the peaks of the sound wave and the length of the vocal tract. But if the two waves are out of phase, their peaks and troughs will cancel each other out. The result is that certain frequencies sound much louder than others do as they come out of your mouth.

This pattern of louder and softer frequencies helps to determine the timbre of a voice. Even a modest change in the length of your vocal tract can change your voice’s timbre. You can test this yourself with a simple experiment. Read this sentence aloud as you smile; then say it again with your lips puckered. Puckering doesn’t change pitch or volume, but it does temporarily lengthen your vocal tract and thus makes your voice sound different—richer, deeper. This sort of “color” is an important ingredient of timbre.

Aside from puckering and smiling, however, there is not much one can do to change the timbre of one’s voice. Vocal tract length in humans and other mammals is tightly linked to skull size, and skull size is closely correlated with body size. As a result, timbre reveals a

Opposite page, clockwise from bottom: A trumpet manucode, a greater black-backed gull, a Eurasian spoonbill, a Japanese crane, and a crested guinea fowl. Only the gull has the relatively short and straight windpipe of most birds. The others belong to a select group of species with elongated windpipes that are coiled or looped in various ways to fit inside the body.
The big sound made by birds with elongated windpipes may help attract mates or scare away rivals.

Therein, according to Fitch, may lie the explanation for the labyrinthine tracheas found in some birds. The length of a bird's trachea is not tightly tied to skull or body size. Individual birds born with a slightly elongated trachea will sound bigger than those less well endowed, and perhaps, if their inflated image helps scare off rivals or attracts mates, they will have greater reproductive success.

Fitch is just starting to test this idea, but he can already point to some interesting correlations. Birds with an elongated trachea tend to live where visibility is poor and where they may thus not be able to size one another up by sight alone (some, such as cranes, live in open grasslands but like to make their nests in overgrown areas). He has also found that in species where both sexes participate in territorial defense, both males and females generally have elongated tracheas; where only the male is territorial, generally only he has a long trachea. One species—the greater painted snipe—appears to be the exception proving his rule: only the females are territorial and only they have elongated tracheas.

If Fitch's hypothesis proves correct, birds may not be alone in manipulating their voices, although in the case of humans, the goal may often be to sound smaller, not bigger, and therefore unthreatening. Picture an obsequious worker trying to ingratiate himself to his boss. Chances are he's got a smile on his face—and a shortened vocal tract as a result.

Science writer Carl Zimmer lives in New York. His first book, At the Water's Edge, is now available in paperback.
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A WEALTH OF FLORA AND FAUNA ABUND

0 WONDER MANY NATURALISTS SET their sights on Costa Rica. Many birders have made their first Neotropical trip to sample the varied habitats in this breathtaking natural avia. Home to an astonishing number of diverse ecosystems, Costa Rica is one of the biologically wealthiest nations in the world. From the lush, forested slopes of its volcanoes to the coral reefs off both coasts, Costa Rica offers a sweeping panorama teeming with colorful birds.

During the past few decades, more and more Costa Ricans have come to realize the value of their natural heritage and biodiversity. Their exemplary National Conservation System is ensuring the survival of endangered species while The Costa Rica National Biodiversity Institute catalogues and studies the country’s nearly overwhelming varieties of flora and fauna.

About 9,000 different kinds of flowering plants grow in Costa Rica, including more than 1,300 species of orchids. The country is also home to 209 species of mammals, 383 kinds of reptiles and amphibians, about 2,000 species of butterflies and at least 4,500 different types of moths. Although Costa Rica covers only 3.4 percent of the surface of the earth, about 5 percent of the planet’s plant and animal species are found here. Nearly 850 species of birds have been identified within the country’s borders, more than are found in all of the United States, Canada and the northern half of Mexico combined.

Costa Rica’s forests offer a breathtaking visual backdrop for birders. Giant tropical trees create a canopy over a deep tangle of epiphytic vegetation as varied and naturally harmonic as the birds that live in their midst. Biologists have classified the diversity of forests in this region into a dozen different life zones. However, most of those forests fall into three more general groups: rain, cloud and dry forests. Rain forests, with their massive trees, very high canopies and little growth on the dimly lit forest floor, can be found in the Atlantic lowlands and the southwest.

Northwest Costa Rica contains some of the last remnants of the tropical dry forest, a less exuberant life zone that shares much of the diversity of the rain forests. Cloud forests, which cover the upper slopes of most mountains and volcanoes, are the most luxuriant of the tropical forests, with mosses and other small plants covering the trunks and branches of trees. All the forests are beautiful, and in many ways similar, but each offers glimpses of plants and animals that won’t be found in the others.

Visitors to Costa Rica without wings of their own most often fly into the capital city of San José. Most avid birders will want to stay on the edge of town and rent a car for excursions to the surrounding countryside. Trips farther afield may be made by car or air via domestic flights. Travel packages providing transportation make touring around easiest, but intrepid self-tourists armed with reliable, up-to-date maps can easily drive themselves around most of the country.

ON A NARROW BAND OF MOIST LOWLAND forest running from Carara southeast to the Panamanian border, the Pacific lowlands offer some of the best birding in Costa Rica. A number of species unique to this region make this zone essential for the visiting birder. Idyllic beaches and a range of accommodations add to its allure. Near the beach town of Jacó, about two hours from San José lies the Carara Biological Reserve, home to a large population of scarlet macaws and acres of unspoiled Pacific low-
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land forest. Many tourists make this area a

Varied life zones offer many
daytrip from San José, but birders will want to

birding adventures in one trip.

either get a very early start or stay over in Jacó

Confidencial

or in Tárcoles/Playa Azul. The scarlet macaws

can be seen early or late in the day as they fly

between the reserve and roosting areas to the

northwest. Well over 100 notable species can be

easily spotted in the Carara Reserve, including

the great tinamou, red-lored parrot, crimson-

fronted parakeet and scarlet-rumped cacique.

Other good spots for birding in the Pacific low-

lands include Río Tárcoles Estuary, the Tivives

of the Rio Tempisque at Palo Verde National

Park are the last stronghold of the jabiru in

Central America. Barra Honda National Park

is known for its well-preserved limestone caves

as well as consistently good birding along its

trails. Relatively sparse vegetation make

species like thicket tinamou, lesser ground

cuckoo, and long-tailed manakin easy to

observe and photograph.

The volcanic ranges that form the spine of

Costa Rica — the country’s most striking

geographical feature — are the source of great

biodiversity. Many of the best birding

sites are within easy reach of San

José. Most of the best sites are on

the middle-elevation Caribbean

slope, which has a distinctive

avifauna with substantial numbers

of otherwise difficult-to-find species. Braulio

Carrillo National Park offers outstanding

scenery and a good transect of Caribbean

doctor forest populated by local birds such as

yellow-eared toucanet, lattice-tailed trogon,

purple-backed quail-dove, and ash-

doctor bush-tanager. Other mountain sites

well worth visiting include Tapanti National

park, Volcán Irazú National Park, and Guayabo

National Monument, the most significant pre-

Columbian archeological site in the country.

The Monteverde Biological Reserve is one of

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Finca La Selva Reserve has an excellent trail

system and a huge birdlist of well over 200

species. On the Caribbean coast south of Limón,

the tourist areas of Cahuita and Puerto Viejo

are good starting points for birders, and

Tortuguero National Park provides a rare look at

nesting sea turtles, sungrebe, green and rufous

kingfisher, and rufescent tiger-heron.
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Scotland
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LEGENDARY FOR ITS RUGGED COASTLINES, spectacular highlands, ancient woodlands and verdant glens, Scotland is an ideal destination for birders with an eye for drama. The Scots have always taken great pride in the natural beauty of their countryside, and they've recently made their inspiring landscapes even more inviting with new facilities and opportunities for naturalists.

In areas both settled and remote, visitors can join various ranger-led walks. For the more active, orienteering events and well-marked cycle trails make exploration especially rewarding. Scotland is home to a great number and variety of bird species, including the most golden eagles and peregrine falcons in Europe and some of the greatest concentrations of seabirds in the world. Many species — including gannets, puffins, guillemots, and kittiwakes — nest on cliffs over 900 feet high. Many thousands of wintering wildfowl feed and roost among the country's estuaries and salt marshes. The great sweeps of white shell and sea-meadows of the west coast and pristine islands, such as Shetland and Skye, are rich in ground-nesting birds and colorful displays of wildflowers in early summer. The Royal Society for the Protection of Birds (RSPB) reserve on North Uist is a fine example of Scotland's pristine natural habitats. Only one hour from Edinburgh, the Bass Rock is dramatically situated near the mouth of the Forth River. Boat trips are available from nearby North Berwick. During the breeding season, more than 70,000 North Atlantic gannets (over 25 percent of the world's population) flock to Bass Rock, creating an enchanting spectacle. This year heralds the opening of The Scottish Seabird Centre at North Berwick Harbour. Using state-of-the-art remote cameras from various strategically located observation areas, visitors can now see a range of species up close, in their natural habitat, without disturbing them. Also notable this year are The Millennium Forest for Scotland projects, a series of 77 initiatives throughout the country designed to extend and enhance native natural habitats. Visitors to Perthshire, in the heart of Scotland, are invited to celebrate the survival of the country's ancient woodlands with the aid of new, way-marked trails enhanced by multimedia technology. This project — Scotland's Ancient Woodlands: A Trail from the Past to the Future — also involves walks at Crinan in Argyll and Abriachan on the shores of Loch Ness.

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LIKE ART LOVERS, FASHION MAVENS, and gourmands, bird watchers will find more to love in France than can possibly be consumed. Itineraries can be as varied as the avifauna, among the most alluring in the world.

Northern France offers a range of birding options for beginner and expert alike. A typical farming village in this region attracts tree sparrows, black redstarts, gray partridge, skylarks, and hen harriers. Itineraries in the northern regions of the country include internationally important sites like Somme Bay, the Rommelaere with rich alluvium soil, has been cultivated since the Middle Ages. The open landscape is harmoniously composed of grain fields, rice paddies, orchards, rape fields and vineyards.

Salt plains cover the southeastern corner, where the Grand Rhône flows into the sea by Salin-de-Giraud. At the center of the Camargue, surrounding the Etang de Vaccarès, is a huge zoological and botanical reserve teeming with wildlife.

A must for birding, the Parc Ornithologique de Pont de Grau comprises a variety of landscapes and species. Within approximately twenty acres of marshland set in the greater

More than a mecca for culture vultures, France is an ornithological dream of unspoiled habitats.

Marshes, Cap Gris-Nez and Blanc Nez as well as trips to see the migrating cranes and white-tailed eagles at Lac du Der Chantecoq.

Farther south, between the cities of Arles and Marseilles, lies the Camargue region. Arguably the ornithological capital of France, the Camargue is like a country in itself. A series of long, level roads criss-cross its marshes and farmlands, making the colorful avifauna easily visible. With a bird book, binoculars and camera in hand, any visitor to the area will catch an eyeful of natural beauty on the wing. Eagles, hawks, and harriers soar above black bulls and white horses grazing in the fields, horseback riders file into low brush and cyclists paddle against the winds, along the roads, or on lanes closed to motor vehicles.

The upper region of the Camargue, blessed reserve, most of the birds of Camargue, both resident and migratory, can be seen close at hand in the wild and in large cages. The central area of the park is home to various birds of prey, including multiple species of owls, eagles, hawks, harriers, buzzards, and vultures. Wetlands are a lure for geese, swans, ducks, egrets, storks, herons and the icon of the Camargue, the pink flamingo.

O N THE EASTERN SIDE OF THE CAMARGUE lies the Tour du Valat, a private, non-profit research and study center dedicated to the conservation of Mediterranean wetlands. The central part of the domain is the Voluntary Natural Reserve, the largest in France, staffed by 30 full-time researchers. Its various programs are open to both French and foreign students. Guided tours through the Camargue include horseback and jeep safaris. Renting bicycles is a good idea, partly because many areas are off-limits to motorized traffic. Flat, open terrain makes cycling here particularly inviting.

The French countryside lures birders with wide-open vistas of breathtaking color.
saskatchewan
FOR OVER A CENTURY, THE PROVINCE HAS TAKEN PRIDE IN ITS BEAUTIFUL BIRDS

Located in the heart of North America, Saskatchewan is home to the continent’s oldest bird sanctuary, Last Mountain Lake, established in 1887. Every year, as many as 40,000 sandhill cranes and hundreds of thousands of other waterfowl congregate here. The sanctuary has two nature trails, and its Bird Observatory is an active station for bird banding as well as for monitoring bird species and numbers.

As home, migratory stop and breeding ground, Saskatchewan hosts over 25 percent of the continent’s ducks and geese. In the summer season, swans and sandhill cranes flock to the province by the millions. Saskatchewan also is one of the best places on earth to view rare whooping cranes, magnificent white birds bordering on extinction. The Canadian Wildlife Service hosts a Whooping Crane Hotline (306-975-5595) for reports on the latest sightings.

Beginning in May, waves of migrating birds stop down in Saskatchewan to rest and feed before continuing on to breeding grounds farther north. Visitors to Grasslands National Park can witness the mating dance of the sage grouse or get a look at the sharp-tailed grouse, Saskatchewan’s bird emblem. Long-billed curlews, burrowing owls, chestnut-collared and McCowan’s longspurs summer in the park.

Other not-to-be-missed birding destinations include Buffalo Pound Lake, Valeport Marsh, Chaplin Lake, the Quill Lake region, Redberry Lake, and Galloway and Miry Bays.

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The Alabama Gulf Coast is located in the Mississippi Flyway Zone, a major route for migratory birds. There are two major bird migrations annually. The first, in the spring, usually peaks between late March and early May. A fall migration occurs from mid-September through mid-November.

The Alabama Coastal Birding Trail, arranged as a series of loops, offers birders an ideal guide to the best sites in the state. Several public areas along the trail provide excellent perspectives on a colorful variety of species, migration zones, and natural habitats. Alabama Point, Bon Secour National Wildlife Refuge, Gulf State Park, Fort Morgan, Battleship Point, and Dauphin Island are just a few of the major destinations for avid birders visiting this inviting state. Its many inland bays and waterways also support indigenous wading and shorebirds.

The Gulf Shores/Orange Beach Loop of the Alabama Coastal Birding Trail is especially

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FOCUS ON BIRDING

popular, combining excellent opportunities for birding with an array of resort accommodations and activities. Among the most notable species along the loop are the snowy plover, a rare, threatened species that most often nests near the dunes along the shoreline, elegant great egrets; and sandhill cranes, canvasback ducks and herons; as well as a variety of pelicans and other striking seabirds. All along the loop, sites are marked with great detail, alerting visitors to which birds to look for, and when to find them.

West of Gulf Shores, at Fort Morgan, the Hummer Bird Study Group conducts a bird-banding project in both the spring and fall. Volunteers set up nets, retrieve the birds and take them to banding stations. The birds' weight, length, health, and species are recorded, then they are banded and released for their migratory trips. The public is welcome to participate in both seasonal events.

Established by a special legislative act over two decades ago to protect and preserve rapidly vanishing coastal barrier habitats, the Bon Secour National Wildlife Refuge is a

A handy 51-page booklet offers a detailed guide to the Alabama Coastal Birding Trail.

triumph of man and nature. The maritime forests, coastal marsh, sandy beaches, and open waters of the refuge provide essential habitats for an amazing diversity of birds, including loons, grebes, petrels, boobies, gannets, pelicans, herons, egrets, storks, cranes, cuckoos, and an astonishing assortment of shorebirds and waterfowl.

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OME TO SOME OF THE MOST PICTURESQUE birding sites in the U.S., Worcester County, Maryland has always been a favorite destination for naturalists of every kind. This year, on April 28-30, the county hosts the one event avid birders will not want to miss. The Delmarva Birding Weekend celebrates the migration of hundreds of warblers, shorebirds and waterfowl as well as many nesting birds and raptors.

Participants in this event are invited to special lectures and dinners, casual social gatherings, canoe trips, boat excursions, day treks, and nighttime explorations of the natural habitat, including an “owl prowl” guided tour of nature trails in the Pemberton Historical Park. For more information on the weekend’s events, or to register, contact the Worcester County Tourism office at 800-852-0335.

As interest in birds soars, be on the look-out for more special events and programs with a focus on birding.

THIS SPRING, PBS STATIONS ACROSS THE country will air *Stokes Birds at Home*, a thirteen-part series produced by Donald and Lillian Stokes, internationally-renowned birding experts and authors of many birding guides. Specific airing times will be determined by local stations. This program is being sponsored by Swift Instruments, Inc., one of the leading producers of high-quality binoculars favored among birding enthusiasts. Established in 1926, Swift Instruments continues to strive for technical excellence and enduring quality in all that they do. Their sponsorship of this series is a reflection of their devotion to birding as well as the popularity of their advanced line of birding binoculars and spotting scopes within the birding community. Swift Instruments’ dedication to optical excellence is clear to anyone who uses their products. Knowledgeable bird watchers everywhere clearly recognize their expertise in viewing nature at its best.

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Australians ponder solutions to their kangaroo problem.

By Terry Domico

Grinding forward in low gear, the four-wheel-drive truck bucks and sways along the dirt track. It’s nearly midnight, but there’s still another hour to go until Ted Heineman’s “lunchtime.” As we bounce along in the truck’s cab, Heineman’s assistant flicks the beam of the roof-mounted spotlight back and forth across the dark landscape. For an instant, a small tree glows in the light, then a bush, then three red kangaroos. The animals scatter as soon as the truck comes to a halt. “Roos are very skittish on windy nights like this,” says Heineman. “The best times for hunting them are just a day or two before you get rain.” As one of Australia’s many full-time professional roo shooters, he speaks from experience.

The flitting spotlight momentarily catches three more kangaroos. “Two females and a joey.” The truck and spotlight move on. Another group of six roos is illuminated briefly, then also passed over. Because his fee is based on carcass weight, Heineman shoots only big males and the largest females.

Near a line of trees we glimpse numerous green eyes. “Sheep!” comments the shooter. “We’d best move on. Sheep and roos don’t like to mix.” Soon we see two big male kangaroos. One continues to graze while the truck stops. Heineman readies the rifle, an expensive-looking .225 caliber center-fire mounted with an 8x scope.

“Shhhh . . .” He lays the rifle barrel across the padded armrest mounted on the driver’s door. A tense moment passes. Bang! A hit. Bang! Another hit. A third animal moves into his line of sight, but he passes it up: “Too small—we’ll let it grow up.”
We drive over to the prostrate forms and get out of the truck. In the headlights we can see the blood; both roos were shot in the head, killed instantly. Like many other kills, these were made at more than a hundred yards away. We load the carcasses onto the truck and roll onward. There are now eleven dead kangaroos on the truck. All of them have been shot in the head.

This killing leaves me feeling queasy, but I'm determined to see for myself what Australia's "kangaroo problem" is all about. Most of the shooters I've accompanied in the past three months seem to care about their quarry, and all try to be humane by making every shot an instant kill.

Australia is home to all of the large species in the kangaroo family as well as to most of their smaller relatives. For thousands of years, many of these animals provided the Aborigines with meat and other products. Long sinews and their agriculture, the face of Australia began to change irrevocably. At first, the kangaroo was an important part of the newcomers' diet, too—probably because domestic stock was still too valuable to be killed. But as the colonial presence expanded, mutton began to replace kangaroo meat on the dinner tables of the wealthier farms. By the mid-1800s, eating kangaroo was associated with being a poor farmer.

Bit by bit, the image of the kangaroo as a resource was replaced by its reputation as a nuisance. The animals not only damaged crops and fences but competed with domestic sheep and cattle for precious grass. "Coursing clubs" were formed to hunt them on horseback. To aid in the chase, settlers bred the kangaroo dog—a swift, greyhoundlike runner with powerful jaws. Meanwhile, however, as they cleared the land and created and improved watering places for livestock, the sett-

dlers enabled the roos to multiply exponentially. An 1863 editorial in the newspaper Bordonwatch warned:

'It is becoming daily more apparent that some system of wholesale destruction will have to be devised for checking the rapid increase of kangaroos. So much have these animals increased in late years that if measures are not speedily taken against them, they threaten to overrun the district . . .
We should therefore preach a crusade against kangaroos.

Coursing was not up to the task of eradicating large numbers of the animals, however. The battue, a hunt in which bushes are beaten to drive out the game (a method used by the Aborigines), proved to be much more successful. Kangaroos were rounded up and driven into a dead end or a pit, where they could be shot or clubbed to death. After kangaroos were legally declared noxious in 1880, under ACT#11.44 VIC, rural communities pursued the animals’ eradication with a vengeance. A decade later, in a battue that took place in Queensland, a dozen shooters killed a total of 20,000 kangaroos in six weeks. Still, the roos continued to multiply.

Over the years, an industry has grown up around the killing of kangaroos. “There needs to be a reasonable balance struck,” says Bob Miles, a researcher with the Queensland Department of Primary Industries, which helps farmers solve production and management problems. “Kangaroos are a native animal, and they need protecting, but the estimates now indicate that we still have nearly as many kangaroos in southwest Queensland as we have sheep.”

Professional shooters are invited to hunt on properties that are heavily populated by kangaroos. The hunters then sell the skins to tanneries and the meat for pet food and to specialty meat markets for human consumption. (Kangaroo meat, which contains less than 2 percent fat and almost no cholesterol, has been called “the red meat that’s good for you to eat.”) It’s praise-worthily that not all the carcasses are wasted, as they were during the era of the battue, but about half are still being left to rot after the skin has been removed. And while some Australians see the trade in kangaroos as a humane use of a natural resource, others are upset that wild animals are being commercially exploited.

Currently, only five species of large kangaroo are considered fair game (most other species are protected and, with the possible exception of the swamp wallaby, are not considered worth pursuing). Shooters target primarily the red kangaroo, the eastern gray kangaroo, the western gray kangaroo, and the common wallaroo, with a smaller number of whiptail wallabies taken as well. As a rule of thumb, roughly 15 percent of a population is considered a safe annual harvest. With considerably more than 20 million of the targeted animals around, these species are not in danger of extinction.

Methods of kangaroo management vary to some extent from state to state, but each one sets commercial quotas to prevent overharvesting. The number is determined by the Federal Minister of the Environment and is based on recommendations from the government and from a wildlife-use advisory committee that represents various nongovernmental organizations. Numerous factors are taken into account: population estimates based on aerial and ground surveys, the proportions of the different species, the sizes and sex ratios of kangaroos that were recently shot, and local seasonal conditions. Zones in which kangaroos are proving to be a severe nuisance are allocated higher quotas than are other areas, but in every case the welfare of the overall roo population is kept in mind.

Some critics contend that the kangaroo culling quotas are too high. In 1975 slightly more than a million kangaroos were legally available for commercial harvest. This number increased to 3 million in 1981 and to 5.2 million in 1992 before reaching 5.7 million in 1999. The organization Greenpeace argues that continuing commercial killing at this level may ultimately threaten the kangaroo with extinction. “There may even be as many [kangaroos] as there were 200 years ago,” concedes Molly Olson, former direc-
tor of Sydney’s Greenpeace office, “but they’re now living in a much more confined area.” The concern is that an environmental collapse within the reduced territory could have devastating effects on the animal’s long-term survival.

But Bill Bonthrone, manager of Ingaby Station farm in southeastern Queensland and past president of the United Graziers’ Association of Queensland and the National Farmers’ Federation, insists that the commercial harvesting should continue. “If it should end, it means we farmers will have to do the culling,” he says. “And if I’m forced to do it, the day will come when I won’t shoot them. With kangaroo numbers increasing like they are, I’ll be forced to poison them. That’s just how serious the situation is. You can’t have a crop that’s worth $50,000 wiped out by kangaroos and expect to survive.”

Gordon Grigg, a professor of zoology at the University of Queensland in Brisbane, has been looking long and hard at the kangaroo problem. Piloting a Cessna, he takes part in the annual aerial survey that helps determine the current population figures for kangaroos in the arid and semiarid zones of Australia. “After more than a decade of flying kangaroo surveys over the eastern two-thirds of Australia,” he wrote in 1987, “the strongest impression I am left with is the huge impact that the hard-hoofed, hard-feeding sheep have had on the landscape. It is difficult to find a scene where the imprint of hooves is not clearly visible. The vegetation has been ground underfoot, exposing the fragile soil, changing its drainage properties and lessening its suitability for plant growth.” By contrast, kangaroos have soft feet that do not harm tender vegetation.

More than a decade later, little has changed. Grigg estimates that some 770,000 square miles (about 55
Sheep converging on a bore (well) in western New South Wales have left their mark, eradicating vegetation and damaging the fragile soil. Lacking sharp hooves, kangaroos are gentler on the landscape.

percent) of the arid zone has now been seriously degraded and is at risk of becoming permanent desert. The obvious way to address the problem is by reducing the number of sheep (as well as cattle). But how? With their backs to the economic wall, many graziers are trying to survive by putting more livestock on the already depleted land. It’s a vicious cycle, in which everyone will be losers sooner or later.

“Kangaroos thrive in unnaturally high numbers on these same lands where they are regarded as pests,” says Grigg. “In a nutshell, my idea is that we should undertake a marketing drive for kangaroo products, raising the price to such an extent that graziers will find it worthwhile to reduce their traditional hard-footed stock in favor of free-range kangaroos. In turn, the reduction of sheep numbers would help halt land degradation.”

If Grigg’s idea is ever implemented, kangaroo management practices would probably become similar to those of commercial fisheries. People would not own kangaroos, the way they do sheep and other livestock. Instead, the animals would be managed and harvested as a natural resource in areas and on properties where they range in sufficient numbers.

The “Grigg proposal,” as it is publicly referred to in Australia, has garnered mixed and heated reviews. Some critics are concerned that the economy would be flooded by this new meat supply. Grigg counters that if all the kangaroos that were culled each year were sold as supermarket specialty meat, this would represent less than 3 percent of the country’s total meat sales. Others say that rural communities are much too conservative to try such an unusual thing as kangaroo ranching. Yet the country’s sheep industry is often in economic crisis and may soon fail in many regions. Some folks abhor the idea of eating their national symbol, but they seem to forget that millions of the animals are killed each year simply as pests.

Kangaroos evolved on this landmass and are finely tuned to its seasonal changes. Perhaps it will prove easier all around to take advantage of their presence. As one Australian newspaper headline recently reported, “Eating Roos Will Save Them: Govt.”

Terry Domíco, who lives on an island off the coast of Washington State, is a naturalist, writer, and photographer. Among his books are Kangaroos: The Marvelous Mob (Facts on File, 1993) and Bears of the World (Facts on File, 1988).

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Haeckel’s distortions did not help Darwin.

By Stephen Jay Gould

Revolutions cannot be kind to prominent and unreconstructed survivors of a superseded age. But the insight and dignity of vanquished warriors, after enough time has elapsed to quell the immediate passions of revolt, often inspire a reversal of fortune in the judgment of posterity. (Even the most unabashed Northerner seems to prefer Robert E. Lee to George McClellan these days.)

This essay details a poignant little drama in the lives of three great central European scientists caught in the intellectual storm of Darwin’s *Origin of Species*, published in 1859. This tale, dormant for a century, has just achieved a vigorous second life, based largely on historical misapprehension and creationist misuse. Ironically, once we disentangle the fallacies and supply a proper context for understanding, our admiration must flow to Darwin’s two most prominent opponents from a dispersed and defeated conceptual world: the Estonian (but ethnic German) embryologist and general naturalist Karl Ernst von Baer (1792–1876), who spent the last forty years of his life teaching in Russia; and the Swiss zoologist, geologist, and paleontologist Louis Agassiz (1807–1873), who decamped to America in 1846 and founded Harvard’s Museum of Comparative Zoology, where I now reside as curator of the collection of fossil invertebrates that he began. By contrast, our justified criticism must fall upon the third man in the topsy-turvy drama, the would-be hero of a new world order: German naturalist Ernst Haeckel (1834–1919), the primary enthusiast and popularizer of Darwin’s great innovation. Haeckel’s forceful, eminently comprehensible, if not always accurate, books appeared in all major languages and surely exerted more influence than the works of any other scientist, including Darwin and Huxley (by Huxley’s own frank admission), in convincing people throughout the world about the validity of evolution.

Cynic that I am, I nonetheless confess to hero worship for the raw intellectual breadth and power of three great men: Darwin, who constructed my world; Antoine-Laurent Lavoisier, because the clarity of his mind leaves me awestruck every time I read his work; and Karl Ernst von Baer, who lived too long and became too isolated to win the proper plaudits of posterity. T.H. Huxley, who ranks fourth on my list, regarded von Baer as Europe’s greatest pre-Darwinian naturalist.

As the leading embryologist of the early nineteenth century, von Baer discovered the mammalian egg cell in 1827 and, in 1828, published the greatest monograph in the history of the field: *Über Entwicklungsgeschichte der Thiere* (On the Developmental History of Animals). He then suffered a mental breakdown and never returned to the field of embryology. Instead he moved to Saint Petersburg in 1834 (a common pattern for Central European scientists, because Russia, lacking a system of modern education, imported many of its leading professors in scientific subjects). There he enjoyed a long and splendid second career as an Arctic explorer, a founder of Russian anthropology, and a geomorphologist credited with discovering an important law relating the erosion of riverbanks to the Earth’s rotation.

In Ernst Haeckel’s drawing, the early embryos (top row) of a pig, dog, monkey, and human are nearly identical.

Von Baer’s theories of natural history allowed for limited evolution among closely related forms but not for substantial transformation between major groups. Moreover, he held no sympathy for Darwin’s mechanistic views of evolutionary causality. Darwin’s book shook the aged von Baer from decades of inactivity in his former zoological realm, and this great man—whom Agassiz, in his last (and posthumously published) article of
1874, would call “the aged Nestor of the science of Embryology”—came roaring back with a major critique entitled Über Darwins Lehre (On Darwin’s Theory).

In another article written in 1866 to criticize a brave new world that often forgot, and more frequently disparaged, the discoveries of previous generations, von Baer made a rueful comment that deserves enshrinement as one of the great aphorisms in the history of science. Invoking Agassiz, his younger friend and boon companion in rejecting the new theory of mechanistic evolution, von Baer wrote:

> Agassiz says that when a new doctrine is presented, it must go through three stages. First, people say that it isn’t true, then that it is against religion, and in the third stage, that it has long been known. (Author’s translation)

Ernst Haeckel, with his characteristic mixture of gusto and bluster, fancied himself a Darwinian general embattled in Agassiz’s first two stages, unfurling the new evolutionary banner not only for a biological truth but for the righteousness of all stripes. In 1874 he wrote:

> On one side spiritual freedom and truth, reason and culture, evolution and progress stand under the bright banner of science; on the other side, under the black flag of hierarchy, stand spiritual slavery and falsehood, irrationality and barbarism, superstition and retrogression. . . . Evolution is the heavy artillery in the struggle for truth.

Men of large vision often display outsized foibles as well. No character in the early days of Darwinism can match Haeckel for enigmatic contrast of the admirable and the dubious. No one could equal his energy or the extent of his output—mostly of high quality, including volumes of technical taxonomic description (concentrating on microscopic radiolarians and on jellyfishes and their allies), and not merely theoretical effusions. Yet no major figure took so much consistent liberty in imposing his theoretical beliefs upon nature’s observable factuality.

I won’t even discuss Haeckel’s misuse of Darwinian notions in the service of a strident German nationalism based on claims of cultural, and even biological, superiority—a set of ideas that became enormously popular and did provide later fodder for Nazi propagandists (obviously not Haeckel’s direct fault, although one does bear some responsibility for exaggerated, but not distorted, uses of one’s arguments [see Daniel Gasman, The Scientific Origins of National Socialism: Social Darwinism in Ernst Haeckel and the German Monist League, London: MacDonald, 1971]). Let’s consider only his drawings of organisms, supposedly a far more restricted subject, imbued with far less opportunity for any “play” beyond sober description.

I do dislike the common phrase “artistic license,” especially for its parochially smug connotation (when used by scientists) that creative humanists care little for empirical accuracy. (After all, the best artistic “distortions” record great skill and conscious intent, applied for definite and fully appropriate purposes; moreover, when great artists have chosen to depict external nature as seen through our eyes, they have done so with stunning accuracy.) But I don’t know how else to describe the work of Haeckel, who was, by the way, a skilled artist and far more than a Sunday painter.

Haeckel published books at the explicit interface of art and science—and here he stated no claim for pure fidelity to nature. His Kunstformen der Natur (Art Forms in Nature), published in 1904 and still the finest work ever produced in this genre, contains 100 plates of organisms crowded into intricate geometric arrangements. One can identify the creatures, but their invariably curved and swirling forms so closely follow the reigning conventions of art nouveau (called Jugendstil in Germany) that one cannot say whether the plates should be labeled as illustrations of actual organisms or as primers for a popular artistic style.

But Haeckel also prepared his own illustrations for his technical monographs and scientific books—and here he did claim fidelity to nature, as standard practice and legitimate convention also required. Yet Haeckel’s critics recognized from the start that this master naturalist, this more than competent artist, took systematic license in “improving” his specimens to make them more symmetrical or more beautiful. In particular, the gorgeous plates for his technical monograph on the taxonomy of radiolarians (intricate and delicate skeletons of single-celled planktonic organisms) often “enhanced” the actual appearances (already stunningly complex and remarkably symmetrical) by inventing structures with perfect geometric regularity.

This practice cannot be defended in any sense, but distortions in technical monographs cause minimal damage, because they rarely receive attention from readers without enough professional knowledge to recognize the fabrications. “Improved” illustrations masquerading as accurate drawings spell much more trouble in popular books intended for general audiences lacking the expertise to sep-
parate a misleading idealization from a
genuine signal from nature. And here,
in depicting vertebrate embryos in sev-
eral of his most popular books,
Haeckel took a license that subjected
him to harsh criticism in his own day
and that, in a fierce brouhaha (or
rather a tempest in a teapot), has resur-
faced in the last two years to haunt him
again and even to give some false com-
fort to creationists.

We must first understand Haeckel's
own motivations—not as any justifica-
tion for his actions but as a guide to a
context that has been sadly missing
from most recent commentary, thereby
leading to the magnification and dis-
tortion of this fascinating incident in
the history of science. Haeckel remains
most famous today as the chief archi-
tect and propagandist for a famous argu-
ment that science disproved long
ago but that popular culture has never
fully abandoned, if only because the
standard description sounds so won-
derfully arcane and mellifluous: "on-
togeny recapitulates phylogeny," other-
wise known as the theory of recapi-
tulation or, roughly, the claim
that organisms retrace their evolution-
ary history (or "climb their own family
tree," to cite an old catchphrase) dur-
ing their embryological development.
Thus, the gill slits of the early human
embryo supposedly repeat our distant
ancestral past as a fish, while the tran-
sient embryonic tail, developing just
afterward, marks the later reptilian
phase of our evolutionary ascent. (My
first technical book, Ontogeny and Phy-
logeny [Harvard University Press,
1977], includes a detailed account of
the history of recapitulation—an evolu-
tionary notion exceeded only by
natural selection itself for impact upon
popular culture.)

As primary support for his theory of recapi-
tulation, and to advance the
argument that all vertebrates may be
traced to a common ancestor, Haeckel
frequently published striking drawings
showing parallel stages in the develop-
ment of diverse vertebrates, including
fishes, chickens, and several species of
mammals, from cows to humans (see,
for example, page 42). The figure
below comes from Evolution of Man, an
inexpensive popular English transla-
tion, published in 1903, of his famous
Anthropogenie. Note how the latest de-
picted stages (bottom row) have al-
ready developed the distinctive features
of adulthood (the tortoise's shell or the
chick's beak). But Haeckel drew the
earliest stages (first row), showing tails
below and gill slits just under the pri-
mordial head, as virtually identical for
all embryos, whatever their adult des-
tination. Haeckel could therefore claim
that this near identity marked the
common ancestry of all vertebrates—
for, under the theory of recapitulation,
embryos pass through a series of stages
representing successive adult forms of
their evolutionary history. An identi-
tical embryonic stage can only imply a sin-
gle common ancestor.

To cut to the quick of this drama:
Haeckel had exaggerated the similari-
ties by idealizations and omissions. He
also, in some cases—in a procedure
that can only be called fraudulent—
simply copied the same figure over and
over again. At certain stages in early
development, vertebrate embryos do
look more alike, at least in gross
anatomical features easily observed
with the human eye, than do the adult
tortoises, chickens, cows, and humans
that will develop from them. But these
early embryos also differ far more sub-
stantially, one from the other, than
Haeckel's figures show. Moreover,
Haeckel's drawings never fooled expert
embryologists, who recognized his
fudgings right from the start.

At this point, a relatively straight-
forward factual story, blessed with
a simple moral message as well, be-
comes considerably more complex,
given the foibles and practices of the
oldest primate of all. Haeckel's draw-
ings, despite their noted inaccuracies,
entered into the most impenetrable
and permanent of all quasi-scientific
literatures: standard student textbooks
of biology. I do not know how the
transfer occurred in this particular
case, but the general (and highly trou-
bling) principles can be easily identi-
fied. Authors of textbooks cannot be
experts in all subdisciplines of their
subject. They should be more careful,
and they should rely more on primary
literature and the testimony of expert
colleagues, but shortcuts tempt us all,
particularly in the midst of elaborate
projects under tight deadlines.

Therefore, textbook authors often
follow two suboptimal routes that us-
ually yield adequate results but can also
engender serious trouble: they copy
from previous textbooks, and they
borrow from the most widely available
popular sources. No one ever sur-
passed Haeckel in fame and availability
as a Darwinian spokesman and a noted
professor at the University of Jena. So
textbook authors borrowed his famous
drawings of embryonic development,
probably quite unaware of their noted
inaccuracies and outright falsifications—or (to be honest about dirty laundry too often kept hidden) perhaps well enough aware, they then rationalized with the ever tempting and ever dangerous argument “Oh well, it’s close enough to reality for student consumption, and it does illustrate a general truth with permissible idealization.” (I am a generous realist on most matters of human foibles. But I confess to raging fundamentalism on this issue. The smallest compromise in dumming down by inaccuracy destroys integrity and places an author upon a slippery slope of no return.)

Once ensconced in textbooks, misinformation becomes cocooned and effectively permanent, because, as stated above, textbooks copy from previous texts. (I have written two essays on this lamentable practice: one on the amusingly perennial description of the eohippus, or “dawn horse,” as the size of a fox terrier, even though most authors, including yours truly, have no idea of the dimensions or appearance of this breed; and the other on the persistent claim that elongating giraffe necks provide our best illustration of Darwinian natural selection versus Lamarckian use and disuse when, in fact, no meaningful data exist on the evolution of this justly celebrated structure.)

We should therefore not be surprised that Haeckel’s drawings entered nineteenth-century textbooks. But we do, I think, have the right to be both astonished and ashamed by the century of mindless recycling that has led to the persistence of these drawings in a large number, if not a majority, of modern textbooks! Michael Richardson, of the St. George’s Hospital Medical School in London, a colleague who deserves nothing but praise for directing attention to this old issue, wrote to me (letter of August 16, 1999):

**If so many historians knew all about the old controversy over Haeckel’s falsified drawings, then why did they not communicate this information to the numerous contemporary authors who use the Haeckel drawings in their books? I know of at least fifty recent biology texts which use the drawings uncritically. I think this is the most important question to come out of the whole story.**

The recent flap over this more-than-twice-told tale—an almost comic manifestation of the famous dictum that those unfamiliar with history (or simply careless in reporting) must be condemned to repeat the past—began with an excellent technical paper by Richardson and six other colleagues in 1997 (*Anatomy and Embryology*, vol. 196), following a 1995 article by Richardson alone (*Developmental Biology*, vol. 172). In these articles, Richardson and his colleagues discussed the original Haeckel drawings, briefly noted the contemporary recognition of their inaccuracies, properly criticized their persistent appearance in modern textbooks, and then presented evidence (discussed below) of the differences among early vertebrate embryos that Haeckel’s tactics had covered up and that later biologists had therefore forgotten. Richardson invoked this historical tale in order to make an important point, also mentioned below, about exciting modern work in the genetics of development.

From this excellent and accurate beginning, the reassertion of Haeckel’s old skullduggery soon spiraled into an abyss of careless reporting and self-serving utility. Elizabeth Penisi’s news report in the September 5, 1997, issue of *Science* told the story well, under an accurate headline (“Haeckel’s Embryos: Fraud Rediscovered”) and with a textual acknowledgement that Haeckel’s work was first “found to be flawed more than a century ago.” But the shorter squib in Britain’s *New Scientist* of September 6, 1997, began the downward spiral by implying that Richardson had discovered Haeckel’s misdeed for the first time.

As so often happens, this ersatz version, so eminently more newsworthy than the truth, opened the floodgates to a torrent of sensationalist (and nonsensical) assertions: a primary pillar of Darwinism, and of evolution in general, had been revealed as fraudulent after more than a century of continuous and unchallenged centrality in biological theory. If evolution rests upon such flimsy support, perhaps we should question the entire enterprise and give creationists, who have always flubbed their day in court, their day in the classroom.

Michael J. Behe, a Lehigh University biologist who has tried to resuscitate the most ancient and tired canard in the creationist arsenal (Paley’s “argument from design,” based on the supposed “irreducible complexity” of in-
tricate biological structures, a claim well refuted by Darwin himself in his famous discussion of transitional forms in the evolution of complex eyes), reached the nadir in a recent op-ed piece for the New York Times (August 13, 1999), commenting on the Kansas Board of Education’s decision to make instruction in evolution optional within the state’s science curriculum. (In fairness, I liked Behe’s general argument in this piece, for he stayed away from irrelevant religious issues and attacked the Kansas decision by saying that we would never get a chance to present his supposed refutations if students didn’t study evolution at all.)

As his putatively strongest refutation of Darwinism, Behe cites the ersatz version of Richardson’s work on Haeckel’s drawings. (Behe discusses only two other arguments for evolution, one that he accepts as true [the evolution of antibiotic resistance by several bacterial strains], the second judged as “unsupported by current evidence” [the “classic” case of industrial melanism in moths], with only this third point—the tale of Haeckel’s drawings—declared “downright false.” So if this piece represents Behe’s best shot, I doubt that creationists will receive much of a boost from their latest academic poster boy.) Behe writes:

_The story of the embryos is an object lesson in seeing what you want to see. Sketches of vertebrate embryos were first made in the late 19th century by Ernst Haeckel, an admirer of Darwin. In the intervening years, apparently nobody verified the accuracy of Haeckel’s drawings. . . . If supposedly identical embryos were once touted as strong evidence for evolution, does the recent demonstration of variation in embryos now count as evidence against evolution?_

In this context of media hype and public confusion, we should step back and reassert the two crucial points that accurately situate Haeckel’s drawings as a poignant and fascinating historical tale and a cautionary warning about scientific carelessness (particularly in the canonical and indefensible practices of textbook writing) but not, in any way, as an argument against evolution or as a sign of weakness in Darwinian theory. Moreover, as a testament to greatness of intellect and love of science, whatever the ultimate validity of an underlying worldview, we may look to the work of von Baer and Agassiz, Darwin’s most valiant opponents in his own day, for our best illustrations of these two clarifying points.

Of Haeckel’s early pig, dog, and tortoise embryos, Agassiz railed, “Nothing like this exists in the entire literature.”

1. Haeckel’s forgeries as old news (Agassiz’s contribution): Tales of scientific fraud excite the imagination for good reason. Getting away with this academic equivalent of murder and then being outed a century after your misdeeds makes even better copy. Richardson reexamined Haeckel’s drawings for good reasons and never claimed originality in uncovering the fraud. But press commentary then invented and promulgated this phony version.

Haeckel’s expert contemporaries recognized what he had done, and said so in print. For example, a famous 1894 article by Cambridge University zoologist Adam Sedgwick (“On the Law of Development Commonly Known as von Baer’s Law”) included the following withering footnote of classical Victorian understatement:

_I do not feel called upon to characterise the accuracy of the drawings of embryos of different classes of Vertebrata given by Haeckel in his popular works. . . . As a sample of their accuracy, I may refer the reader to the varied position of the auditory sac in the drawings of the younger embryos._

I must confess to a personal reason, emotional as well as intellectual, for long and special interest in this tidbit of history. Some twenty years ago, I found, in the open stacks of our Museum’s library at Harvard, Louis Agassiz’s personal copy of the first (1868) edition of Haeckel’s _Naturliche Schöpfungsgeschichte_ (The Natural History of Creation). (After his death, Agassiz’s library passed into the Museum’s general collection, where indifferent librarianship—before the present generation—led to open access, through nonrecognition, to such priceless treasures.)

I noted, with the thrill that circumstances vouchsafe to an active scholar only a few times in a full career, that Agassiz had penciled copious marginal notes—some forty pages’ worth of typed transcription—into this copy. But I couldn’t read his scribblings. Agassiz, a typical Swiss polyglot, annotated books in the language of their composition. When he wrote marginalia into a German book published in

Once ensconced in a textbook, misinformation becomes effectively permanent, because textbooks copy from previous texts.
Roman type, he composed the notes in Roman script (which I can read and translate). But when he read a German book printed in old but easily decipherable Fraktur type (as in Haeckel's 1868 edition), he wrote his annotations in the corresponding and now extinct Sütterlin script (which I cannot read at all). The Roman goddess Fortuna then smiled upon me, for my secretary, Agnes Pilot, had been educated in Germany just before the Second World War, and she, Gott sei Dank, could still read this archaic script. So she transliterated Agassiz's squiggles into readable German in Roman type, and I could finally sense Agassiz's deep anger and distress.

In 1868 Agassiz, age 61 and physically broken by an arduous expedition to Brazil, felt old, feeble, and bypassed, especially in the light of his extended opposition to evolution (his own graduate students had all "rebelled" and embraced the new Darwinian model). He particularly disliked Haeckel for his crass materialism, his scientifically irrelevant and vicious swipes at religion, and his haughty dismissal of earlier work (which he often shamelessly "borrowed" without attribution). And yet, in reading through Agassiz's extensive marginalia, I sensed something noble about the quality of his opposition, however ill-founded in the light of later knowledge.

To be sure, Agassiz waxes bitter at Haeckel's excesses, as in his final note appended to the closing flourish of Haeckel's book, including the author's gratuitous attack on conventional religion as "the dark beliefs and secrets of a priestly class." Agassiz writes sardonically: "Gegeben im Jahre I der neuen Weltordnung (given in year one of the new world order). E. Haeckel." But Agassiz generally sticks to the high road, despite ample provocation, by marshaling the facts of his greatest disciplinary expertise (in geology, paleontology, and zoology) to refute

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Haeckel's frequent exaggerations and rhetorical inconsistencies. Agassiz may have been exhausted and discouraged, but he could still put up one whole of a fight, even if only in private.

Agassiz proceeded in generally measured prose until he came to page 240, where he encountered Haeckel's falsified drawings of vertebrate embryology—a subject of extensive personal research and writing on Agassiz's part (see page 45). He immediately recognized what Haeckel had done, and he exploded in fully justified rage. Above the nearly identical pictures of dog and human embryos, Agassiz wrote: “Woher copiert? Gekünstelte Ähnlichkeit mit Ungenauigkeit verbunden, z.B. Coloboma, Nabel, etc.” (Where were these copied from? [They include] artistically crafted similarities mixed with inaccuracies, for example, the eye slit, umbilicus, etc.)

At least these two drawings displayed some minor differences. But when Agassiz came to page 248, he noticed that Haeckel had simply copied the same exact figure three times (see page 46) in supposedly illustrating a still earlier embryonic stage of a dog (left), a chicken (middle) and a tortoise (right). He wrote above this figure: “Woher sind diese Figuren entnommen? Es gibt solas in der ganzen Litteratur nicht. Diese Identität ist nicht wahr.” (Where were these figures taken from? Nothing like this exists in the entire literature. This identity is not true.)

Finally, on the next page, (see page 49) he writes his angriest note next to Haeckel's textual affirmation of this threefold identity. Haeckel stated: “If you take the young embryos of a dog, a chicken, and a tortoise, you cannot discover a single difference among them.” And Agassiz sarcastically replied, “Naturlich—da diese Figuren nicht nach der Natur gezeichnet, sondern eine von der andern copiert ist! Abscheulich.” (Naturally—because these figures were not drawn from nature, but rather copied one from the other! Atrocious.)

2. Haeckel's forgeries as irrelevant to the validity of evolution or Darwinian mechanisms (von Baer's contribution): From the very beginning of this frenzied discussion two years ago, I have been thoroughly mystified as to what, beyond simple ignorance or self-serving design, could ever have inspired the creators of the sensationalized version to claim that Haeckel's exposure challenges Darwinian theory or even evolution itself. After all, Haeckel used these drawings to support his theory of recapitulation—the claim that embryos repeat successive adult stages of their ancestry. For reasons elaborated at excruciating length in my Ontogeny and Phylogeny, Darwinian science conclusively disproved and abandoned this idea by 1910 or so, despite its persistence in popular culture. Obviously, neither evolution nor Darwinian theory needs the support of a doctrine so conclusively disconfirmed from within.

I do not deny, however, that the notion of greater embryonic similarity, followed by increasing differentiation toward the adult stages of related forms, has continued to play an important, although scarcely defining, role in evolutionary theory—but through the later evolutionary version of another interpretation first proposed by von Baer in his 1828 treatise. In a pre-evolutionary context, von Baer argued that development, as a universal pattern, must proceed by a process of differentiation from the general to the specific. Therefore, the most general features of all vertebrates will arise first in embryology, followed by a successive appearance of ever more specific characters of particular groups.

In other words, you can first tell that an embryo will become a vertebrate rather than an arthropod, then a mammal rather than a fish, then a carnivore rather than a rodent, and finally good old Rover rather than Ms. Tabby. Under von Baer's reading, a human embryo grows gill slits not because we evolved from an adult fish (Haeckel's recapitulatory explanation) but because all vertebrates begin their embryological lives with gills. Fish, as "primitive" vertebrates, depart least from this basic condition in their later development, whereas mammals, as most "advanced," lose their gills, and grow lungs during their maximal embryological excursion from the initial and most generalized vertebrate form.

Von Baer's law, as biologists soon christened this principle of differentiation, received an easy and obvious evolutionary interpretation from Darwin's hand. The intricacies of early development, when so many complex organs differentiate and interconnect in so short a time, allow little leeway for substantial alteration, whereas later stages, with fewer crucial connections to the central machinery of organic function, permit greater latitude for evolutionary change. (In rough analogy, you can always paint your car a different color, but you had better not mess with basic features of the internal combustion engine as your future vehicle rolls down the early stages of the assembly line.)

The evolutionary version of von Baer's law suggests that embryos may give us better clues about ancestry than
Outraged by Haeckel's distortions, Agassiz ends his marginal comments with “Atrocious.”

they retain no distinctive traits of their larger affiliation. The adult stage of the parasitic barnacle *Sacculina*, for example, becomes little more than an amorphous bag of feeding and reproductive tissue within the body of its crab host. But the larval stages that must seek and penetrate a crab can hardly be distinguished from the early stages of ordinary barnacles. Darwin makes the key point succinctly when he states in *Origin of Species* that “community in embryonic structure reveals community of descent”.

Von Baer's law makes good sense, but nothing in Darwinian theory implies or requires its validity, while evolution itself clearly permits embryology to proceed in either direction (or in no linearized manner at all); from embryonic similarity to adult discordance (as in groups that follow von Baer’s principle) or from larval discordance to adult likeness (as in several invertebrate groups, notably some closely related sea urchin species, where larvae have adapted to highly different lifestyles of planktonic floating versus development from yolk-filled eggs that remain on the seafloor. Meanwhile, the highly similar adults of both species continue to live and function like ordinary sea urchins).

The bottom line may now be simply stated: the validity and relative frequency of von Baer’s law remains an open, empirical question within evolutionary theory, an issue that can be resolved only by observational evidence from a wide variety of organisms. Moreover, this issue has become quite important in the light of current excitement over recent advances in genetics that have finally allowed us to identify and trace the genes regulating early development. In this crucial and valid context, Richardson wisely chose to reevaluate our complacency about the probable validity of von Baer’s law.

Richardson realized that the continuing re-publication of Haeckel’s fraudulent figures might be tipping our beliefs in von Baer’s favor for indefensible reasons of inherited and unquestioned tradition (based on falsified drawing, to boot) rather than good observational evidence. He therefore called attention to this likely source of unrecognized bias as he marshaled several colleagues to make the basic observations that could resolve a truly open question, falsely regarded by many colleagues as an issue decided long ago, partly on the strength of Haeckel’s doctored evidence.

The jury will be out for some time as they debate and actively research this important issue, too long neglected, in the sciences of natural history. But the 1997 paper by Richardson and six colleagues has already poked some important holes in the old and (as we now learn) poorly documented belief in early embryonic similarity among related lineages, followed by increasing disparity toward adulthood. The early embryonic stages of vertebrates are not nearly so similar as Haeckel’s phony drawings had led us to believe. For example, at the stage that Haeckel chose for maximal similarity, the number of somites (vertebral segments) of actual embryos ranges from eleven for a Puerto Rican tree frog to sixty for a blindworm (the common name for an unfamiliar group of limbless amphibia with a basically snake-like adult form). Moreover, although Haeckel drew his embryos as identical in both size and form, actual vertebrate embryos at their stage of maximal anatomical similarity span a tenfold range in body size.

In short, the work of Richardson and colleagues goes by a simple and treasured name in my trade: good science. The flap over Haeckel’s doctored drawings should leave us feeling ashamed about the partial basis of a widely shared bias now properly exposed and already subjected to exciting new research. But Haeckel’s High Victorian (or should I say Bismarckian) misdeeds provide no fodder to foes of Darwin or of evolution.

In other words, to give von Baer and Agassiz a final due, we need not fear the first and second stages of a scientific revolution, because we will fight like hell (perhaps unwisely and too well but at least with gusto) so long as we regard a new idea as either ridiculous or opposed to “religion” (that is, to conventional belief). But we must beware the dreaded third stage, for when we capitulate and then smugly state that we knew it all along, we easily fall into the greatest danger of all—smug complacency—because we have ceased to question and observe. And no situation in science could possibly be more abscheulich—atrocious!

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Erratum: The portrait of Marcel Duchamp in the 12/99–1/00 issue of Natural History was incorrectly credited. The photographer was Victor Obsatz, to whom we apologize for the error.
DUETS AND DRAWSLS

When two scientists lent an ear to tropical stripe-backed wrens, they heard more than songs and calls; they heard family histories. Here they describe the unique vocalizing of a very social bird.

By Jordan Price and R. Haven Wiley

On a July morning in the llanos, or savannas, of Venezuela, the air is muggy and thick with mosquitoes. Most of Hato Masaguaral, the cattle ranch and wildlife refuge where we work, is covered with water and mud a foot deep. On the few patches of dry ground, tropical rattlesnakes lie low, and in shallow pools, spectacled caiman doze just beneath the surface. Occasionally we disturb the sleeping reptiles as we wade across the llanos, probably because our minds are less on the perils beneath our feet than on the staggering abundance of birds above our heads.

More than 300 species of birds—from waterfowl and parrots to hawks and flycatchers—can be seen on this ranch alone. For birds that breed in the llanos, July (the peak of the wet season, which extends from May to October) is a time of plenty, when food for hatchlings is abundant. The air is filled with the sounds of birds busy raising their families. High in a grove of trees, a dozen or so small, gray-and-white streaked songbirds chase each other through the dense foliage. These are stripe-backed wrens, a species common throughout the llanos of Colombia and Venezuela. Two neighboring groups are fighting over the common boundary of their territories. Choosing our steps carefully, we move in for a closer look.

The owner of Hato Masaguaral, Tomás Blohm, has preserved much of the ranch’s natural habitat and has allowed birders, naturalists, and scientists from around the world to use it as a tropical research station. Biologists from the University of North Carolina at Chapel Hill and from Purdue University have intensively studied the ranch’s stripe-backed wrens since the 1970s. Each bird wears a unique combination of colored plastic bands for easy identification; most have been banded in their natal territories during their first year. By using these genealogies and DNA fingerprinting techniques, Kerry Rabenold and his team from Purdue have worked out the family histories of nearly every bird in the population. But our research has focused mainly on the wrens’ vocalizations. Without even looking at their leg bands, we can tell which birds belong to which family, simply by listening to their sounds. Our most recent work with stripe-backed wrens has revealed a complex system of vocal communication that includes two sets of learned vocalizations. One of these has a pattern of cultural transmission unlike that of any other songbird. Passed from fathers to sons and from mothers to daughters, these vocalizations are as reliable as any high-tech method for determining family ties.

The development of vocal traditions in this species probably derives in part from its social organization. Stripe-backed wrens never live alone. Year-round residents of the llanos, they are cooperative breeders that live in groups and work together to defend permanent territories of about an acre. Each group is an extended family consisting of a breeding male and female and up to twelve of their offspring from previous years. Both male and female offspring help the breeders maintain the communal nest, tend the young, and, as we are seeing in the feuding families above us, defend the home turf from intruding neighbors.

In each of the families we are watching, the breeding male belongs to the patriline, or male lineage, that has occupied the territory for generations. The breeding female has immigrated into the group from a nearby territory.

A pair of stripe-backed wrens sing a duet near their nest, a compartment in a multiplex assembled by a rufous-fronted thornbird. The silent wren on the left is probably a “helper.”
Males usually remain in the territory of their birth and wait to inherit the breeding position when it becomes available, while females disperse after a few years of serving as helpers and compete for vacant breeding positions in other groups. Male helpers form a kind of queue based on age: the oldest bird is first in line to become the next breeder. Like the scions of some old European royal families, a few unfortunate males spend their entire lives waiting to succeed their fathers. An adventurous few roam far afield and attempt to found their own dynasties, but most of these birds are unsuccessful.

The wren families squabbling above us produce a variety of sounds as they dart from branch to branch. Particularly prominent are their duets, Sung by a male and female, these consist of loud staccato notes. (The sound is the source of the species’ onomatopoeic Spanish name, choochoo.) Although the complex syncopated rhythms of duets can sound to the untrained ear as if they are coming from one bird, they are the efforts of two wrens perched side by side and interposing their notes with precise timing.

The stripe-backed wren’s duets, like those of such other tropical duettists as the Central American bay wren, seem to be the equivalent of the territorial songs issued by individual males of many temperate-zone songbird species. They advertise a group’s occupation of a territory and are usually performed by the breeding pair. The strident take-home message of a duet is basically, “This territory will be defended against intruders, and no, there are no available breeding positions here.”

But we can also detect subtler utterances that act as a kind of counterpart to the duets. Individual wrens emit nasal calls, some of which sound like a human voice drawling, “Where are you?” For this reason, despite our best efforts to avoid anthropomorphism, we have come to call these querulous-sounding phrases WAY calls. The modulated nasal sounds and interspersed raspy clicks of WAY calls are some of the strangest vocalizations produced by songbirds.

WAY calls are not nearly as loud as duets and can be heard at only about one-quarter the distance. Often they are not audible much beyond a group’s home ground. The back-and-forth WAY-calling of family members can, in fact, with a little imagination, sound almost like a human conversation. We believe that WAY calls are used for close-range communication rather than for conveying information between neighboring groups at a distance.

Like other songbirds, young stripe-backed wrens have to learn the complex sounds that characterize their species. Songbirds are one of the few groups of animals in which vocalizations are learned rather than genetically inherited (others include parrots, hummingbirds, whales, and, of course, humans).

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**ABSTRACTS**

**NEANDERTHAL FLOWER POWER** The 1976 discovery of a 50,000-year-old Neanderthal skeleton together with clusters of ancient pollen grains and plant stalks convinced many scientists that it had been deliberately buried with garlands of wildflowers. The Middle Paleolithic remains were found in Shanidar Cave, Iraq, with evidence of yarrow, grape hyacinth, and Saint Barnaby’s thistle. Shanidar’s discoverer, Ralph Solecki, opined in 1971 that “with the finding of flowers in association with Neanderthals, we are brought suddenly to the realization that the universality of mankind and the love of beauty go beyond the boundary of our own species.”

At about the same time, however, zoo-archaeologist Richard Redding excavated several burrows of *Meriones crassus*, a gerbil-like rodent found in the Zagros Mountains, and observed that the animal stores large numbers of similar flowers in its tunnels. Learning about the habits of these rodents almost three decades later, Jeffrey D. Sommer, of the University of Michigan’s Museum of Anthropology, reexamined accounts of the Shanidar excavations and noticed references to preserved rodent bones and burrows “very close to the skeletons.” Sommer proposes that the flowers may well have been deposited at Shanidar by the Persian jird, *M. persicus*, another inhabitant of the region’s barren and rocky slopes. “While the investigation of Neanderthal cognition should continue,” he concludes, “the flower pollen recovered near Shanidar IV is more likely to have resulted from the activities of rodents than Neanderthals.” (“The Shanidar IV ‘Flower Burial’: A Reevaluation of Neanderthal Burial Ritual,” *Cambridge Archaeological Journal* 9:1, 1999)
BIGGEST OF THE SMALL

An extinct species of the disc-shaped, single-celled organism Nummulites may have been the biggest (and perhaps the longest-lived) unicellular creature that ever existed. Some individuals were the size of large clams.

A subgroup of foraminifera (microscopic creatures that encase themselves in elaborate calcium carbonate shells), the largest nummulites lived some 50 million years ago. While most modern forams are amoeba-sized, the Eocene species N. millecaput reached more than six inches in diameter. Louise M. A. Purton, of Trinity College, Dublin, Ireland, and Martin D. Brasier, of the University of Oxford, investigated the conditions under which these protozoans attained such great size. They found that the Eocene nummulites lived in nutrient-rich environments during a warm climatic phase. Their shells indicate that individuals grew slowly but steadily and may have lived more than a century. Although there are not enough remains of the largest nummulites for definitive studies, researchers can estimate their life spans by comparing fragments with remains of the closely related smaller species N. laevigatus, which lived about six years. Studying alterations in carbon and oxygen isotopes in the fossilized shells, the researchers examined seasonal records of these extinct giants of the unicellular world and could thus extrapolate growth rates and ages. (“Giant Protist Nummulites and Its Eocene Environment: Life Span and Habitat Insights From δ18O and δ13C Data From Nummulites and Venericardia, Hampshire Basin, UK,” Geology 27:8, 1999)

BIGGEST OF THE BIG

Dinosaur bones discovered in 1994 in a remote area of southeastern Oklahoma may be the remains of the largest of all sauropods. Four neckbones, the longest of which reaches nearly five feet,

If thornbird nests are not available, wrens construct their own, with softer architectural details.

mans). Like all learning, song transmission in birds can involve occasional errors; if passed on to other individuals, these become variations that are in turn perpetuated. Biologists who study birdsong can compare the acoustic details of different birds’ sounds to determine who their teachers were. In northern temperate zones, songbirds usually copy songs not from their parents but from unrelated members of the same species, usually neighbors. Much less is known, however, about vocal learning in tropical birds with more complicated social relationships, such as stripe-backed wrens. In this species, vocal complexity appears to mirror social complexity.

Rather than learning from unrelated neighbors, male stripe-backed wrens pick up WAY calls from their fathers and older brothers, and young females learn from their mothers and older sisters. Many of the birds involved in the skirmish above us are males, and they call more frequently than the females do as they chase each other from branch to branch. All the male wrens in a family have identical repertoires of about twelve distinct WAY calls, while unrelated males rarely share any call patterns at all. During territorial disputes, group-specific calls—like the colors of sports-team jerseys—signal to each contestant who is and who is not on its team. WAY calls seem not to be given to proclaim the whereabouts of a good food source or to alert the group to the presence of danger (the wrens have a distinct call to unmask predators).

Female wrens’ WAY calls consist of sounds that resemble those of males. We cannot tell, just by hearing a WAY call, whether it is produced by a male or a female. However, females have smaller repertoires, usually of about four different calls. Male and female family members never share the same call patterns, nor do female WAY calls match those of males in nearby groups or those of any unrelated females. Instead, the calls are passed from mother to daughter in a separate, matrilineal tradition.

Females often issue WAY calls when they search out and compete for breeding vacancies in other territories. Female relatives (usually sisters) often travel together and compete as teams, so their WAY calls, like those of males, might be used to verify who’s on which team. Contests for breeding opportunities sometimes involve females from a number of families and are characterized by much WAY-calling by female competitors and resident males. This is one of the few situations in which females WAY-call intensively.

Because we can trace genealogies in this population back several generations, we have shown that WAY calls are passed from older to younger wrens with remarkable fidelity. This is illustrated by our finding that while the males of each group normally have a unique set of WAY calls, there are exceptions—cases of two widely separated groups in which males have a
nearly identical repertoire of calls. In each of these cases, however, the family trees (compiled by Rabenold and others) reveal that the males in these groups shared a paternal ancestor that left one group generations earlier to join the other one and apparently carried his WAY-call repertoire with him. In two of these instances, the shared patriarch was a great-grandfather that had died as much as two decades earlier. Few other birds are known to have such lasting cultural traditions.

Amid the seeming cacophony of calls to which young birds are exposed during development, wren offspring somehow manage to learn only the WAY calls produced by the parent of the same sex. Even under close inspection, male and female stripe-backed wrens look alike (presumably to one another, as well), so sex-specific calls could serve to distinguish the sexes in this highly social species. Also, because WAY calls reflect genealogy, they may permit individuals to identify unknown relatives by comparing other birds’ calls to their own or to the calls of known relatives and thus may allow them to direct cooperative behavior preferentially toward close kin. On the other hand, if a female looking for a breeding vacancy finds that a widowed male of another group has WAY calls very like those of her father, she might withdraw to avoid close inbreeding. Although we don’t know for certain whether the birds do use the calls in this manner, we have shown, by playing tape-recorded WAY calls to males, that individuals react differently to the calls of relatives and outsiders.

To a lesser extent, sex-specific learning is also necessary for singing duets. Since duets cannot be performed by members of the same sex, when two males or two females attempt to initiate a duet, their efforts will degenerate into a series of sputtering notes. A proper duet has a male part and a female part, learned from older birds of the same sex. But unlike the same-sex teachers of WAY calls, duet vocal coaches need not be relatives. Some duet patterns of neighboring families can be nearly identical, although playback experiments have shown that the wrens can identify neighbors solely by hearing their duets.

The gregarious stripe-backed wrens of Hato Masaguaral continue to spur scientific inquiry. Their vocal communication alone has proved to be rich and layered, with two sets of learned vocalizations: duets and WAY calls. The dual, his-her routes of WAY-call transmission are unlike any previously described. Yet we suspect they might not remain unique for long. Many tropical birds have complex social organizations, and many await the attention of rubber-booted, caiman-hopping researchers eager to learn more about them. Once we do, we are likely to discover patterns of avian communication of equal or maybe even greater complexity.

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were found by amateur paleontologist Bobby Cross, who thought they were the trunks of prehistoric trees. Close examination of the bones by Richard Cifelli and his colleagues at the University of Oklahoma revealed that they belonged to a relative of Brochisaurus.

Extrapolating from the fragmentary bones, the researchers believe that the animal, which they named Sauroposeidon ("earth-lord lizard") proteles, was thirty times larger than the largest giraffe ever known. It was nearly a hundred feet long, weighed more than sixty tons, and had a thirty-foot neck.

Since the dinosaur lived about 110 million years ago, toward the end of the Age of Dinosaurs, it was given the species name proteles, from the Greek for "completion." This new find may begin to fill in the blanks about the last North American sauropods, which may have left behind the gigantic tracks near Glen Rose, Texas, that have puzzled researchers for decades. ("Sauroposeidon proteles, a New Sauropod From the Early Cretaceous of Oklahoma," Journal of Vertebrate Paleontology 20:1, 2000)

**AND SPEAKING OF TRACKS...**

After six years of searching for tracks in the Raton basin of southern Colorado and northern New Mexico, geologist William T. Caneer discovered imprints in Upper Cretaceous sandstone that he believes were made by the king of carnivores. One track, in Colorado, indicates a Tyrannosaurus rex walking in normal, bipedal fashion. The New Mexico tracks may be impressions made by the animal’s forearms and two-digit "hands." Caneer believes that the individual was rising from a prone position. ("One of Two T. rex Tracks From the Raton Basin Left Traces of the Forearms and Hands in Addition to the Foot," Journal of Vertebrate Paleontology 19:3, 1999)—Richard Milner
Researchers are constantly adding to the list of substances that trigger asthma. They’re also finding more and more genes that influence susceptibility. But the real problem may be our pampered immune systems.

By Matt Ridley

Unless you are unlucky enough to have a rare and serious genetic condition (and most of us do not), the impact of genes upon your life is a gradual, partial, blended sort of thing. You are not tall or dwarf, like Mendel’s pea plants; you are somewhere in between. You are not wrinkled or smooth, but somewhere in between. There is a hint of your father’s looks in your face, but it blends with a hint of your mother’s looks, too, and yet is not the same as your sister’s.

Welcome to pleiotropy and pluralism. Your looks are affected not by a single “looks” gene but by lots of them—and by nongenetic factors as well, with fashion and free will figuring prominently among them. Asthma is another good example of these muddy genetic waters. As a disease, it is not very clear-cut and certainly not genetic in the usual sense. In fact, it has proved maddeningly resistant to simplification. Everything about it screams pleiotropy—a technical term for the multiple effects of multiple genes.

Nearly every statement we might care to make about asthma can be challenged, including the assertion that it is getting worse. One study says that asthma incidence has grown by 60 percent in the past ten years and that asthma mortality has trebled. Another study, published just a few months later, claims with equal confidence that the increase is illusory; according to this argument, people are more aware of asthma, more ready to go to the doctor with mild cases, and more prepared to define as asthma something that would once have been called a cold.

Still, the probability is that asthma and allergy problems are getting worse and that the cause is, in a word, pollution. But what kind of pollution? Most of us inhale far less smoke than our ancestors did, with their wood fires and poorly constructed chimneys, so it seems unlikely that ambient smoke can have caused the recent increase. Some modern, synthetic chemicals can cause dramatic and dangerous attacks of asthma. Transported about the countryside in tankers, used in the manufacture of plastics, and leaking into the air we breathe, chemicals such as isocyanates, trimellitic anhydride, and phthalic anhydride are a new form of pollution and a possible cause of asthma. When one tanker overturned, spilling its load of toluene disocyanate on a U.S. highway, it turned the police officers who directed traffic around the wreck into chronic asthmatics. Yet there is a difference between exposure to pollutants at acute, concentrated levels and at the normal levels encountered in everyday life. So far, no link has been found between asthma and low-level exposure to such chemicals. Indeed, asthma appears in communities that have never encountered them.

There are more than 250 defined causes of occupational asthma, and the list of asthma triggers compiled by the American Lung Association covers substances and factors occurring in all walks of life: pollen, feathers, molds, foods, colds, stress, vigorous exercise, cold air, plastics, metal vapors, wood, car exhaust, cigarette smoke, paint, sprays, aspirin, heart drugs—even, in one kind of asthma, sleep. But by far the most common asthma trigger— accounting for about half of all cases—is the humble dust mite’s droppings. Microscopic arachnids, dust mites are creatures that benefit from our fondness for centrally heated indoor winter stuffi-
ness, and make their home in carpets and bedding.

There is material here for anybody to grind any axe. One theory holds that people who wash too much as children or who encounter less dirt in everyday life are more likely to become asthmatic: that hygiene, not lack of it, is the problem. In a study of 14,000 children near Bristol, in Britain, it emerged that those who washed their hands five times a day or more and bathed twice a day stood a 25 percent chance of having asthma, while those who washed their hands less than three times a day and bathed every other day had slightly over half that risk of asthma. The theory is that dirt contains bacteria, especially mycobacteria, which stimulate one part of the immune system, whereas routine

**AIR QUALITY** As early as the 1870s, investigators were connecting asthma with airborne particles. Subsequent research has linked the disorder with dust mites, cockroach body parts, animal dander, molds, pollen, and fungi, as well as with smoke, ozone, nitrogen dioxide (the brown in smog), and other particles from fuel combustion. Recently, several molecular studies showed that fumes from household cleaners and industrial chemical waste are also asthma triggers. Nonetheless, the connection between air quality and asthma remains elusive: a major 1992 German study showed that the highly polluted city of Leipzig had a lower incidence of asthma than did cleaner Munich.

vaccinations stimulate a different part. Since these two parts (the Th1 cells and Th2 cells, respectively) normally inhibit each other, the modern, sanitized, disinfected, and vaccinated child is bequeathed a hyperactive Th2 system, which is specially designed to flush parasites from the wall of the gut with a massive release of histamines—hence hay fever, asthma, and eczema. Our immune systems, the theory goes, are set up in such a way that they “expect” to be educated by soil mycobacteria early in childhood; when they are not, the result is an unbalanced system prone to allergy. More than one study supports this theory. Asthmatic attacks can be staved off in mice that have been made allergic to egg-white proteins by the simple remedy of forcing them to inhale mycobacteria. Among Japanese schoolchildren, all of whom receive the BCG tuberculosis vaccine (a dose of weakened Mycobacterium tuberculosis) but only 60 percent of whom become immune as a result, the immune ones are much less likely to develop allergies and asthma than are the nonimmune ones. This may imply that giving the Th1 cells some stimulation with a my-
cobacterial inoculation triggers the suppression of asthmatic effects. The message here seems to be that we should throw away those bottle sterilizers and seek out mycobacteria.

Another, somewhat similar, theory holds that asthma is the unleashed frustration of the worm-fighting element in the immune system. Back in the Stone Age (or the Middle Ages, for that matter), the immunoglobulin E (IgE) system had its hands full fighting off roundworms, tapeworms, hookworms, and flukes; it had no time for being precious about dust mites and cat hair. Today it is kept less busy and gets up to mischief instead.

A related hypothesis is that asthma’s connection with urbanization is actually a connection with prosperity—wealthy people stay indoors, heat their houses, and sleep on feather pillows infested with dust mites. Yet another theory is based on the undoubted fact that mild, casual-contact viral infections (such as the common cold) are increasingly common in societies with rapid transport and compulsory education. There is a definite connection between childhood infection with mild viruses—such as respiratory syncitial virus—and asthma susceptibility. Schoolchildren harvest new viruses from the playground at an alarming rate, as every parent knows. When nobody traveled much, the supply of new microbes soon ran out, but today, with people jetting off to foreign lands or meeting strangers at work all the time, parents pick up and pass along an endless supply to their children, who then sample one another’s viruses at the saliva-rich, germ-amplifying stations we call primary schools. More than 200 different kinds of viruses can cause what is known as the common cold. A theory now in vogue holds that chlamydia—a bacterial infection that causes nonspecific urethritis in women and in men, as well as pelvic inflammatory disease in women, and is becoming more common at roughly the same rate as asthma—may set up the immune system in such a way that it responds aggressively to allergens in later life.

Take your pick. My favorite theory, for what it’s worth, is the hygiene hypothesis, though I wouldn’t go to the stake for it. But one thing is for sure: we cannot argue that asthma is on the increase because “asthma genes” are on the increase. The genes could not have changed that quickly.

So why do so many scientists persist in emphasizing that asthma is at least partly a genetic disease? What do they mean? Asthma is a constriction of the airways. It is triggered by histamines, which are in
turn released by mast cells, whose transformation is triggered by their IgE proteins, whose activation is caused by the arrival of the very molecule to which they have been sensitized. It is, as biological chains of cause and effect go, a fairly simple concatenation of events. The multiplicity of causes is brought about by the design of IgE, a protein that comes in many forms, any one of which can fit onto almost any foreign molecule or allergen. Although one person’s asthma may be triggered by dust mites and another’s may be triggered by coffee beans, the underlying mechanism is still the same: the activation of the IgE system.

Where there are simple chains of biochemical events, there are genes. Every protein in the chain is made by a gene (or, in the case of IgE, two genes). Some people are born with, or develop, immuno-

**GENES, GENES, GENES** In 1989 William Cookson, of Oxford University’s Wellcome Trust Centre for Human Genetics, and other researchers identified a gene on chromosome 11 that controls the immunoglobulin E response, a component of asthma. This was the first of several genes to be associated with the disorder.

Several recent studies have revealed genes on chromosomes 2, 5, 6, 12, and 13 that are strongly connected specifically with asthma susceptibility. Other asthma-related genes have been found on chromosomes 14, 16, and (again) 11.

That asthma has a genetic component is dramatically illustrated by the residents of Tristan da Cunha, an island in the mid-Atlantic. Despite the virtual absence of pollutants and allergens there, fully one-third of the population of about 300 are asthma sufferers. Historical records reveal that three of the island’s original fifteen settlers had the condition. Efforts to locate a specific group of “asthma genes” within this community are under way.

 logical hair-triggers, presumably because their genes are subtly different from those of other people, thanks to certain mutations. That much is clear from the fact that asthma tends to run in families (a fact known, incidentally, to Maimonides, the twelfth-century Jewish sage). In some places, by accidents of history, asthma mutations are unusually frequent. One such place is the isolated mid-Atlantic island of Tristan da Cunha, whose asthma-susceptible inhabitants are descendants of a few settlers who had the disorder. Despite a fine maritime climate, more than 30 percent of the inhabitants have overt symptoms of asthma. In 1997, seeking the mutations responsible for this state of affairs, a group of geneticists funded by a biotechnology
company made the long sea voyage to the island and collected the blood of 270 of the 300 islanders.

To find those mutant genes would be to find the prime cause of the underlying mechanism of asthma and, with it, all sorts of possibilities for a cure. Although hygiene or dust mites can explain why asthma is increasing on average, only differences in genes may explain why one person in a family gets asthma and another does not. But with asthma, it is not obvious (as it is with, say, sickle-cell anemia) that one version of the gene is “normal” and the other “abnormal.” Back in the Stone Age, before feather pillows, an immune system that fired off at dust mites was no handicap, because dust mites were not a pressing problem in a temporary hunting camp on the savanna. And if that same sensitive IgE system was also especially good at killing gut worms, then the individuals who were (even theoretically) vulnerable to asthma would be the normal ones, and the abnormal (or mutant) individuals would be those who were vulnerable to worm infestations.

In the late 1980s, off went various groups of scientists in confident pursuit of the “asthma gene.” By mid-1998, they had found not one but fifteen. There were eight candidate genes on chromosome 5 alone, two each on chromosomes 6 and 12, and one on each of chromosomes 11, 13, and 14. This list doesn’t even include the two genes on chromosome 1 involved in making parts of IgE, the molecule at the center of all allergic processes. The genetics of asthma could be underwritten by all of these genes in varying orders of importance or by any combination of them—and by others, too.

Each gene has its champion, and feelings run high. William Cookson, an Oxford University geneticist, has described how his rivals reacted to his discovery of a link between asthma susceptibility and a marker on chromosome 11. Some were congratulatory. Others, usually on the basis of flawed or
small sample sizes, rushed into print to contradict him. One wrote haughty editorials in medical journals, mocking his “logical disjunctions” and “Oxfordshire genes.” One or two turned vitriolic in their public criticism, and one anonymously accused him of fraud. (To the outside world, the sheer nastiness of scientific feuds often comes as something of a surprise; by contrast, politics is a relatively polite affair.)

This is the reality of gene hunting. There is a tendency among ivory-towered moralists to disparage some geneticists as gold diggers seeking fame and fortune. The whole notion of “genes for” such things as alcoholism and schizophrenia has been mocked because such claims have often been retracted, and the retractions are taken not as evidence against this or that specific genetic link but as a reason to condemn altogether the practice of seeking genetic links. Yet anybody who discovers evidence of a link between a disease and a gene has a duty to publish it, even though the simplistic headlines used in the media to announce it can be very misleading. If the connection proves illusory, little harm is done. Arguably, more damage has been done by false negatives (reliance on inadequate data to prematurely rule out important genetic links) than by false positives (suspicions of a link that later prove unfounded).

Cookson and his colleagues eventually got their gene and pinned down a mutation within it that the asthmatics in their sample carried more often than the nonasthmatics did. It was an asthma gene of sorts. But it accounted for only 15 percent of the explanation of asthma, and the finding has proved remarkably hard to replicate in other subjects—a maddening feature of asthma-gene hunting that has recurred with distressing frequency. By 1994 one of Cookson’s rivals, David Marsh, was suggesting a strong link between asthma and the gene for interleukin 4, on chromosome 5, based on a study of eleven Amish families. That, too, proved hard to replicate, and by 1997 a group of Finnish researchers was comprehensively ruling out a connection between asthma and this gene. The same year, scientists studying a mixed-race population in the United States concluded that eleven chromosomal regions, of which ten were unique to only one racial or ethnic group, could be linked to susceptibility to asthma. In other words, the gene that most defined susceptibility to asthma in blacks was not the same gene that most defined susceptibility to asthma in whites, nor was it the
one that most defined susceptibility to asthma in Hispanics.

Gender differences are just as pronounced as racial ones. According to research by the American Lung Association, whereas ozone from gasoline-burning cars triggers asthma in men, particulates from diesel engines are more likely to trigger asthma in women. As a rule (although rules have exceptions, of course, including the rule that rules have exceptions), males seem to undergo an early bout of asthma and then to outgrow it, while females develop asthma in their mid- or late twenties and do not outgrow it. This could explain something peculiar about asthma inheritance: people often appear to inherit it from mothers but rarely from fathers. However, this could simply mean that the father’s asthma had occurred in his youth and been largely forgotten.

The trouble seems to be that there are so many ways of altering the body’s sensitivity to asthma triggers (at so many points along the chain of reactions leading to the symptoms) that even though all sorts of genes may be “asthma genes,” no single one can explain more than a handful of cases. ADRB2, for example, lies on the long arm of chromosome 5. It is the recipe for a protein called the beta 2 adrenergic receptor, which controls bronchodilation and bronchoconstriction, or tightening of the airways—the main symptom of asthma. The commonest antiasthma drugs work by attacking this receptor. A mutation in ADRB2 might make it a prime “asthma gene.” First pinned down in a study of cells derived from the Chinese hamster, the gene is a fairly routine, 1,239-letter recipe of DNA. In another study, this one done on humans, a promising difference between some severe nocturnal asthmatics and some nonnocturnal asthmatics soon

**IMMUNIZATION** In 1996 Taro Shirakawa and Julian Hopkin, of the Churchill Hospital in Oxford, England, and several colleagues studied 867 Japanese schoolchildren who had received the BCG vaccine (a dose of weakened *Mycobacterium tuberculosis*) in early childhood. The children with the strongest immune response to subsequent tuberculin skin tests turned out to be the least likely to have asthma. Shirakawa and Hopkin suggest that the bacteria in the BCG vaccine induce the kind of T-cell response that not only fends off the invading pathogen but also suppresses overreactions to airborne particles, such as dust and pollen. Exposure to cold viruses and other respiratory pathogens, the scientists maintain, may accomplish the same task.
emerged: letter number 46 of ADRB2 was G instead of A. But the result was far from conclusive. Approximately 80 percent of the nocturnal asthmatics, but only 52 percent of the nonnocturnal asthmatics, had a G in that position. The study suggested that this difference was sufficient to prevent the damping down of the immune system that usually occurs at night in nocturnal asthmatics.

But nocturnal asthmatics are a small minority. To muddy the waters further, the very same “spelling” difference has since been linked to a different asthmatic problem: resistance to asthma drugs. People who have a G in position 46 of the same gene on both copies of chromosome 5 are more likely to find that their asthma drugs (such as formoterol) gradually become ineffective over a period of weeks or months than are people with an A on both copies.

**HYGIENE** Building on a hypothesis first proposed in 1989 by David Strachan, an epidemiologist at Saint George’s Hospital in London, two researchers at the University College London medical school—Graham Rook and John Stanford—suggested in 1998 that excessive cleanliness may be the main factor in the rise in asthma. To achieve a balance between the body’s two main T-cell responses, they argue, the immune system must be constantly “primed” with small doses of germs throughout childhood. In industrial societies, the general elimination of once-common human parasites such as the tapeworm, combined with an obsession with antibacterial products, may be biasing the immune system toward allergy.

“More likely,” “probably,” “in some of”: this is hardly the language of determinism. The A-to-G change at position 46 on the ADRB2 gene plainly has something to do with asthma susceptibility, but ADRB2 cannot be called the “asthma gene,” nor can it be used to explain why asthma strikes some people and not others. It is at best a tiny part of the tale, applicable in a small minority of cases or having a small influence that is easily overridden by other factors.

We’d better get used to such indeterminacy. The more we delve into the genome, the less fatalistic it will seem. Gray indeterminacy, variable causality, and vague predisposition are the hallmarks of the system. The genome is as complicated and indeterminate as ordinary life because it is ordinary life. This should come as a relief. Simple determinism—whether of the genetic or the environmental kind—is a depressing prospect for those with a fondness for free will.
Crowded in with the rest of the midmorning passengers on Mumbai's commuter trains are the dabbawalas, men who convey heavy loads of metal lunch pails—dabbas—from their clients' home kitchens to the clients' workplaces in offices, mills, and factories. In this modern Indian metropolis of more than 15 million, formerly called Bombay, many workers go out for lunch, but others prefer traditional home-cooked meals—in part because different dietary precepts distinguish the many religious, ethnic, and caste groups that populate the city.

In addition to being or not being vegetarian, various groups observe prohibitions against eating certain spices, vegetables, and other foods, and they obey particular caste and kosherlike rules of ritual purity that govern the preparation of meals. As a consequence, the curries, breads, and rice dishes prepared by a mother, wife, or trusted cook will be pure, delicious, and familiar. In addition, home cooking enhances family relationships and is cheaper than restaurant food. Fixing a freshly cooked Indian meal is time consuming, however, and often the food is not ready until after a worker has left home for the day. Somehow the two have to connect at lunchtime. Enter the dabbawalas.

The business of delivering dabbas—also known as tiffins, from an Anglo-Indian word for "lunch"—began more than a century ago, reputedly at the request of a hungry English administrator. From small beginnings, spurred by enthusiastic Indian patronage, Mumbai's unique network of dabbawalas evolved. The profession includes some 3,000 deliverymen and 2,000 supervisors; the latter acquire rights to a collecting territory, pay monthly
Story by Doranne Jacobson ~ Photographs by Kadir van Lohuizen
salaries and expenses, and coordinate the operation. Together these 5,000 men see to the delivery of more than 100,000 lunches daily.

Each carrier is responsible for a particular section of a route and is part of a relay team of at least four members. By following a code of colorful symbols painted on the lunch pails, the largely illiterate dabbawalas can transport meals from outlying neighborhoods to the commercial zones precisely at lunchtime and later collect the owners’ empty tiffins for delivery back home. The service costs the clients, who range from mill hands to government servants and corporate executives, less than $10 per month (some parents use the service for schoolchildren, too). For hauling the huge wooden trays or pushing the carts laden with dabbas, a carrier earns about $100 per month.

Dabbawalas are extremely proud of their reliability: lunches are rarely late or lost. The entire system depends on each carrier being unfailingly present and punctual—a rarity in much of traditional India. Trust and cooperation are essential. The tiffin carriers belong to a union, which helps settle grievances among members or between members and clients. But perhaps most important to the success of this complex network is the way dabbawalas are linked through kinship and religion.

Virtually all are migrants from rural villages near the city of Pune, eighty miles southeast of Mumbai, and obtain their jobs and learn the trade through family ties. They wear the traditional white cap and clothing of their region. In “Mumbai’s Dabbawalla: Omnipresent Worker and Absent City-Dweller,” an article in the March 29, 1997, issue of Mumbai’s Economic and Political Weekly, French researcher Alexandra Quien explains that the carriers identify themselves as Marathas, a Hindu group with a martial heritage, and their names suggest roots in the Kunbi agricultural caste. Their families—often poor—remain in the villages, and the dabbawalas’ earnings help support them and finance the expansion of their farms. The tiffin carriers visit their home villages frequently and usually retire there.
As a homeless woman sleeps, empty dabbas are sorted at the train station, left, for their homeward journey. Transport and distribution of the dabbas depends on relay teams of dabbawalas, or tiffin carriers, below, who may consume any uneaten lunches.

The dabbawalas’ identity and sense of purpose, Quien has observed, is also shaped by reverence for the thirteenth-century poet-saint Jnaneshwar and by membership in a sect devoted to the Hindu deity Vithoba, a form of Vishnu. The tiffin carriers have endowed pilgrims’ rest houses at several sites sacred to their sect and wear a rosary signifying dedication to their way of life. On a rare break from their arduous work, a group of dabbawalas may travel together on a religious pilgrimage.

Changes in eating habits and an increase in women’s employment, as well as traffic jams and rising costs, threaten to undermine the tiffin carriers’ livelihood. But for now the dabbawalas remain an essential fixture of daily life in Mumbai.
SECRETS OF THE FLOODED FOREST

Where do Amazonia’s top aquatic predators nest?
Scientists find the hidden nurseries of black caiman.

By John Thorbjarnarson and Ronis Da Silveira ~ Photographs by Luiz Claudio Marigo

“It is scarcely exaggerating to say that the waters of the Solimões are as well stocked with large alligators in the dry season as a ditch in England is in summer with tadpoles,” wrote Henry Walter Bates in 1863. A British naturalist, Bates was astonished by the abundance of “alligators”—or black caiman—particularly in western Brazil, where the Amazon River is referred to as the Solimões (Bates’s Solimões). For more than four years, Bates lived in the sleepy village of Ega, now called Tefé, and observed the natural history of the region, including the habits of the area’s top predator, the black caiman.

During the mid-twentieth century, the black caiman became the target of intensive commercial skin hunting and in the 1970s was declared endangered. With the cessation of hunting, black
caiman have made a comeback in some areas. Today the largest known population resides in the Mamirauá Reserve, just upstream from Bates's old haunts. A complex of islands at the confluence of the Amazon and Japurá Rivers, the reserve encompasses 2.7 million acres of forest, lakes, marshes, streams, and river channels. Yet every year the distinct features of the landscape are largely submerged, for this is the land of the flooded forest, or varzea, that borders the white-water rivers of the Amazon basin. Water ebbs in September and October and begins to rise in November and December, reaching its annual peak in June. During an average year, the water level in the reserve can rise thirty to forty feet.

In the varzea and in other Amazon aquatic lowlands where they are numerous, black caiman have probably long played an important ecological role. Yet little was known about the natural history of this large reptile—and in particular about its nesting habits in the varzea—when we began to study it in 1993. We have found the Mamirauá Reserve, which was first established in 1990 (see p. 75), to be the ideal location for our work. Here the eminently practical solution both for staying dry and for doing research is to live in a floating house, or flutuante, built on massive logs from the spiny-trunked asacú trees common in the varzea. Our project's buoyant house, named the Cauaçu, after a local palm, is situated in Lake Mamirauá, one of the largest lakes in the reserve. We rope the house to trees along the shore to prevent it from drifting away when we are buffeted by strong winds during the area's frequent tempests.

When the Amazon is high, the reserve is a water world where the trunks of trees disappear into dark depths that are home to freshwater dolphins, more than a hundred species of fish, and the occasional Amazon manatee, as well as black caiman. Caiman belong to the group known as crocodilians, which also includes alligators and crocodiles. Black caiman are slightly larger than American alligators—adult males reach lengths of seventeen feet—but they are not easy to spot from our floating station at this time of year, being widely dispersed throughout the flooded forest. Using an old hunter's trick, however, we imitate the caiman's calls and find that they reveal themselves by bellowing in return, at times in an impressive chorus of voices that emanate from the surrounding forest. Later, during the height of the dry season, the tree trunks emerge from the water, and the lakes and streams take shape. Caiman from nearby areas concentrate in the upper end of Lake Mamirauá, which takes on a primeval look as thousands of black caiman rub shoulders. In some areas the eyeshines that reflect our headlamps are so numerous that they resemble the distant lights of a modern metropolis—a startling sight in the black Amazonian night.

We knew that black caiman needed dry land near the water's edge for nesting and that, like alligators, they laid their eggs in mounds of decaying vegetation scraped together by the female. So dur-

Motors defend the nests against most animal predators, but only the boldest 2 or 3 percent dare take a stand against humans.

ing our first year in Mamirauá, we began looking for nests, during the dry season, in the most logical place we could think of—the forested banks that line many streams in the reserve. These are some of the park's most elevated areas and are flooded for only one to two months at a time. We thought they would offer female caiman the best chance of keeping eggs safe from rising water during the two to three months of incubation.

But the nests we found along the stream banks
were those of a smaller species, the spectacled caiman. Situated in the dense shade of the trees, the nests were occasionally as much as several hundred yards from any permanent water source. We would sometimes also discover a four- to five-foot-long female not far from the nest, hidden under leaves or wedged beneath a fallen log. Many of the nest mounds had been opened by predators, and in some areas, half the nests had been lost to egg-raiding animals. We were surprised by this finding; the entire reserve constitutes a group of islands even when not flooded and is thus an inhospitable place for the usual caiman-egg predators, such as raccoons and foxes. Some nests had clearly been raided by tegus—large black-and-white lizards common in the reserve—and jaguar footprints and scratch marks on trees near nests implicated the big cats as well. Typical jaguar prey (including agouti, deer, peccary, and tapirs) are not found on the varzea islands, so during at least part of the year, the jaguars turn to caiman eggs and, in some cases, we discovered, to the nesting females themselves.

Black caiman nests, however, remained a mystery. It was not until we started working with local fishermen who knew their way into some of the most inaccessible lakes that we hit the mother lode of black caiman nesting sites. To reach some of these lakes, we spent hours paddling or poling up vegetation-choked streams, or dragging a canoe through the forest that separates the lakes from the

Opposite page: A hatchling is marked for identification. After much vocalizing within the leathery confines of its egg, a black caiman breaks out. Above: An unusually bellicose female guards her nest of newborns.
main rivers and channels. Some of the lakes are full of the floating mats common in the varzea. These range from flimsy "floating meadows" of intertwined grass to thick rafts of peatlike material that often support rooted trees and are likely to support nests as well. While we found some black caiman nests on the mats, most were on land, within two or three feet of the lake's edge.

Black caiman appear to be more selective about where they nest than their spectacled cousins are. The edges of Lago Sarapaio, a small forest lake, were home to many nests, while the perimeter of Lago Samaumeirinha, a very similar lake in many respects, had none. On our first excursion to the lakes, while paddling and portaging between the two, we noticed that the water level of Lago Sarapaio, judging by vegetation and water marks, appeared to have been static over the previous few weeks. On Lago Samaumeirinha, in contrast, we found evidence that the water level had dropped about two and a half feet just in the preceding few days.

While much of the Amazon floodplain appears

An aerial view of western Brazil's flooded forest
to be a flat, monotonous landscape, we found that by virtue of slight topographical differences, the water levels of certain lakes are decoupled from that of the Amazon River, with its great yearly oscillations. These lakes are to some degree raised or “perched,” and their water levels are determined by the height of the surrounding land and by the streams that lead from the lakes into the main Amazon. From October through December, as the river falls and then rises, water levels in perched lakes can remain high—up to thirteen feet higher than the

More Than a River View

The Mamirauá Reserve is the brainchild of J. Márcio Ayres, a biologist for the Wildlife Conservation Society in New York who first went to the várzea of Brazil in 1983 to study a unique species of monkey, the white uakari (see “Scarlet Faces of the Amazon,” Natural History, March 1990). While living in the flooded forest, Ayres recognized the singular character of the region and also witnessed the rapid loss of its resources to commercial fishing, logging, and other human enterprises, largely launched from outside the area.

As a result of Ayres’s work, the Mamirauá area was first given regional protection in 1990 and in 1996 became the first Sustainable Development Reserve in Brazil. Some 10,000 people live in and around Mamirauá and depend on this part of the flooded forest for their daily needs; they fish, hunt, or plant a variety of seasonal crops on the higher ground. More than 100,000 other users indirectly depend on Mamirauá for fish or other products. Ayres’s approach has been to inform local communities of the results of scientific research and to collaborate with them in making decisions to ensure that their activities benefit both people and wildlife. By limiting commercial fishing, Mamirauá is now famous for an abundance of fish that are becoming rare elsewhere.

The reserve also offers visitors unmatched opportunities to see Amazonian wildlife, including freshwater dolphins; sloths; uakari, howler, and squirrel monkeys; macaws, kingfishers, herons, and many other birds; and, of course, caiman. A source of income for residents of the reserve is a tourist lodge on a floating house near Mamirauá Lake.

Ayres’s efforts to protect central Amazonia continue to bear fruit. In 1998, in an area contiguous with the reserve, Amaná Sustainable Development Reserve was created. This new reserve links Mamirauá with Jauí National Park. Together these tracts form the world’s largest block of protected tropical forest, covering an area larger than that of Costa Rica.—J.T.

For information on the Mamirauá Reserve, go to www.cnpq.br/namiraua/namiraua2.htm.
Amazon at its lowest—and also stay relatively constant. The perched lakes make ideal nesting areas for black caiman because they allow females to build their nests right along the edge of the water. Brief periods of intense rainfall can temporarily raise water levels, but they usually return to normal after a few days, and caiman eggs appear to be highly resistant to occasional flooding.

Since 1993 we have found many more of the small, hard-to-reach, vegetation-clogged lakes that serve as the breeding nuclei of black caiman in the Mamirauá area. They are always full of the reptiles. Once we understood the hydrology of the preferred nesting sites, we set out to gather information on black caiman numbers and habits. While mothers defend the nests against animal predators, only the most aggressive 2 or 3 percent dare take a stand against humans. Even so, counting the eggs in a caiman nest does require a bit of caution. Nest predators are the same as for spectacled caiman, the top three being tegu lizards, jaguars, and humans (who collect the eggs for consumption). Jaguars, however, appear not to prey upon black caiman females, which can grow to almost double the length of their spectacled counterparts. And while spectacled mothers hide out near nests on land, black caiman females station themselves near nests but in the water.

The average black caiman clutch consists of thirty to thirty-five eggs that incubate in the warm mounds and usually hatch within eighty-five to ninety days. Eggs are less apt to be guarded than are new hatchlings. For the first few months of their lives, young caiman nest mates stay together and are watched over by the female. At this stage, they eat mostly insects and other aquatic invertebrates. As they grow, their diet shifts to include more vertebrate fare, including fish, some birds, turtles, and even other young caiman (both black and spectacled). We believe most young stay in their home lakes for two or three years before moving out.

We learned that black caiman have one nesting season annually but that not all females nest every year. On average, a female will nest every two to three years. During the past three years, we have radiotagged eleven females to keep track of their whereabouts year-round. We have found that even when not nesting, females still spend most of their time in the nesting lake, moving only a short distance into the forest during the high-water period.

Staying afloat in the flooded forest takes varied forms: residents of Mamirauá’s Jarauá village, top left; Amazon water lily, bottom left; and black caiman in Lake Mamirauá, above.
Males, which do not tend eggs or young, usually disperse farther afield.

Black caiman appear to have a social hierarchy. While most adult males do not breed but live a reproductively marginal existence in the less remote streams and lakes, such as Lake Mamirauá, where there are no nests, dominant males maintain territories in the nesting lakes, where they have access to females. These animals are usually the biggest and oldest—and also the wariest. Survivors of the era of widespread hide hunting that was most intense from 1950 to 1970, they avoid the prying eyes of hunters and researchers. Our closest encounters with these savvy males have taken place when we accidentally stepped on their backs as we hopped across the floating mats to reach nests. On these occasions, both parties beat a rapid retreat and sought to avoid any conflict.

Caiman numbers have rebounded in the thirty years since commercial hunting was prohibited in 1968. That industry, which primarily enriched people who did not live in the region, decimated the reptile’s numbers. Today, although caiman hunting is illegal in Brazil, both spectacled and black caiman are taken for meat and are an economic mainstay for many permanent native inhabitants of the Mamirauá Reserve. A vital part of our research involves finding out how this smaller-scale but widespread hunting affects caiman populations. The situation is complex, but basically our conservation goal is to control illegal hunting and possibly replace it with a managed, legal hunt that would maintain healthy caiman numbers and also benefit the people who have inhabited the varzea and lived during the flood season, the water level rises thirty to forty feet. The varzea becomes an aquatic world where trunks of trees disappear into dark depths.
with and hunted these creatures for centuries.

Toward this end, we are investigating the population ecology of both black and spectacled caiman and have started what is called a mark-recapture project. We use a little motorboat to search for the crocodilians at night, when they are active. With long-handled tongs we grab relatively small ones, and we catch larger ones by slipping a noose on a pole over their heads. After it struggles a bit, a captured caiman will tire, and we close the mouth with tape or rubber bands and pull the subdued beast into the boat or, if it is hefty, haul it onto land or the floating house. We place a metal tag in the toe webbing on a rear foot and clip a unique pattern into the scales of its tail. Within ten to twenty minutes of capture, the animal is released, equipped to do its part for conservation biology. Over time, these identifiable caiman will provide information

On occasion, we have accidentally stepped on the backs of dominant male caiman as we hopped across floating mats of vegetation to reach nests.

on growth rates, density of population in different habitats, and numbers according to size.

Even after five years of intensive study, we have no firm estimates of overall numbers. Mamirauá harbors the largest known population of black caiman in the world, but the nature of the habitat hinders a full count; we see only a fraction of the total. Yet more and more young are hatching, and as the perched lakes become saturated, young black caiman are dispersing into the surrounding areas and will eventually fill the Amazon River itself during the dry season, just as they did when Bates observed them more than a century ago. While caiman are certainly not as numerous as they were in Bates's time, we can safely say that the population in the reserve is growing. The species also appears to be holding its own in parts of French Guiana and Guyana and throughout the lowland Amazon basin in Colombia, Peru, Ecuador, and Bolivia.

The nursery lakes, by virtue of their hydrology and the surrounding forest, buffer the black caiman against the vagaries of the level of the Amazon River and from the worst impacts of an ever-expanding human presence in the region. If Mamirauá is any indication, black caiman may once again reign as the monarchs of the flooded forest.
Beasts and Brain Power

Specializations do not make one species "smarter" than another, but they do make for uniquely sculpted minds.

Do animals think? And if they do, how similar are their thoughts to our own? Traditionally, scientists have taken two approaches to cognition in animals, with the "liberals" (often those who study wild animals) arguing that there are clear parallels between animal and human thinking and the "skeptics" (often those who focus on captive animals) defending the uniqueness of the human mind. Harvard psychologist Marc Hauser is in an ideal position to evaluate the nuances of both positions, because in addition to observing and running experiments on cotton-top tamarins in the lab, he has studied vervet monkeys in the Kenyan savanna, chimpanzees in a Ugandan rainforest, rhesus monkeys on a Caribbean island, and crows on a California golf course. Plus he knows and lucidly cites the work of the evolutionary biologists, ethologists, neuroscientists, developmental psychologists, and cognitive scientists who have contributed to this burgeoning field.

Hauser introduces us to an extraordinary range of feats of cognition by animals—from the New Caledonian crow, which constructs and modifies tools, to Clark's nutcracker, which uses its extraordinary spatial memory to locate during the winter the 30,000 or so pine nuts that it stored during the fall. In this thoughtful book, Hauser gives evidence to support both the skeptical and the liberal camp. Believing that language is unnecessary for certain kinds of animal cognition, and that we must look at the environments in which animals evolved to understand what they think and feel, he concludes, "We share the planet with thinking animals."

All animals, according to Hauser, have the mental tools for three distinct tasks: recognizing objects, evaluating quantity, and navigation. But how do we know that animals universally possess these capacities, and how do these abilities expand or contract in particular species? In experiments with tamarins and macaques, Hauser adapted a technique used by developmental psychologists to show that preverbal infants understand cause and effect, are able to discriminate quantity, and know that objects exist even when they can't be seen. Like infants, Hauser's monkeys show little interest when two toys are lowered behind a screen and the same two toys are revealed when the screen is raised. But both monkeys and infants demonstrate that they know when the number has changed: if there is only one toy or if there are two different toys when the screen is raised, both look longer at the scene.

Other cognitive abilities appear to be restricted to a few species. Great apes that encounter mirrors demonstrate self-awareness. If a researcher surreptitiously places a mark on a part of the ape's face that it can see only by using the mirror, some of these animals react by immediately grooming the spot, suggesting that they recognize...
Digital Earth

I have always loved maps in all their forms. Globes are especially nice because they show the world without the distortion that comes from flattening it. While I still prefer the kind I can spin with my hand, some of the Internet’s three-dimensional representations of our planet display information that you won’t get from old globes, with their outdated political boundaries.

The Great Globe Gallery (hum.anu.edu.pl/~zbzw/glob/glob1.htm) gathers together a remarkable number of globes and world maps, although most of the images lack proper captions. Exploring the whole gallery takes time, but finding images that show the planet in new ways is worth the effort. Click on any of the hundreds of gallery choices, and you’ll be linked to the site where they originated. I particularly liked the “Atlas of Cyberspaces,” which shows how the planet is wired, and “Breathing Earth,” an interesting animation showing the global occurrence of earthquakes.

For map lovers, a wonderful new site called TopoZone (www.topozone.com) offers U.S. Geological Survey topographic maps (adjustable to different scales) of any spot in the United States. You can search by latitude and longitude or by place name, but make sure to check Find Tips first, since place names must be put in the correct form. Before setting out on a weekend drive or hike, you can print out a map that shows every road and every rise and dip in the terrain. Although printed maps are undoubtedly nicer, the Internet versions are a lot easier to come by.

Robert Anderson is a freelance science writer based in Los Angeles.
BOOKSHELF

The Pepper Trail: History and Recipes From Around the World, by Jean Andrews (University of North Texas Press, 1999; $50; 261 pp.)
The dispersal of Capsicum peppers (of prehistoric Bolivian origin)—which accelerated when Columbus brought them back to Spain after his first voyage—has made them, after salt, probably the world’s most popular condiment. Andrews describes more than twenty-five species and offers recipes for such unlikely edibles as Arizona chile tepin ice cream, roasted bell-pepper mousse, and jalapeño truffles.

While examining the “lunatic fringe of the orchid world,” Hansen exposes the failure of the 1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) to protect orchids. Along the way, the reader is treated to a dazzling array of facts and lore on a plant family encompassing some 25,000 naturally occurring species and 100,000 artificial hybrids, some of which are used in products ranging from ice cream and aphrodisiacs to pig feed, adhesives, and medicine for sick elephants.

Brother Astronomer: Adventures of a Vatican Scientist, by Brother Guy Consolmagno (McGraw-Hill, 2000; $24.95; 256 pp.)
An American baby boomer of Italian and Irish ancestry, Consolmagno worked as a planetary scientist at MIT, spent two years in Kenya in the Peace Corps, and taught physics at Lafayette College before joining the Jesuits at the age of thirty-seven and becoming curator of the Vatican Observatory’s collection of some 1,000 meteorites. The book mingles memoir with theology and science and includes a particularly memorable chapter on meteorite hunting in Antarctica.

Rare Earth: Why Complex Life Is Uncommon in the Universe, by Peter Douglas Ward and Donald Brownlee (Copernicus, 2000; $27.50; 333 pp.)
Basing their theory on, among other things, Earth’s unique features and conditions, paleontologist Ward and astronomer Brownlee believe that microbial life-forms probably permeate the galaxies but that complex life may exist almost nowhere.

Journey of the Pink Dolphins: An Amazon Quest, by Sy Montgomery (Simon and Schuster, 2000; $26; 317 pp.)
Weaving together legend and natural history, Montgomery lyrically portrays the Amazon’s freshwater dolphins, which are thought to descend from toothed whales that entered the river before the formation of the Andes interrupted the Amazon’s westward flow to the Pacific.

Tigers in the Snow, by Peter Matthiessen (North Point Press, 2000; $25; 169 pp.)

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PHOTOGRAPHY

Desert: The Mojave and Death Valley
Photographs by Jack Dykinga; text by Jay McClimans
(Harry N. Abrams, Inc., 1998; $49.50; 143 pp.)
Those who enjoyed *Dersu the Trapper*, a nineteenth-century tale of exploration in Russia's Far East, or Akira Kurosawa's film *Dersu Uzala*, can return to the coastal Sikhote-Alin Mountains—now a 1,340-square-mile wildlife reserve—via Matthiessen's report on the Siberian tiger. His account also touches on the fate of other tiger populations that once ranged from eastern Turkey to the Sea of Japan.

**Linnaeus: Nature and Nation**, by Lisbet Koerner (Harvard University Press, 1999; $39.95; 320 pp.)

The fame of Swedish botanist Carolus Linnaeus rests on the system of nomenclature for organisms that he began to develop in the 1730s. According to Harvard historian of science Koerner, Linnaeus was no visionary modernist but a provincial eccentric who, incorporating the mercantile ideas of his day, dreamed of somehow creating a tropical empire in Nordic climes.

The books in “Natural Selections” are usually available from the Museum Shop of the American Museum of Natural History, (212) 769-5150.

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Bob and Marie Bergh love to travel. Since their first trip with the Museum in the early 1980’s, they have participated in eight Discovery Tours, to destinations as diverse as the British Isles, the Black Sea, Scandinavia, the Caribbean, Greenland, Antarctica, the North Pole, the Middle East, India and Southeast Asia.

Exploring the world on Discovery Tours, Bob and Marie have become increasingly aware of the significance of the Museum's work. This is why they recently decided to provide for the Museum's future through a Charitable Gift Annuity.

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A Gift Annuity is a way to support the Museum and provide lifetime income to one or two people. When low-yield stock is used to fund the plan, capital gains tax is avoided. Marie offers a tip to Natural History readers: "We learned about the Museum's Gift Annuity program through this magazine, and we encourage you to find out about it, too!" Here are the sample rates and benefits for one person with a $10,000 gift:

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<th>Age</th>
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Kinship Envy
Musings on the ties of blood and marriage

By Meredith F. Small

On the left-hand side of the entrance to the African Peoples hall at the American Museum of Natural History is a small diorama that lacks the usual accoutrements of culture that a viewer might expect to see—no traditional costumes, no sacred items, no curious tools. Instead, it is a miniature model of an African village, laid out according to its kinship network. Garnished by a border of green forest, groups of tiny thatched huts are set together to form compounds, or extended households. Rising above them is an elaborate scaffolding of sticks, triangles, and circles representing individuals in the village and their relationships. Every time I visit the Museum, I drift toward this display, arrested by its simple but profound message about connections between people.

It looks complex from a distance, but up close and with a little time, a visitor can follow paths of individual relationships and eventually figure out the whole system. When lines of sticks are connected vertically, they show descent; double lines connected horizontally show marriage. In keeping with the traditional shorthand that anthropologists employ to trace kinship, males are shown as triangles and females as circles.

Immediately above each compound are the circles and triangles of the household—Mom, Dad, and the kids—colored red, blue, green, or yellow to distinguish lineage. Because descent in this village is patrilineal, offspring are the same color as Dad. Branching from the parents are lines that connect to other households across the clearing or that reach outside the village. It's striking to follow a few individuals through the maze and to see that by one route or another, everyone has connections throughout the village. What we don't see is how relatedness affects village society: how one woman helps another tend the field because their mothers are sisters or how two men exchange livestock because they have a common relative.

And those ties also affect marriage rules, which may be simple and general (such as marrying outside the village) or quite specific. Most common are cross-cousin matches (a daughter or son marrying the father's sister's or mother's brother's offspring) or parallel-cousin matches (a daughter or son marrying the father's brother's or mother's sister's offspring).

As the diorama illustrates in microcosm, humans have a long history of knowing and relying on others; knowing to whom we belong is inextricably linked to knowing who we are. And without the ties of kinship, we would be nothing more than a disconnected horde. But in Western culture, it is easy to forget the power of kinship. Our families are usually nuclear, and relatives beyond the ring of first cousins are virtual strangers. Frequently, young people dream of leaving their families behind and creating a new nuclear unit of their own. These days, knowing one's more distant relatives seems important only in the doctor's office: Any cancer in the family, or heart disease, or depression? Long-lost relatives become significant only after the doctor reconstructs a patient's pedigree and estimates the probability of death from a particular cause.

To compensate for this, I think we often imprint lines of kinship on friends and colleagues, transferring familial expectations onto those with whom we share time but not blood or genes or vows, so that we can have the experience of an extended family. Young people join gangs, older people join clubs, and even babies are put into play groups. Pushed by a culture that favors independence and self-reliance, the social animal in us nonetheless seeks connections, even if they are bloodless and fragile.

Perhaps the weakness of kinship ties in my own culture is what draws me to the diorama in the glass case. The title of the display is simply “Family,” but this hypothetical African village appears to be knit together more strongly than any family I know. And so, time and again on my visits to the Museum, I find myself standing before the diorama and feeling a bit envious as I trace the connections that belong to others.

Meredith F. Small is a writer and a professor of anthropology at Cornell University. She writes frequently for Natural History. Her latest book is Our Babies, Ourselves (Bantam Doubleday Dell, 1999).
EVENTS

MARCH 1
In the final talk of the 7:00 p.m. series “The Primal Feast: Food, Sex, Foraging, and Love,” Susan Allport, author of A Natural History of Parenting, focuses on foraging and food sharing among humans and other animals.

MARCH 2 AND 30
In the first of a series of five 7:00 p.m. lectures sponsored by Earthwatch Institute, archaeologist Christopher DeCorse talks about the medieval empire of Ghana’s coastal kingdoms and their trading cultures. In the second, biologist Rolf Peterson discusses his long-term studies of wolves and moose on Lake Superior’s Isle Royale. Both talks are at 7:00 p.m.

MARCH 3, 4, AND 5
In conjunction with the body art exhibition, the Kunjy Opera Theatre presents the sixteenth-century opera The Peony Pavilion. For performance times, call (212) 769-5315.

MARCH 6
As part of the “Frontiers in Astrophysics” series, Mario Livio, of the Space Telescope Science Institute, gives a talk at 7:30 p.m. entitled “Beauty in Physics and Cosmology.”

MARCH 8
At 7:00 p.m., Niles Eldredge, curator of invertebrates in the Museum’s Division of Paleontology, gives a talk entitled “Field Guide to the Sixth Extinction,” about the value of—and increasing loss of—biodiversity.

MARCH 9
Natural history writer Sy Montgomery, in a slide-illustrated talk at 7:00 p.m., discusses her four expeditions to the Amazon River to study freshwater dolphins—the subject of her new book—Journey of the Pink Dolphins: An Amazon Quest.

MARCH 9, 16, 23, AND 30
The wetlands of eastern North America are the subject of a series of four talks at 7:00 p.m. by William Schiller, Museum botany lecturer. (He gives the same talks on four consecutive Mondays, at 2:30 p.m., starting March 13.)

MARCH 11
“Why Is the Earth Habitable?”—a 1:30 p.m. discussion led by Edmond A. Mathez, of the Museum’s Department of Earth and Planetary Sciences—is the last in a series by geologists and climatologists on issues explored in the new Gottesman Hall of Planet Earth.

MARCH 15 AND 22
“What’s New in Geology” is the subject of two 7:00 p.m. talks by Sidney S. Horenstein, the Museum’s Coordinator of Environmental Programs.

MARCH 18
Beginning at 10:30 a.m., panelists in a symposium entitled “The Changing World of Tattoo” discuss the cultural and social facets of the phenomenon in the United States. Call (212) 769-5176 for information.

MARCH 20
The seventieth annual James Arthur Lecture on the evolution of the human brain—“Do We Owe Our Intelligence to a Predatory Past?”—will be given at 6:00 p.m. by South African zoologist C. K. Brain, former director and currently emeritus curator of the Transvaal Museum in Pretoria.

MARCH 27
As part of the “Distinguished Authors in Astronomy” series, Thomas Gold, of Cornell University, gives a talk at 7:30 p.m. entitled “The Deep Hot Biosphere.”

MARCH 28
At 7:00 p.m., primatologist Birut Mija Galdikas and primate communication specialist Nancy Erickson Briggs talk about working with orangutans in Indonesia, as outlined in their book Orangutan Odyssey.

MARCH 29
David Hurst Thomas, curator in the Museum’s Division of Anthropology, discusses his new book, Skull Wars: Kennewick Man, Archaeology, and the Battle for Native American Identity, at 7:00 p.m.

DURING MARCH
The Interfaith Center of New York and the Museum have scheduled free presentations, panel discussions, workshops, and performances March 10–12 and 25–26 to explore youth violence and discuss strategies for collaboration and conflict resolution. Call (212) 769-5176 for information.

For the first three weekends in March, the Museum celebrates International Women’s History Month with the theme “Women Honoring Women.” For a complete schedule of free films, storytelling, lectures, and dance and music performances, call (212) 769-5315.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, call (212) 769-5100. Visit the Museum’s Web site at www.amnh.org.
Coming Out

An Arctic ground squirrel in Alaska surveys the thawing landscape from beneath a retreating snowbank—a sure sign of spring. Ranging from Alaska to the Hudson Bay area of northeastern Canada, the species is adapted to long, harsh winters, short growing seasons, permafrost, and limited cover. Active foragers in summer, these ground squirrels scour the terrain for berries, seeds, leaves, grasses, and tubers. But in fall they retreat to underground burrows, which they line with grasses and sedges, for a seven-month period of dormancy.

Males emerge in mid-April, when they establish territories that they defend against rivals. Females appear above ground shortly thereafter and take up residence in a male’s territory. A territorial male typically impregnates several females, and litters of six to eight young are born in early June.

Hibernators without peer, Arctic ground squirrels can withstand temperatures below 30°F for months at a time, to all appearances frozen solid. How they are able to survive without suffering extensive cell damage is a mystery that has long intrigued physiologists.—Richard Milner

Photograph by Michio Hoshino

Minden Pictures
The eminently adaptable polar bear has already survived many oscillations in the Arctic climate since its relatively recent evolution from the brown bear some half a million years ago. Recent climate studies in parts of the Arctic, however, suggest that a strong, long-term warming trend may be threatening its icy home.

By the breakup of sea ice each spring, the bears can no longer hunt and may come ashore to rest and fast for weeks or months, living off their stored fat. But in the Eurasian Arctic and in western Hudson Bay (although not in the eastern Canadian Arctic or in northern and eastern Hudson Bay), steadily rising spring air temperatures are causing the ice to break up about two weeks earlier than it did only two decades ago.

From 1981 through 1998, my colleagues and I monitored the condition and reproductive rates of adult polar bears, as well as the age of their cubs at weaning. We were able to tranquilize, collar, weigh, and generally evaluate individuals that had come ashore during the summer, after the sea ice had melted.

We found that the bears have been coming ashore in progressively poorer condition and that their birth rate has steadily decreased over the past two decades. In addition, cubs are staying longer with their mothers before being able to hunt seal pups on their own. The western Hudson Bay polar bear population is the only one known in which some cubs become independent at one and a half years (two and a half is the norm). But over the course of fifteen years, the proportion that matures early has declined from 40 percent to about 10 percent. Without their seal-hunting platforms, the bears have less time to accumulate fat. If the early-warming trend continues, the bears of western Hudson Bay will eventually disappear: they cannot move farther north because that habitat is already occupied.

But how secure are the northern populations of bears, especially those of the Eurasian Arctic, where the rate of climate change has been the greatest to date? Some recent research results are worrisome. One study found that since 1978, the ice cover in the circum-polar Arctic has fallen by about 3 percent per decade; another estimate puts it at 14 percent per decade. Moreover, the average thickness of ice over the Arctic Ocean has decreased by 4.3 feet since 1976 (after holding relatively constant at 10.2 feet over previous decades).

Are humans aggravating the situation by contributing to the increase in greenhouse gases, or is the current trend toward earlier ice breakup simply part of a natural cycle? Cores from the Greenland ice sheet do show significant shifts of climate in the past (the polar bear’s distribution is now Arctic and circum-polar, but an 11,000-year-old skull was found near London’s Kew Gardens). Similarly, trapping, hunting, and fishing records from Greenland over the past two centuries show marked changes in the distribution and abundance of arctic animals every fifty years or so, apparently because of fluctuations in the amount of sea ice. We also know that climatic variations from decade to decade are normal, so the possibility exists that the vanishing ice of Hudson Bay is part of a larger natural pattern.

However, a group of meteorologists recently concluded, on the basis of computer weather modeling, that there is a less than 2 percent chance that the observed changes in sea ice across the entire Arctic have resulted from natural causes alone. How much of the current warming trend is attributable to industrialization is uncertain, but I believe such studies should be interpreted as yet another warning that we should move quickly to reduce production of greenhouse gases. Our canary in the coal mine just might turn out to be a polar bear.

Ian Stirling is a research scientist with the Canadian Wildlife Service in Edmonton, Alberta.
TECHNOLOGY UPDATE

Make your cell phone “hands-free”...

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Navigator Hands-Free Kit™ turns your cell phone into a speaker phone, powers and charges, and moves between cars without expensive adapters or installation.

by John Bell

It's a fact, more and more automobile accidents are being blamed on the use of cell phones while driving. The problem has become so bad that many states have made it illegal to use a phone while driving, unless it is equipped with a hands-free speakerphone. Until now, if you wanted to purchase an adapter for your car, you were forced to buy one from the phone manufacturers or cell phone carriers. Now, there's a great new product that lets you keep both hands on the wheel while using your cell phone: the Navigator Hands-Free Kit™.

No more dangerous driving. Chances are, you've seen people driving down the road, cradling a cell phone on their shoulder, as they try to carry on a conversation while navigating traffic. With the increasing number of cell phone users on the road, the problem has gotten progressively worse. You've seen them, drifting across the center line while they're talking on the phone.

For that very reason, some states have enacted legislation banning the use of cell phones in cars, unless they are operated hands-free. Now, there's a great new way to carry on conversations that's safe, convenient and affordable. The Navigator Hands-Free Kit is a snap to install and incredibly easy to use. Now you can turn your cell phone into a car speakerphone. This enables you to keep both hands on the wheel while using your Motorola, Nokia or Ericsson cellular phone. No more cradling the phone between your ear and your shoulder...and no more dangerous one-handed driving.

Installs in seconds. Simply plug the DC adapter into your car's cigarette lighter and set your phone in the cradle. A special connector in the base charges your phone, saves your battery and converts your conversations to speakerphone mode. The speaker at the top of the cradle provides your in-car audio and the microphone at the bottom captures your voice. The unit also features a built-in volume control and an adjustable swivel connector between the cradle and the DC plug for perfect positioning in almost any vehicle.

Why pay your cellular carrier for expensive adapters? Hands-free speaker Adjustable power source Volume control Microphone

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COLLARED GREENS
The great green macaw, the second-largest parrot in the New World, is endangered. In Costa Rica, a radiotelemetry project aims to play a role in the bird’s salvation.
STORY BY CHARLES BERGMAN
PHOTOGRAPHS BY STEVE WINTER

THE HIDDEN UNITY OF HEARTS
Question: How did the heart evolve from a simple tube to a multichambered pump? Answer: Quickly.
BY CARL ZIMMER

AND THE BEAT GOES ON
BY WARREN BURGGREN

BATS, BEES, AND BRAZIL NUT TREES
In some parts of the Amazon, you can’t go far without bumping into a member of the Brazil nut family.
STORY BY SCOTT MORI
ILLUSTRATIONS BY MICHAEL ROTHMAN

CUTTLEFISH SAY IT WITH SKIN
Cuttlefish are quick-change artists with a vast vocabulary of colors and textures.
BY MARGUERITE HOLLOWAY

AUSTRALIA’S ROCK STARS
BY SIMON FOALE AND MARK NORMAN

COVER A pair of courting cuttlefish. Researchers are beginning to decipher how these cephalopods communicate.
STORY BEGINS ON PAGE 70
PHOTOGRAPH BY MARK STRICKLAND; OCEANIC IMPRESSIONS

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Collisions

In an ideal world, every article in Natural History would be something like this month’s cover story on cuttlefish—a pure celebration of the natural world and how it works. But explorations of natural science may also lead in disturbing directions—often because of the human factor.

About 3 million years ago in Africa, a handful of hominid species (their total population numbering perhaps in the tens of thousands) lived among the multitudes of animals, plants, fungi, and unicellular organisms that populate our planet. These protohumans probably didn’t live in perfect harmony with nature (if there is such a state), but they weren’t colliding with it either. Their impact on the biosphere must have been negligible.

We are the sole surviving descendants of those early Africans. A single species, Homo sapiens, we number more than 6 billion. And because of our sheer numbers, we are bumping into, moving about, and altering other living things on every continent. Some of the consequences—erosion, deforestation—are obvious; many more are just beginning to be understood. As science writer Yvonne Baskin reports this month, our tiniest earthly companions (protozoans, fungi, bacteria, viruses) are being forced into novel encounters with some of our more familiar fellow travelers (frogs, squirrels, birds, elephants). Such abrupt introductions, which are the natural result of our species’ proclivity to manipulate the environment, have promoted the emergence of diseases that threaten wild animals. To learn more, turn to “A Sickening Situation” (page 24).

—Ellen Goldensohn

TO THE EDITOR

Emphasize the Emptiness

Hooray for your February 2000 issue (“To Know the Universe”)! But with all the pictures of things in the sky, you should have mentioned how much empty space there is out there. The ratio of space to all the visible and invisible matter in the universe is approximately that of ten cubic meters to one atom of hydrogen. And it takes about ten million hydrogen atoms to span the diameter of the head of a pin.

Pete Seeger
Beacon, New York

Wrong Distance

The caption on page 48 of the February 2000 issue says that Supernova 1987A exploded 12 million years ago. But since it is in the Large Magellanic Cloud, I think the time must be much more like 175,000 years ago.

Stephen Hopkins
via e-mail

You are right. The supernova (at left) exploded only 175,000 years ago, and the light reached us in 1987. (Many of the nearby bright stars in the picture are members of a generation of stars that became supernovas 12 million years ago.) We apologize for the error.—Eds.

In Praise of Skunk Cabbage

As a nearly lifelong observer and writer about skunk cabbage, I thank you for again bringing that plant to the attention of your readers (“First With a Flower,” March 2000). When bruised, the plant indeed releases malodorous substances (once described as a combination of burnt sugar and rotting onions), but the flowers in the enclosed spathe have a faintly sweet and pleasant smell and are even attractive to honeybees. The presence of dung beetles or flesh flies in the inflorescence can most easily be explained by their attraction to the heat produced by the plant, not its odor.

The skunk cabbage’s reputation for malodorousness has deprived generations of early-spring swamp explorers of a pleasurable experience.

Go smell a skunk cabbage. You must get really close to the opening of the spathe, but the effort is worth it. No carrion, no dung—only the sweet smell of spring.

Roger M. Knutson
Charlevoix, Michigan
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For ten years, Merrill Lynch and the American Museum of Natural History have worked together to create a successful partnership built on a mutual belief in the importance of science and education, both today and in the next millennium.

A Partnership in Motion

For well over a century, the American Museum of Natural History has been a leader among the world’s science, research, and educational institutions. Since its founding in 1869, it has dedicated itself to the compelling quest to understand the natural world and man’s place in it. The Museum’s innovative and interactive presentations educate about four million visitors each year on-site, and over 30 million visitors on-line.

To continue its 130-year tradition of excellence in scientific research, unparalleled exhibitions and innovative educational programs, the Museum relies on support from the corporate community.

THE COMMITMENT

Over the past ten years, Merrill Lynch, one of the world’s leading financial management and advisory companies, has been an important supporter of the American Museum of Natural History. Like the Museum, Merrill Lynch has been devoted to community service and leadership in education through its participation in educational initiatives, such as its ScholarshipBuilder program. On a global scale, all of the company’s philanthropic efforts flow from a fundamental belief that people from all walks of life can become self-sufficient, fulfill their dreams, and realize their goals when offered access, tools, and knowledge.

In 1996, Merrill Lynch was the principal sponsor of the acclaimed “Leonardo’s Codex Leicester: A Masterpiece of
Science,” on view at the Museum from October 26, 1996 through January 1, 1997. This exhibition of a rare manuscript by Leonardo da Vinci offered an in-depth view of the scientific thinking of one of the greatest geniuses in the history of the Western world. The Codex Leicester, written between 1506 and 1510, opens a window into the mind of the awe-inspiring Renaissance artist, scientist, and thinker while illuminating both the scientific and creative process. This enlightening exhibition included an innovative demonstration room, lectures, and children’s workshops.

An additional grant from the Merrill Lynch Foundation in support of education programs to complement the exhibition allowed over 6,000 children from New York City public schools (grades 6-12) to attend the exhibition with a guide and to participate in special pre- and post-viewing programs.

The tremendous success of this partnership has led to an enduring relationship between the Museum and Merrill Lynch, and in 1996 Chairman and Chief Executive Officer David Komansky joined the Board of Trustees of the Museum.

“The American Museum of Natural History has been a source of inspiration, fun, and knowledge throughout my life,” says Komansky. “I’m pleased that, as a trustee of the Museum, I’m able to support the vital role this institution plays—not only in the metropolitan area, but wherever knowledge is highly valued.”

THE MOVEABLE MUSEUM

In July 1997, Merrill Lynch made a $1 million, three-year gift targeted to the Museum’s educational outreach programs. As part of the gift, Merrill Lynch purchased and outfitted a new “Moveable Museum,” a recreational vehicle converted into a mobile exhibition space. The Moveable Museum now travels to schools, community centers, parks, street fairs and other neighborhood organizations throughout the five boroughs of New York City.

The Merrill Lynch vehicle features an exhibition called “Structures and Culture,” which invites visitors to explore the traditional homes of nomadic people in Africa, Asia, the Middle East and North America and to discover what architecture and artifacts tell us about each culture.

“With our new ‘Structures and Culture’ Moveable Museum, we can bring thousands of school kids on a virtual, round-the-world expedition of cultural discovery,” says Jeff Rodgers, Director of the Moveable Museum Program. “Merrill Lynch helped us create a new way for kids to learn about their world without ever leaving their neighborhood.”

“I’m especially proud that Merrill Lynch will be honored for helping the Museum fulfill its growing mission. The truth is, it’s very easy to support an institution that appeals to all people and is characterized by excellence at every turn.”

David Komansky

MUSEUM EDUCATION AND EMPLOYMENT PROGRAM

In addition to supporting exhibitions both within and beyond the Museum’s walls, Merrill Lynch allocated a portion of its three-year grant to the Museum Education and Employment Program (MEEP), to demonstrate its support of the Museum’s “human” resources. The MEEP program offers meaningful work experience to 60 young adults in New York City. These students complete a rigorous training program that prepares them to serve for six weeks as Museum guides, thereby enriching the Museum experience for the thousands of children who visit it each summer.

As Rosa Almonte, MEEP Program Supervisor, described so well, “This year’s program was so rich. Not only did I learn earth science in the Hall of Planet Earth, but I also learned about myself by interacting with such a diverse group of people.”

THE PARTNERSHIP

In 2000, the American Museum of Natural History will honor David Komansky and Merrill Lynch for their generous support of the institution and of science and education in general. “David Komansky and Merrill Lynch have been generous both with the Museum and the entire New York City community. David is a valued trustee and member of the business community and we look forward to acknowledging his and Merrill Lynch’s tremendous support and vision as we enter the new millennium,” says Ellen V. Futter, President of the American Museum of Natural History.

For information on the many programs that the American Museum of Natural History offers, please call 212-769-5100.
On leave from Pacific Lutheran University in Tacoma, Washington, where he teaches English literature and nature writing, Charles Bergman (“Collared Greens”), left, is currently spending a year as a Fulbright scholar in Mexico. While there, he has been taking the opportunity to learn more about Mexican and Central American wildlife and conservation issues. Bergman is the author of Orion’s Legacy: A Cultural History of Man as Hunter (Penguin, 1997). He wrote about the Iberian lynx for the October 1998 issue of Natural History. Photographer Steve Winter has traveled the world on diverse projects involving ice climbing, river rafting, Haitian culture and music, oil pollution in the Galápagos, medicinal rainforest plants, nesting ridley sea turtles, and Guatemala’s resplendent quetzal—as well as the great green macaw. His work has appeared in many publications, including National Geographic, Time, and Newsweek.

“I’ve always been fascinated by how evolution produced complicated things like the heart and the brain,” says freelance journalist Carl Zimmer (“The Hidden Unity of Hearts”), “and now scientists are coming up with good evidence for how it happened.” Zimmer put his interest in evolution to good use in his last book, At the Water’s Edge (Touchstone, 1999), which describes recent research on two of the most significant transitions in the history of life: from fish to four-legged land vertebrate and then, back to the water, from land mammal to whale. This September, Simon & Schuster will publish Zimmer’s next book, Parasite Rex, a close look at tapeworms, flukes, and other long-underestimated parasitic organisms that just may turn out to be “the dominant force in the evolution of life.” Zimmer also writes a monthly column on biomechanics for Natural History.

Scott Mori (“Bats, Bees, and Brazil Nut Trees”) is a curator at the New York Botanical Garden (NYBG) and director of its Institute of Systematic Botany. A native of Wisconsin, he has taught botany and zoology, managed herbaria in Panama and Brazil, and pursued the study of tropical plants in Mexico, Costa Rica, and Panama and throughout South America. He is shown with a “monkey’s bailing cup,” left, one of the extraordinary fruit casings produced by plants in the Brazil nut family. To illustrate the article, Mori chose Michael Rothman, renowned for his attention to scientific accuracy as well as his superb draftsmanship. Rothman accompanied Mori to French Guiana, sketching and photographing plants on the ground and in the canopy. Five years ago, he joined NYBG botanists on a field trip to the Brazilian Amazon. Rothman’s drawings often grace the New York Times’s science section, and his many children’s books include Jaguar in the Rain Forest (William Morrow, 1996) and Here Is the Tropical Rain Forest (Hyperion, 1997).

Marguerite Holloway (“Cuttlefish Say It With Skin”) is a New York City–based freelance journalist specializing in environmental and science reporting. She has written for many publications, including Scientific American (where she is a contributing editor), Discover, Audubon, Wired, and the Nation. Her last piece for Natural History was “The Paradoxical Legacy of Franz Boas” (November 1997). Holloway developed an inordinate fondness for cuttlefish during a fellowship several summers ago at the Marine Biological Laboratory in Woods Hole, Massachusetts, and has been obsessed with them ever since.

Steve Bentsen (“Going Online”) lives in McAllen, Texas, on the Mexican border, and splits his time between two professions: veterinary medicine and freelance photography. An avid birder and outdoorsman, he has published photographs in Birder’s World, Living Bird, Outdoor Life, Smithsonian, and Field & Stream. He photographed the buff-bellied hummingbird after receiving a call from the local media about the unusual nest.
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Spring Break  A coastal wetland nourishes birds, and the endangered...
On the west coast of Mexico near the town of San Blas is a limestone spring called La Tobara (or La Tovara), part of an inviting system of lagoons, canals, and navigable tidelands. These wetlands are about a ninety-minute drive from Tepic, the state capital of Nayarit, but I traveled there from the coastal town of Puerto Vallarta, Jalisco, where I was staying. Heading north on Mexico’s Highway 200, I soon crossed from the Central into the Mountain time zone. The route followed the coastal plain—past crops of avocado, mango, papaya, teak, and pineapple—and then meandered up and down the low foothills of the Sierra Madre. As I continued along the coast on Route 161, a mangrove swamp lay to my left, on the ocean side of the road, while to the right were agricultural crops, including peanuts and jackfruit.

Just north of the village of Santa Cruz, I stopped to investigate a small stream flowing toward the ocean. What caught my eye was a tree that looked very much like the black willow that grows in the temperate eastern half of the United States. It turned out to be a yew-leaf willow, which ranges from western Texas and southern Arizona all the way south to Guatemala. Near the stream I noted buttonbush, golden glow, and bushy broom sedge—all familiar plants that I hadn’t expected to find in Mexico.

Eventually, just three miles south of San Blas, I reached La Aguada boat docks, the starting point for my trip through the wetlands (a second boat landing, El Conchal, is at the edge of town). Boarding a motorized canoe called a panga, which carried seven other passengers and our guide, I set out on one of the most captivating nature excursions I have ever taken.

After leaving the dock, we glided slowly and quietly along a narrow canal that had been cut through an otherwise impenetrable jungle of red, white, and black mangroves, with overhanging branches and intricate tangles of curved prop roots. About ninety species of mangrove exist worldwide. They grow primarily in tropical climates between 25° north latitude and 25° south latitude, in salty or brackish water—near the ocean, in marshes, and at the mouths of rivers. The root cell membranes of the red mangrove are specialized to reduce the intake of salt from the water, and the thick, leathery leaves of the black and white mangroves are adapted to excrete salt compounds. Red mangrove roots provide protection for young fish, invertebrates, reptiles, mammals, and birds, while the underlying peat formed from root matter traps soil and silt and filters runoff and pollution.

As we made our way along the canal, we saw several American crocodiles sheltering within the mangrove roots, as well as a modest-sized green iguana lying on a low-hanging branch. Although they feed primarily on fruits and leaves, iguanas in this part of Mexico may grow nearly six feet long; their heavy tails can deliver a good wallop, and their strong jaws can inflict a deep bite.

Our guide was especially knowledgeable about the bird life and was able to show us three boat-billed herons—magnificent tropical birds with broad bills. This kind of heron uses its sensitive bill to detect edible food in the water (mainly fish and shrimp), which it can then quickly engulf. We were treated as well to the sight of a common potoo, whose coloration blended perfectly with the lichen-striated mangrove branch on which it sat. A distant relative of the whippoorwill, the potoo feeds mainly at night, opening its short, curved bill very wide to sweep up flying insects. We also saw a citreoline trogon, a
gorgeous bird with a predominantly yellow underside.

Passing out of the mangrove swamp, we entered a deep marsh. Large wading and diving birds seemed to be everywhere: great white egrets, great blue herons, green herons, tricolored herons, roseate spoonbills, anhingas, cormorants, and jacanas. Just as we were leaving the deep marsh, we startled a bare-throated tiger heron, which flew away from our panga, while a chachalaca (a pheasant-sized bird whose name reflects its call) went scurrying off among the trees. We followed the canal into another wooded area, this one with swamp forest trees instead of mangroves. Our journey ended at a beautiful lagoon fed by La Tobarra spring. Here visitors may leave their pangas for a guided tour around a crocodile breeding farm that was created to help preserve these endangered creatures.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

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HABITATS

Mangrove swamp has abundant red mangrove and lesser numbers of black mangrove and white mangrove. Other common trees are mahoe, whose large yellow flowers turn red as they mature, and the palm Sabal mexicana. Bromeliads, including at least three kinds of Tillandsia, bedeck many trees. In the understory is the giant leather fern, the same species that grows in brackish waters in peninsular Florida, and a huge Crinum lily with strap-shaped leaves up to six feet long and clusters of foot-long white flowers.

Deep marsh is dominated by false cane, a grass that grows as tall as twelve feet and has large terminal clusters of spikelets, and flag plant, which reaches ten feet and has large, cannalike leaves and rather small lavender flowers borne on slender, zigzagging stems. Narrow-leaf cattail, with stout stems up to ten feet tall, is also common. Somewhat shorter plants include Johnson grass, the same species that is a troublesome weed in the United States; a five-foot-tall deciduous fern (Thelypteris interrupta) related to the lady fern of the eastern United States; and a broad-leaved arrowhead that appears to be the same species common in southern U.S. wetlands. Smaller herbs are marsh pennywort and camphor weed (both also common in U.S. wetlands). Other plants are false nettle, a pink Saint-John’s-wort, and two species of white-flowered smartweeds. Morning glory vines and climbing hempweed scramble over much of the vegetation.

Wooded swamp trees usually have either thick, leathery, toothless leaves or leaves divided into numerous leaflets. In the first group is Persea podadenia (similar to and related to the red bay of the southeastern United States) and a tropical species called Pisonia aculeata. In the second group are a species of mimosa and a cat’s-claw, members of the legume family. Here also are the palm Acrocomia mexicana and several large species of wild fig. Wild orchids and bromeliads find homes in the crotches of many trees. Visitors should beware of poison ivy, the same species found in the United States.

Spring-fed lagoon plants include watercress, a species that inhabits spring-fed swamps in many parts of the world. Overhanging the lagoon are several handsome specimens of Cecropia pelata, a tree whose large lobed leaves have a whitish underside.
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Everybody Into the Pool

Wood frogs mate and their eggs and tadpoles mature en masse.

IN THE FIELD

By Bernd Heinrich

A male wood frog, atop a female, will hold fast until his mate sheds her eggs, even if it means taking a ride.

In the Maine woods, winter lasts well into April, but toward the middle of the month I begin to watch some dozen roadside ditches and small pools in anticipation of a rite of spring. Snowstorms still come and go. On some nights, ice covers pools and ponds. But whenever I’m outdoors, I watch and listen. Then, from one day to the next, the whole surface of a newly ice-free pool will sprout wood frogs. Spaced almost evenly a foot or so from one another, dozens upon dozens of the three-inch-long frogs float with their legs extended, hind legs buoyed apart, and snouts above water. If I had failed to see the frogs, I would have heard them. Calling, they pump their cheeks in and out, Dizzy Gillespie–like. But on the pool there are no solos. When one frog calls, the others immediately join it in a concert of quacks and croaks.

As I creep toward the pool for a closer look, all the callers fall silent. Many remain motionless on the water’s surface. One step closer, and they submerge with kicking strokes, dive the foot or two to the bottom, and hide under last year’s fallen leaves. But I’ve found I can conjure them up again, simply by playing back their calls with a tape recorder. Thus summoned, they will cautiously resurface, approach the sound, and resume their concert.

The wood frog, Rana sylvatica, is well named, being adapted to life in a sylvan, or woodland, setting. In summer, one seldom sees these tan frogs with the black eye stripes, and I consider it a rare treat to encounter one in the woods near my cabin. For the six months of winter, they are totally under cover, having burrowed under fallen leaves or loose soil. In a physiological feat, wood frogs survive subfreezing temperatures by manufacturing a glucose that protects their cells (which shrink in winter) from being penetrated by ice, while the fluid outside the cells freezes. After their spring resurrection, they abound in temporary bodies of water left by the previous fall’s rains and by melting snow.

By far the majority of frogs I see are males. They have lost the tan tones of summer and taken on a rich chocolate brown to almost black color, save for a delicate touch of yellow on the head and a chalk white belly. Occasionally, however, I see pinkish tan, slightly larger individuals. These are the females. I seldom see more than six or so females at any one pool, but that does mean they are not there. They come to the water mostly under cover of darkness, when they can be seen crossing roads and heading directly toward song-filled pools of waiting males.

Once at a pool, a female is not to be found sprawling at the surface like the males. If she is at the surface, the female will be engulfed in a bobbing ball of up to twelve males, all jockeying for position and pushing in a frenzied contest to claim her as a mate. A male takes possession by perching on the female’s back and clasping his powerful front legs around her neck. Once this headlock—the scientific term is amplexus—has been achieved, the two can be disentangled only by force. (A woman once brought a thus engaged wood frog couple to me, thinking it was a two-headed frog.) The female, with male attached, sometimes dives to the bottom of the pool. The male will hold on until she

“Explosive” breeders, wood frogs congregate in large numbers to mate in temporary pools.
sheds her cluster of eggs. In captivity, I found, he will cling for several days. In the pool, he holds fast for a day or less; the female lays her eggs on the evening of their coupling. With the male appended, she swims to a spawning site near submerged vegetation and extrudes black, gelatin-coated eggs in a mass that is partially exposed at the water’s surface. The male fertilizes the eggs, and the pair decouple. Each female deposits about a thousand eggs—I counted 1,025 in one egg mass. The gelatin encasing each egg is highly hygroscopic and thus quickly absorbs water. Within hours, the egg cluster swells from walnut size to baseball size.

Wood frogs are aptly known as “explosive” breeders. After just the first night of the mating orgy, hundreds of egg clusters float in a supercluster at one end (in my experience, usually the eastern end) of the pool. Why would all the females in a particular pool put their eggs into one big “basket”? It may lessen the risk of predation; alternatively or additionally, it could relate to the temporary nature of the breeding places, where timing is a matter of life and death to the young. I’ve measured egg-mass temperature and found it to be at least 2°C higher in communal masses—where the output from many females is bunched up—than in a single mass. This temperature difference speeds up the hatching rate of the eggs by a day or more. And a clumping of thick, gelatinous masses reduces convective heat loss as the black eggs are warmed by the sun.

Speedy development of the eggs and tadpoles is crucial. As a survival strategy for their offspring, wood frogs generally avoid permanent bodies of water, which may contain fish, leeches, and other predators. Suitable temporary pools are colonized quickly; one that I dug by backhoe near my cabin attracted dozens of breeding wood frogs (determined by counting egg masses) the first spring and nearly a hundred the second. But while eggs and tadpoles thus escape becoming a meal for a predator, they must develop into froglets by the time the pools have dried up in late June or early July.

The tadpoles of some species, such as the bullfrog, take as long as two years to metamorphose into young frogs. Wood frogs take just forty-five days on average to go from egg to tadpole to froglet. This metamorphosis is fast even when compared with the development rate of other amphibians that breed in temporary pools. Also, unlike other tadpoles I know of here in the Northeast, wood frog tadpoles will, like fish, swim around in schools. I have seen them swimming in long lines and sometimes in giant circular formations. Slow moving, they stay close to the water surface. At frequent intervals one can see their silver bellies as they twist about at the surface to gulp air or graze on algae.

Many questions posed by the wood frog’s unusual, seemingly social, behavior are not yet answered. Why do the males go precisely to those pools where the competition for females is greatest? Why do they prefer to congregate in specific pools when they could go to a pool with no other wood frogs and thus avoid competition? Why do they join the chorus to produce even louder, and presumably stronger, vocal lures that attract still more males to the arena to compete? I think one answer is that their behavior is driven by females. Given the ephemeral nature of the pools, females need to deposit eggs early and quickly. This means going to pools where the presence of males—and plenty of them—is guaranteed. The same aural cue that entices the females also lures more males: the loudest chorus will be the one that is closest and that also has drawn the most females. I am reminded of some species of tropical fireflies in which males also converge and “call” (flash) synchronously to enhance a communal mating display.

Wood frog reproduction is a boom-and-bust affair. Of an original clutch of a thousand eggs, almost all may develop into froglets and leave the pool, or almost all may perish. In late June, when the pools shrink, the bottoms sometimes turn soupy and black with congealed masses of dead tadpoles. As long as there is a little water, the dying individuals sustain the others, their bodies providing sustenance to their fellows. Just before metamorphosis, the tadpoles weigh only a fraction of an ounce. Within several days, they lose much of their larval body weight, absorb their one-inch tails, and sprout legs. The tiny, freshly metamorphosed wood froglets then leave the water for a life on land. They usually reach at least half their adult body weight by summer’s end in the north woods.

Bernd Heurich is a professor of biology at the University of Vermont in Burlington. His latest book is Mind of the Raven (Cliff Street Books, 1999).
The Astrology Connection

Celestial events are always significant—or are they?

W hen celestial conjunctions occur, they often belong to the close-but-no-cigar school of sky watching. Technically, a conjunction describes a precise alignment of heavenly bodies that happen to have the same celestial longitude—that is, they appear to line up in the sky, one directly above the other. On occasion, the bodies line up one in front of the other, a circumstance that historically has lent itself to all manner of scientific investigations. But on an informal basis, the word “conjunction” generically refers to the fleeting convergence of celestial objects, a happenstance that’s aesthetically pleasing—and astronomically significant for that reason alone. When a serendipitous close gathering of celestial objects is assigned greater significance, the reason is likely to be astrological.

At one time, astronomy and astrology were virtually indistinguishable. Astronomers of old might study the sky to help plan the harvest or coordinate a calendar, but they earned their keep primarily by prophesying favorable heavenly portents for the rulers who employed them. And those portents tended to focus on the movements of the mysterious wanderers—the Sun, Moon, and planets—against the seemingly immovable backdrop of stars.

But in the broad sense, conjunctions mark mere cosmic coincidences, and even then, only from the point of view of an observer on Earth. Once our planet lost its position of privilege as the center of the cosmos, that point of view lost its relevance, except where it might prove useful for science. Studies of the motions of Venus as it neared inferior and superior conjunctions—passing on our side and on the far side of the Sun—helped validate the heliocentric model of the cosmos (see “Venusian Testimony,” Natural History, 6/99). Observations of Mercury and Venus transiting the Sun—passing directly in front of it, from the point of view of an observer on Earth—helped determine the scale of the solar system (see “Mercury in Transit,” Natural History, 11/99). And in 1919, a total solar eclipse (an extreme example, being a conjunction that’s also an occultation) helped validate Einstein’s general theory of relativity.

But what about plain old conjunctions in the broadest sense? For academic purposes, virtually their only astronomical significance is measured in terms of insights they might offer into ancient astrology. (For a riveting
IT HAS A TENDENCY TO COME RIGHT BEFORE THE MOST EXCITING MOMENTS IN LIFE.

www.moet.com
example of how conjunction scholarship can open a window on ancient cultures, see Michael R. Molnar's 1999 book *The Star of Bethlehem: The Legacy of the Magi.*

This is not to say that people don’t still confuse astronomy and astrology (or that, heaven knows, astrology isn’t still popular). In fact, I can personally attest to having been asked many times about my writing on “astrology.” And a subscription mailing referring to this magazine’s coverage of “astrology” was sent out for years before an alert reader finally noticed it. (A similar fate sometimes befalls cosmology. A recent press release for a book by physicist Lawrence M. Krauss highlighted his research into dark matter as “one of the great paradoxes of modern cosmology”—indeed, as a problem “now connected with two of the hottest areas in recent cosmology.” In this case, however, cosmology and cosmetology don’t bear any historical relation to each other, except that both vocations can get a little hairy.)

Even when popular interest in a planetary conjunction isn’t purely astrological, it can still be the result of mere superstition. This year, a gathering of planets on May 5 has generated a great deal of apocalyptic speculation on the Internet, specifically about whether the combined gravitational pull of Mercury, Venus, Mars, Jupiter, and Saturn on the far side of the Sun will be enough to knock Earth off its axis. (It won’t.) To viewers on Earth, alas, that particular spectacular alignment will be lost in the glare of the Sun.

This month, however, offers a rare and equally notable conjunction that will be fully visible. On April 11, just after sunset, Saturn, Mars, and Jupiter will form an equilateral triangle within an area of the western sky about half the size of your fist at arm’s length. Jupiter will be the brightest of the trio and Mars the dimmest, although easily identifiable by its reddish hue. Should the sky be cloudy on April 11, don’t despair; over the following five nights, the three planets will still appear unusually close together—closer than at any time since 1921. In addition, they’ll be joined by a crescent Moon for a few nights starting April 6.

The only possible meaning offered by such a conjunction would be astrological. Nonetheless, this aesthetically auspicious occasion, like all celestial events, will indeed be an important one for professional astronomers. And you’ll even be able to observe it just as they will. Simply follow these directions: go outside and look up.

*Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens (Penguin, 1999).*

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**Worlds you’ve never explored.**

**Creatures you’ve never seen.**

**A television event you’ll never forget.**
Mercury and Venus are all but invisible this month because of their close proximity to the Sun. Both planets are deeply immersed in the bright morning twilight and rise less than an hour before the Sun. A very slender crescent Moon passes south of the planets on the mornings of April 2 and 3 but will probably be of little help in guiding you to them. These two planets pass within half a degree of each other on April 28. This would make for a splendid sight were it not for the fact that on this date, they are too close to the Sun to be visible.

Mars, Jupiter, and Saturn put on a spectacular show during the first half of April, when they are readily seen in the western sky for at least a couple of hours after sunset. During the first week of the month, we'll see a rather dim Mars (magnitude 1.4) and a brilliant Jupiter (magnitude -2) crowding close together in the fading evening twilight, with Saturn (magnitude 0.3) sitting just above them. (On the evening of April 6, the crescent Moon joins this planetary trio, sitting below and just to the left of Saturn.)

During the second week of April, the configuration of the three planets changes noticeably from night to night. On the evening of April 11 they form a beautiful triangle, and on the evening of April 14 they are the closest they'll be to one another for quite a while, fitting into an imaginary circle of just under 5° in diameter. Not until May 2002 will we easily be able to see three planets so close together again. After Mars passes Saturn on April 16, it quickly leaves both Jupiter and Saturn behind to be swallowed up by the bright evening twilight.

The Moon is at new phase on April 4 at 2:12 P.M. It reaches first quarter on April 11 at 9:30 A.M. Full Moon is on April 18 at 1:41 P.M., and last quarter is on April 26 at 3:30 P.M.

Daylight saving time begins on April 2, the first Sunday of the month. Don't forget to set your clocks forward one hour before turning in for the night. Remember, the mnemonic is “Spring forward, fall back.” A note of caution: Hawaii, Arizona, most of Indiana, Puerto Rico, and the Virgin Islands remain on standard time.

Time is not officially counted between 2:00 A.M. and 3:00 A.M. on April 2. Unfortunately, you'll lose an hour of sleep (it's “hour” loss!).

Unless otherwise noted, all times are given in Eastern Daylight Time.
By the 1890s, with the eastern forests of the United States ravaged by extensive logging, the tree-dwelling gray squirrel was in trouble. Hoping to find new homes for the animals, well-meaning souls began exporting them to England, where they were welcomed as novelties and pets. Since then, gray squirrels have gone forth and multiplied.

Unfortunately, their advance has caused the decline of Britain's native red squirrels, all but eliminating them in the south of England. Biologists long assumed that the grays (Sciurus carolinensis) simply outcompeted the reds (S. vulgaris) for food and nesting sites. But recent findings by veterinarian Tony Sainsbury, of the Zoological Society of London, and several colleagues suggest that the takeover has been abetted by a powerful ally: a pathogen known as a parapoxvirus. Sainsbury points out that reports of dead red squirrels with skin lesions characteristic of a viral infection date back to the early 1930s and that the pathogen itself was identified in the late 1970s. Yet, until recently, no one connected the mammal's decline with an infection.

Now, along with Peter Nettleton and Janice Gilray, of the Moredun Research Institute in Edinburgh, Scotland, and John Gurnell, of the University of London, Sainsbury has tested blood taken from red squirrel carcasses all over the United Kingdom and found that very few of the animals had parapoxvirus antibodies. The researchers hypothesize that the red squirrels died because they could not develop resistance to the virus. (Antibodies indicate past exposure to a pathogen or toxin as well as the ability to develop immunity to it.) By contrast, a high proportion of the gray squirrels tested did have antibodies to the virus, indicating that they had been exposed to it and survived.

These scientists do not yet know whether the grays carried the parapox infection with them to Britain or whether they merely serve as a "reservoir" for a local pathogen, enabling it to persist in greater concentrations than it otherwise could. In either case, the plight of the red squirrel highlights what parasitologist Peter Daszak, of the University of Georgia, calls "the role of disease as a hidden mediator of ecological change"—a subject that is drawing particular attention now with the emergence of new wildlife infections, including deadly fungal diseases in frogs on three continents, canine distemper in African wild dogs and lions, and a strain of West Nile encephalitis recently identified as a killer of both birds and humans in the New York City area.

The idea that such diseases pose a significant threat to global biodiversity has been slow to dawn on biologists because, says Daszak, "wildlife disease has always taken second place to veterinary work on domestic animals." Until recently, he adds, even field ecologists paid little attention to dead animals as they went about their studies of plant and animal interactions. With little data to go on, they could only debate whether parasites and pathogens have a significant impact on wildlife populations or whether they simply kill the weak and unfit. Although computer models and lab studies have demonstrated that disease can regulate wild animal populations, it was not until 1998 that some field experiments with game birds confirmed these findings.

Most red grouse populations on the moors of northern England go through
boom-and-bust cycles every four to eight years, and the population crashes were known to coincide with higher rates of infection of the birds by *Trichostrongyulus tenius*, a parasitic worm. To prove cause and effect, however, researchers Peter Hudson, of the University of Stirling, and Dave Newborn, of the Game Conservancy Trust in North Yorkshire, teamed up with Andy Dobson, of Princeton University. Working with gamekeepers, they caught and treated thousands of grouse with an oral worm medication. The result: an end to population crashes.

Dobson finds the grouse results gratifying but not surprising. After all, more than half the species on Earth are parasites, and most organisms are host to a number of them. Pathogens—and the diseases they cause—should therefore play an important role in maintaining genetic diversity in a population, since some individuals prove better able to resist than others. Pathogens may even influence the balance of species in a community. “If you believe predators can be keystone species and lead to increases in biodiversity and affect the way ecosystems function, then it’s appallingly naive to think that pathogens can’t do the same thing,” Dobson says.

The power of pathogens is never so apparent as when they first encounter a vulnerable new host, and thanks to humans, that is happening more and more often, says Peter Daszak. Diseases can emerge when people transport wildlife to new areas, move themselves and their domestic animals into wildlife habitat, or otherwise inadvertently shuffle pathogens around (a phenomenon Daszak and his colleagues call “pathogen pollution”).

The “spillover” of pathogens from domestic livestock and pets to wildlife probably dates back to early human migrations around the globe. Indeed, paleomammalogist Ross MacPhee, of the American Museum of Natural History’s Department of Mammalogy, believes that pathogens brought by Ice Age hunters entering the New World—and not stone-tipped spears or climate change—wiped out the mammoths and other Pleistocene megafauna. Modern history provides less speculative examples. In the late nineteenth century, cattle exported from either Italy or India to colonial Africa set off an epidemic—or, rather, an epizootic—of rinderpest, a disease that swept the continent in only a few years, killing huge numbers of wildebeest, buffalo, and other wild grazers, as well as cattle. By the mid-1960s, widespread cattle vaccination had brought rinderpest under control, but to this day, pockets of unvaccinated cattle in Somalia and elsewhere still act as reservoirs for the pathogen and are responsible for periodic outbreaks of this devastating disease.

Rinderpest is caused by a morbillivirus; other viruses in this group cause distemper and measles. Morbilliviruses are notorious for their ability to exploit new species. The burgeoning population of domestic dogs around Tanzania’s Serengeti National Park is blamed for outbreaks of canine distemper virus, which apparently wiped out the last of the park’s dwindling number of wild dogs in 1991 and killed more than a third of its lions in 1994. Die-offs of seals in both Siberia and Antarctica have been linked to contact with distemper-infected sled dogs. And measles contracted from unvaccinated humans now threatens mountain gorillas in the forests of central Africa.

In some quarters, the recognition that wild animals are threatened by emergent diseases has raised fears that wildlife infections will “spill back” to domestic stock and humans. But as Princeton’s Andy Dobson points out, such public anxiety is often unwarranted, because populations of wild animals are often too small and scattered to sustain a pathogen. Rinderpest, for example, disappeared naturally from wildlife when domestic cattle were vaccinated. Still, badgers in Great Britain have been killed because some believe them to be responsible for the rising incidence of tuberculosis in cattle. And bison wandering out of Yellowstone National Park have been shot because they may carry brucellosis, a disease of cattle. In both cases, there is little evidence to support such measures.

Human modification of the environment also encourages the emergence of infectious diseases in wild animals. With U.S. wetlands shrinking, migratory birds are crowding into remaining sites, causing an upsurge in avian cholera and botulism. Tiger salamanders in Arizona, now confined (because of wetland drainage) to man-made watering holes for cattle, and
common frogs packed into garden ponds in the United Kingdom have been hit hard by outbreaks of emerging iridovirus diseases.

Even such seemingly benign activities as the feeding of backyard birds can bring about unhealthy crowding and commingling of species. In the United States, these conditions have been blamed for the spread of an eye disease, mycoplasmal conjunctivitis, throughout eastern house finch populations.

Holding wild animals in captivity, where they are likely to eat unusual foods and share space with other species they would never encounter naturally, can also foster disease. In Europe, for instance, at least fifty-eight zoo animals (of seventeen different species), including cheetahs, kudu, and an Arabian oryx, died after eating feed contaminated with the infectious protein known to cause bovine spongiform encephalopathy, better known as mad cow disease. And the common zoo practice of housing African and Asian elephants together has apparently allowed a herpesvirus carried by African elephants to infect and kill at least eight juvenile Asian elephants in the United States. In African elephants, the infection seems to cause only skin or genital warts.

When animals are released from captivity, either officially in reintroduction programs or unofficially (and often illegally) as “repatriated” pets, they may carry diseases into previously unexposed wild populations. An upper respiratory tract infection that was first identified in captive tortoises showed up in desert tortoises in the Mojave in 1989. The result was the first disease-induced listing of a species under the Endangered Species Act.

Hunting, agriculture, aquaculture, and the pet trade all involve the transport or displacement of wild animals. In the process, the animals are exposed to new diseases, and the pathogens they already carry are introduced into new environments. Whirling disease—a bone-deforming parasitic infection devastating prized wild-trout fisheries in Colorado, Montana, and other western states—has been linked to hatchery fish imported from Europe in the 1950s. In turn, North American crayfish introduced into Europe carried with them a fungal plague that now threatens related native species.

International trade in produce, raw logs, plants, soil, and livestock, as well as the handling of ballast water and landfill, are spreading novel pathogens to remote parts of the globe. River runoff carrying mud and silt that was washed away by flooding or eroded during land-clearing activities has allowed the terrestrial soil fungus As-
**Pseudophryne xiphioptera** to infect a new group of hosts, the Caribbean sea fans, leaving them with nasty lesions and weakened immune systems.

In many cases of emerging disease, human involvement is suspected but difficult to prove. A recent example, reported by Daszak and others in 1998, is the fungal disease chytridionmycosis, which appears to be responsible for many mass frog die-offs in Australia and the Americas and even for local extinctions of as many as eight amphibian species in the high-elevation tropical rainforests of Costa Rica and Australia. "This is a very rare example of a wildlife disease wiping out multiple species over large areas, in pristine habitats, and on a global scale," Daszak says.

The culprit is a chytrid, a type of fungus found in streams and moist soil worldwide but never before known to infect vertebrates. Because of its global distribution, Daszak suspects that this fungus may have long been endemic in lowland frogs, infecting them in the cool of spring or fall and then dying back in the heat of summer. He hypothesizes that in the past few decades, as people have begun moving higher into the forests, this chytrid has somehow "been introduced into montane regions where it's cool enough all year round to really let it cause havoc in species that never have been exposed."

Preliminary findings by Daszak and others show that the chytrid fungus may be hiding out in an unusual place: tadpoles. This fungus feeds on the protein keratin (the main constituent of hair, nails, horns, and snake and frog skin), which abounds in dead matter in the soil. The mouthparts of tadpoles also consist of keratin, enabling the chytrid to subsist in larval frogs.

The fungus seems to do no harm until the tadpoles start to metamorphose and develop the keratin-rich skin of the adult stage. At this point, it apparently spreads from the mouthparts to the rest of the body, killing the young frogs. "It seems the disease can move into an area, wipe out all the adults, and then live in the environment or in the larvae, which survive in the stream for the rest of the year," Daszak says. "More adult frogs arrive the next year, and the chytrid moves onto them and kills them."

The effects of such a virulent, unusual pathogen will undoubtedly ripple throughout the ecosystem. When rinderpest decimated grazing animals on the African savannas, vast stretches reverted to bush and thicket, providing habitat for the tsetse fly, which carries sleeping sickness. Daszak suggests that loss of tadpoles from tropical mountain streams could cause an overgrowth of the algae they feed on, a decline in water quality, and an unpredictable disruption of the food web.

If pathogen-driven extinctions of mountain frogs are confirmed, they would represent a first for wild populations. But disease is already known to have delivered the coup de grâce to one species whose few remaining individuals had been placed in a captive-breeding program: two years ago, Daszak and colleagues confirmed "the first definitive example of extinction by infection" when they reported that a protozoan parasite had killed the last Polynesian tree snails (*Parula turrita*), a species that was already gone from the wild.

Andy Dobson is quick to point out that the threat posed by emerging pathogens makes up only half the story: "Just as surely as we're causing lots of extinctions in free-living organisms," he warns, "we're creating lots of extinctions in parasitic ones." The disappearance of these organisms may go largely unremarked, indeed unnoticed, but given the ecological power of pathogens and parasites, their passing will not be without effect.

A science writer and frequent contributor to Natural History, Yvonne Baskin is at work on a book about invasive plants, animals, and pathogens.

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Walking on Water

Also rowing, galloping, and sailing—these spiders do it all.

*Story by Carl Zimmer ~ Illustrations by Sally J. Bensusen*

A handful of animals can perform the biomechanical miracle of walking on water. The insects known as water striders flit about on the surface of streams and ponds, and the basilisk lizard (sometimes known as the Jesus lizard) of Central America can rear up on its two hind legs and dash across short stretches of water. An even more accomplished water walker is the fishing spider (*Dolomedes triton*). Basilisk lizards and water striders use only a single gait on water, while fishing spiders can use three different kinds of locomotion, switching from one to another whenever they’re so inclined. For them, the surface of the water is like a dance floor.

**ROWING**

Dimples form where a fishing spider’s legs touch the water’s surface. To row across the water (left to right), a spider uses its middle pairs of legs, sweeping first the third pair from front to back, then the second pair. The dimples act like oars, pushing the spider forward.
Fishing spiders live throughout the United States, although they’re particularly abundant in the South. They lurk along the edges of ponds and streams, and when insects drop to the water, these spiders rush across the surface to attack. They can also dip their legs underwater and grab swimming tadpoles and small fish.

The first order of business for animals with this lifestyle is to stay on top of the water. Fishing spiders do so by taking advantage of surface tension. Water molecules are more attracted to one another than they are to molecules in the air. This molecular pull makes the surface of water act like a sheet of rubber. When a spider sets a leg on the water, a dimplelike depression forms around it, and the water pushes back up to regain a smooth surface.

Surface tension is not a very powerful force—try resting a stone on the water, and it will sink like, well, a stone—but the spiders are real lightweights, usually weighing less than a gram. In addition, the spiders’ legs have a waxy coating that repels water. Their legs are also long, a helpful attribute. Because surface tension pushes on the edges of objects sitting on water, long legs—with their long edges—mean more surface tension. (The same principle explains why a needle will float on water if you set it down carefully.)

Although surface tension can keep fishing spiders afloat, it makes it hard for them to go anywhere. On land they can push their legs against solid ground, generating an opposing force that carries them forward. Their waxy legs can’t get a purchase on the surface of the pond, however; the water is, in effect, too slippery to permit the spiders to move.

But move they do, and for the past few years Robert Suter, a biologist at Vassar College, has been studying just how they do it. What he has found is that the spiders row across the water’s surface by using the dimples their legs make in it. When a fishing spider moves one of its legs from front to back, it draws that dimple back with it. As the dimple moves, it acts like an oar, pushing against the surrounding water and creating a force that propels the spider forward.

A fishing spider rows with the middle two of its four pairs of legs. First it swings back its third pair, then the second pair, and when both pairs are extended as far back as they can go, the spider raises them from the water and brings them forward again. Meanwhile, it keeps its front and rear pairs of legs motionless, using their surface tension to keep itself afloat while it prepares for the next stroke. (Although no one has carefully studied the biomechanics of water striders, Suter says that they, too, move by rowing. But because they have just three pairs of legs, only their middle pair can use dimples as oars.)

There’s a limit to how fast fishing spiders can travel this way, however. To speed up, a spider can either make deeper dimples (giving itself bigger oars) or push them back faster. Yet both these strategies produce greater pressure from the surrounding water, and beyond a certain point, that pressure overcomes surface tension and the dimples collapse.

Thus if they need to go faster than about a foot per second, spiders have to shift to a second gait, which Suter calls a gallop. They rear up, hold their legs up almost vertically, and then slice them down into the water, essentially cutting through the surface. A galloping spider cannot rely on surface tension to keep afloat. Instead, when the spider pushes its legs down and back, the water responds with an opposing force, pushing up and forward. The upward force keeps the spider from being submerged, and the forward force propels it. (Basilisk lizards use a similar technique as they run on water.) Somewhat similar to a galloping horse, the spider, having once pushed off the water with its legs, is completely airborne.

Galopping, which can propel fishing spiders at three feet per second, is hard work. Spiders probably use it only when they need to reach top speeds to chase fast prey or to avoid becoming prey themselves. At less urgent times, the spiders may rely on a third and more efficient form of locomotion: sailing. When a breeze blows, fishing spiders sometimes wave their two front legs into the wind (smaller spiders raise their entire bodies) and let the breeze push them across the water like sailboats. Because the water is so exquisitely slippery under the spider, even a weak push can carry the creature across a pond.

Carl Zimmer’s book Parasite Rex is forthcoming from Simon and Schuster. Zimmer also wrote “The Hidden Unity of Hearts” for this month’s Natural History.
The First Day of the Rest of Our Life

Or, What I Did on January 1, 2000

By Stephen Jay Gould

The comparison of the human body with the universe—the microcosm with the macrocosm—has provided a standard device for explicating both the factuality and the meaning of nature throughout most of Western history. When Leonardo da Vinci, for example, likened our bodily heat, breath, blood, and bones to the lavas of volcanic eruptions, the effusions of interior air during earthquakes, the emergence of streams from underground springs, and the rocks that build the Earth’s framework—and then interpreted both sequences as particular expressions of the four Greek elements of fire, air, water, and earth—he did not view his argument as an excursion into poetry or metaphorical suggestion but as his best understanding of nature’s actual construction.

We now take a more cynical, or at least a more bemused, view of such analogistic reveries, for we recognize that the cosmos, in all its grandness, does not exist for us or as a mirror of our centrality in the scheme of universal things. We would now freely admit that most attempts to understand such geological or astronomical scales of size and time in terms of comfortable regularities noted in our short life spans or puny dimensions can only represent, in the most flattering interpretation, an honorable “best try” within our own mental and perceptual limits or, at worst, yet another manifestation of the ancient sin of pride.

As a striking example, however unrecognized by most people who could scarcely avoid both walking the walk and talking the talk, the recent fuss over our millennial transition cannot be entirely ascribed to modern commercial hype, because the taproot of concern draws upon one of the oldest surviving arguments about deep and meaningful coincidence between the human microcosm and the surrounding macrocosm of universal time and space—in this case, an explicit comparison of human secular calendars to the full sweep of the creation and subsequent history of Earth and life.

By this reckoning, January 1, 2000, should have marked the termination of I feel not the slightest discomfort—on the contrary, nothing but joy—in singing the text of Haydn’s Creation. Its factual inaccuracies are quite irrelevant.

The old order and the inception of something new and at least potentially glorious. This momentous turning of calendrical dials should therefore have inspired our attention for reasons almost immeasurably deeper than the simple visual attraction of changing all four markers from 1999 to 2000—the “odometer rationale,” if you will. (Of course, the vast majority of people in our secular and technological age have forgotten this old, and factually discarded, Christian argument for the significance of millennial turnings. But vestiges of these historical claims still affect both our calendars and our discourse. Moreover, and with potentially tragic results, these vestiges persist as...
The traditional linkage of human calendrical microcosms to universal historical macrocosms followed an argument in five stages:

1. The original millennium, as expressed in the famous biblical prophecy of Revelation, chapter 20, referred to a future 1,000-year period of bliss following the return of Jesus and the binding of Satan, not to a secular passage of 1,000 years in recorded human history. How, then, did the primary meaning of “millennium” change from the duration of a future epoch to the ticking of current calendars?

2. The earliest Christians expected an imminent inception of the millennium, as Jesus had apparently stated in foreseeing his quick return after bodily death: “Verily I say unto you, there shall be some standing here, which shall not taste of death, till they see the Son of man coming in his kingdom” (Matt. 16:28). The failure of this expectation unleashed an extended discussion among early Christians on the meaning of the millennium and the true timing of the Second Coming of Christ.

3. Opinions varied widely, but the most popular claim rested upon several biblical passages suggesting an equation of God’s days with a thousand human years, as in the admonition of 2 Peter 3:8, “But, beloved, be not ignorant of this one thing, that one day is with the Lord as a thousand years, and a thousand years as one day.”

4. The link between human calendars and the inception of the true millennium then rested upon an analogistic argument that we, by modern standards, would tend to regard as fuzzy, indefinite, and metaphorical but that seemed quite satisfactory to many of our forebears (who used their equally powerful brains in different conceptual contexts): If God created the Earth in six days and rested on a seventh, and if each of God’s days equals 1,000 human years, then Earth’s full history must mirror God’s complete span of creation by enduring for 6,000 years, while God’s seventh day of rest must correspond to the forthcoming, blissful millennium of 1,000 additional years. If, therefore, we can count Earth’s history in millennia (periods of 1,000 years representing God’s days), we will know, with precision, the end of the current order and the time of inception for the true millennium, for this transition will occur exactly 6,000 years after Earth’s beginning.

5. This argument inspired a burst of scholarship (culminating in the seventeenth century) that tried to use the Bible and other ancient records to construct a true chronology for universal history. In the most popular scheme, Christ’s birth follows Earth’s creation by exactly 4,000 years, and the current order may therefore persist for an additional 2,000 years. Finally, if the birth of Jesus occurred at the B.C.–A.D. transition of our calendar, then the end of this secular millennium...
should terminate our current order and initiate the blessed millennium (in its original meaning) of Christ's Second Coming. Clearly, then, we should care about microcosmal human calendars because they mark the epochs of macrocosmal universal history and prepare us for the fearful apocalypse followed by a better world to come.

I have presented this influential argument of Christian history as a prologue to the following segue inserted to remind readers about the most boring of all topics for essayists, as we all remember so well from our primary-school years: the inevitable “what I did on my...” that was assigned upon inherent limitations of this general topic.

The purely factual resolution requires but a sentence: I sang in a performance of Joseph Haydn's great oratorio The Creation, presented by the Boston Cecilia at Jordan Hall on New Year's Day. For my larger aim of transcending boredom from the most unpromising of all general topics, let me try to explain (an effort, alas, that will take a bit more space than the factual assertion stated just above) why the conjunction of this particular piece with the millennial day strikes me as so optimally appropriate in a general and symbolic sense; why the privilege of participation meant so much to me.

creation of Adam and Eve, Flemish school, 17th century

every return to school after an extended absence (with “summer vacation” and “Christmas break” as the most common particulars). I shall now dare to regale you with an essay in precisely this dreaded form: “What I Did on the Millennial Day of January 1, 2000.” I can only hope and pray that my prologue, combined with a forthcoming explication, may build an apparatus for overcoming the personally (an otherwise private matter, but vouchsafed to essayists ever since Montaigne defined this genre more than four centuries ago as personal commentary upon generalities); and why a topic so off the left-field wall (to combine two common metaphors for the bizarre)—namely, a musical composition on a text drawn from the same creation narrative, Genesis 1, now urged by our antiscientific...
How did the primary meaning of “millennium” change from the duration of a future epoch to the ticking of current calendars?

issues about dates before we come to Haydn’s magisterial creation of light in C major:

1. With apologies for shining the factual torch of modern science on the best-laid intellectual schemes of ancestral mice and men, Earth is really about 4.7 billion years old, and life’s known fossil record extends back about 3.6 billion years, so days and millennia scarcely qualify as terms for a serious discussion of factual matters related to life’s origin and history.

2. Even within the system that exalted millennial transitions as God’s days and the end of the sixth transition as the termination of our current universe, the year 2000 really doesn’t qualify for much consideration. You see, poor Dionysius Exiguus (Dennis the Short), the sixth-century monk who devised the B.C.–A.D. calendrical system, made a little error in setting Christ’s birth. We have no direct testimony about the historical Jesus, and no eyewitness account can set his time of birth. But we do know that Herod died in 4 B.C. (kings tended to leave better written evidence of their lives than poor kids born in stables). Now, if
Herod and Jesus overlapped—and some of the most rousing biblical stories (the Slaughter of the Innocents; the return of the Magi to their own country, rather than their making a detour to Jerusalem and presenting their promised report to Herod) must be discounted if they did not—then Jesus, despite the oxymoronic nature of the claim, must have been born in 4 B.C. or earlier. Thus, by the millennial chronology, the current order should actually have ended a few years ago—and it didn’t.

3. Even if we had never heard about this inconvenient issue of Jesus’ birth or just wish to maintain a polite fiction about his appearance right at the B.C.—A.D. junction, we have still erred in concentrating our millennial fears on the 1999–2000 transition. Again, we must recognize Dionysius Exiguus as the culprit, although we cannot cast much blame this time. No zero existed in Western mathematics when Dionysius performed his calendrical duties, so he began A.D. time on January 1 of the year one—and our calendar never experienced a year zero. Now, if you believe that the blessed millennium of Jesus’ Second Coming will begin exactly 2,000 years after the inception of A.D. time, then you still have another year to wait, for the completion of 2,000 years since Jesus’ birth occurs at the 2000–2001 transition, not on the fearful day that has recently passed.

As most folks know by now, this same issue underlies the great, unresolvable, and basically silly debate about whether the new millennium starts at the beginning of 2000 or of 2001. I won’t rehearse this particularly well beaten and very dead horse, although you may all consult my now remaindered book Questioning the Millennium if the subject still holds any interest for you. I will only observe, and then promise never to raise the subject again, that this debate expresses nothing new but has erupted at the end of every century (admittedly with greater intensity this time because our turning encompassed a millennium as well and also happened to unfold in an age of media overkill about everything). I merely append a figure (see below) of a French pamphlet published in 1699 and entitled “Dissertation on the Beginning of the Next Century and the Solution to the Problem, To know which one of the two years 1700 or 1701 is the first of the Century.” As our Gallic cousins like to say, “Plus ça change, plus c’est la même chose” (“The more things change, the more they stay the same”).

Haydn’s text faithfully follows the six-day sequence of creation in Genesis 1—the basis (by the traditional argument outlined above) for regarding the day of our singing as the end of history and the inception of a new order. (Haydn wrote The Creation in German but based it on a translated English text, taken mostly from Genesis and from some paraphrases of Milton’s Paradise Lost. Haydn published the text in both English and German, apparently
intending his piece for performance in either language.)

One can easily formulate the obvious and legitimate rationales: “Such great music, but . . .” and “You can’t blame Haydn in 1798 for not anticipating what Darwin would publish in 1859.” But shouldn’t a paleontologist and evolutionary biologist, sitting onstage in the chorus, become at least a bit uncomfortable when the angel Raphael, recounting the origin of land animals on the sixth day, explicitly proclaims their sudden creation “in perfect forms, and fully grown”?

I don’t deny that participation in some great music can raise difficult issues and cause considerable emotional distress, particularly the strongly anti-Semitic choral passages (representing the Jewish crowd taunting Jesus or demanding his death) in J. S. Bach’s sublime St. Matthew and St. John Passions, perhaps the greatest choral works ever written (the power and quality of the music only enhances the discomfort). I find the “blood guilt” passage from the St. Matthew Passion especially disturbing because I know that these very words served for centuries as a primary argument—often with explicitly deadly consequences for my people—for labeling Jews as the killers of Christ. For my own, personal resolution, I decided long ago that whenever we sang this work, I would at least mention, during our first rehearsal, the historical context of this text, based on the statement of the Jewish crowd after

“But, beloved, be not ignorant of this one thing, that one day is with the Lord as a thousand years, and a thousand years is as one day.”—2 Peter 3:8
Pilate finds no guilt in Jesus and literally washes his hands of the affair: “Sein Blut komme über uns und unsere Kinder” (“Let his blood then be upon us and upon our children”).

I do, by the way, accept the different historical context of Bach’s time. I feel no enmity toward this great man, who may never have known a Jew and who probably never considered the issue as he simply set the literal text of Matthew. Nor would I ever consider changing the text for any modern performance, lest an understandable deed for a particular purpose establish a precedent and open a floodgate for wholesale revision of any great work to suit the whims of fashion. But I do think that the issue should never be avoided and should always be explicitly discussed in preconcert lectures or program notes.

But I feel not the slightest tinge of discomfort—and, quite to the contrary, experience nothing but joy—in singing the text of Haydn’s Creation. In explaining these different reactions, I must begin by saying that I don’t use factual accuracy as a major criterion for judging a musical libretto any more than I would look for aesthetic beauty (according to my personal sensibilities) or moral rectitude in assessing the validity of a scientific conclusion. (Much of nature’s factuality strikes us as both messy and unpleasant but no less fascinating thereby.) I recoil from the anti-Semitic Passion texts because they express the worst aspects of our common nature and because these words have wreaked actual death and havoc. Similarly, I embrace Haydn’s Creation text for its moral and aesthetic qualities, while regarding its factual inaccuracies as quite irrelevant and beside the point.

After all, we read the Bible as a source of moral debate and instruction, not as a treatise in natural history. Moreover, even if Haydn had decided to express the science of his day, he would not have written a libretto about evolution. As for creation in six days, Haydn, as a devout Catholic, surely never conceived the text as a set of statements about twenty-four-hour periods, for no literalist tradition existed within the doctrines of his church, and such interpretations had never gained currency after Saint Augustine’s denials more than a thousand years earlier. (Our currently active scourge of fundamentalism, or biblical literalism, arose later and from different traditions.) The basic analogy of God’s days to human millennia, while still ungentherous by the standards of geological time, surely illustrates a Catholic consensus for reading “days” of creation as sequential intervals, not as equal and predetermined tickings of God’s stopwatch.

All cultures generate creation myths, and such stories enter the drama of human life in a role far different from the part we assign to the fascination and utility of factual discoveries made by science. With this perspective, I can summarize my case for Haydn’s text in a paragraph: The Book of Genesis presents two strikingly different creation myths, told in chapters 1 and 2. I find two aspects of the second myth morally troubling, whereas (with one exception) I rejoice in the meanings and implications of the first story. Interestingly, Haydn’s text uses only the first story and explicitly deletes the one theme (human hegemony over the rest of God’s creation) that disturbs me (and has troubled so much of human history). I do not think that these textual decisions were accidental, and I therefore regard Haydn’s Creation as an affirmation of all the themes that a wise and maximally useful creation myth should stress—joy, generosity, and optimism—while not forgetting the dark side and our resulting capacity to make a horrid mess out of such promise.

The second creation myth of Genesis 2—the text that Haydn did not set—emphasizes two themes that I find less than inspiring: God’s demand (by fiat and not by explanation) that we must not seek certain kinds of knowledge, and an anatomical rationale for the subjugation of women. We tend to forget the profound differences between the two stories of Genesis, and we usually amalgamate parts of this second tale with our primary memory of the first story. In Genesis 2, God creates Adam first and then constructs the Garden of Eden. To assuage Adam’s loneliness, he then creates the animals and permits Adam to assign their names. But Adam is still lonely, so God creates Eve from his rib. (Genesis 1, Haydn’s text, says nothing about forbidden fruits and describes a simultaneous creation of man and woman: “So God created man in his own image . . . male and female created he them.”)

The theme of forbidden access to knowledge occurs only in Genesis 2: “And the Lord God commanded the man, saying, Of every tree of the garden thou mayest freely eat: But of the tree of the knowledge of good and evil, thou shalt not eat of it: for in the day that thou eatest thereof thou shalt surely die” (Gen. 2:16–17). (I recognize, of course, that some exegetes favor a benign meaning for these passages by reading them as statements about the need for moral restraint upon our darker capacities. But most people, throughout Western history, have regarded these words as a divine order that we not question certain (Please turn to page 82)
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Jerusalem is a must on any Israel itinerary, especially in this momentous year. Within the ancient walls of the Old City lie some of the world's major religious shrines. Outside the walls, the Mount of Olives, the Garden of Gethsemane and the Church of All Nations punctuate an endlessly fascinating landscape of archeological sites. A variety of early Christian artifacts are displayed at the Tower of David Museum of the History of Jerusalem, part of an enormous complex of buildings known as the Citadel, sections of which are more than 3,000 years old. Newly accessible to the public, the ancient Ramparts Walk offers the best view of the entire city. The holiest of all Jewish sites, the Western Wall is a remnant of the Second Temple retaining wall where Jews have come to for centuries to pray, mourn and leave their written pleas and prayers in its crevices. The Temple Mount marks the site of Solomon's Temple and Herod's Temple, where Jesus prayed and where Mohammed is believed to have ascended to Heaven. The Mount is topped by the massive Dome of the Rock and the Al-Aqsa Mosque, regarded as Islam's third holiest shrine. Of special significance to Christians, the Via Dolorosa follows the Nine Stations of the Cross from St. Stephen's Gate through the Church of the Holy Sepulchre.

A seemingly endless source of archeological finds, the Cardo was Jerusalem's main thoroughfare in the sixth century. A recent excavation has unearthed remnants of Israelite walls and Byzantine structures. In a more modern vein, the Israeli Knesset's reception hall features tapestries by Marc Chagall and the Israel Museum's Billy Rose Sculpture Garden is dotted with works by Henry Moore and other internationally renowned artists.

To the east of Jerusalem lies the otherworldly desert terrain surrounding the Dead Sea, the saltiest and most mineral-rich body of water in the world at the lowest spot on earth, 400 meters below sea level. Year-round, naturally filtered sunshine, high barometric pressure and a relaxed, pollen-free environment combine with its sulfur hot springs and famously therapeutic black mud to make this region the ultimate spa destination. Here, on a high plateau, Herod built Masada, destined to become a symbol of Jewish heroism in the revolt against the Roman conquerors. Recent excavation efforts have made Qumran — the Essene settlement in whose caves the Dead Sea Scrolls lay undiscovered for 2,000 years — more accessible than ever before. The En Gedi Nature Reserve is home to the region's most splendid flora and fauna. The Judean Desert, with its dramatic, craggy cliffs, offers special opportunities for adventurous hikes, climbing, and rappelling.

The Negev Desert is a multifarious natural wonder of stark mountain ranges, cratered canyons and massive sand dunes. Explorations by camel caravans, on horseback, or in desert jeeps lead through ancient highways, waystations, monasteries and fortresses hewn out of rocky cliffs, and Bedouin encampments that have changed little in 4,000 years.

At Israel's southernmost tip, on the shores of the Red Sea, lies the sun-drenched paradise of Eilat. On the site where the Queen of Sheba arrived on her historic visit to King Solomon, nature lovers now enjoy carefree days of escape and exploration in the mountains, on the sea, or underwater amidst some of the world's most beautiful coral reefs.

Three miles north of Eilat, the International Birdwatching Center invites visitors to observe the migration of over four million migrating birds of prey. The breathtaking Timna Park is home to King Solomon's Mines, where geological wonders tell their own story of the earth's earliest history.

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A view from within Jerusalem's Dome of the Rock.

variety of beachfront restaurants and cafes.
Tel Aviv is the centerpiece of a modern nation growing ever more cosmopolitan and sophisticated. This is a city made for walking, from its elegant beachfront promenade through its lovely parks, chic shopping districts and fine museums. Among Tel Aviv's newest cultural treasures is the New Center for the Performing Arts. The city's burgeoning cultural diversity is deliciously expressed in its cuisine, served in an equally diverse array of locales. The birthplace of modern Tel Aviv, the picturesque 4,000 year-old port of Jaffa is a fascinating destination all its own. Long a thriving artists' colony, Jaffa is also home to a wide spectrum of craft shops, galleries, and museums.

In Israel's Galilee region, pastoral settings evoke the feeling of Biblical times. Perched atop Mount Canaan at the highest point in Israel, the ancient holy city of Safed offers magnificent views east to the Sea of Galilee and the River Jordan. Safed is a favorite refuge for many Israelis who revel in the purity of its mountain air, the serenity of its tiny meandering medieval lanes, and the ornate brilliance of its brightly colored synagogues.

On the shores of the Sea of Galilee (also known as Lake Kinneret) lies the scenic and holy city of Tiberias, the ideal base for excursions throughout the Galilee, including the Mount of Beatitudes and Capernaum, two of Israel's most tranquil spots.

There has never been a better time to visit Israel. To mark the advent of the new millennium, Israel invites you to take a pilgrimage of your own design. A variety of special events, exhibitions, and opportunities have been created to make a visit to Israel in 2000 an even more extraordinary journey. Take part in a variety of tours, conferences, and festivals; enjoy special concerts and museum exhibits; commemorate your visit by fulfilling the Biblical injunction to plant a tree in the Holy Land. Whatever you choose to do, your trip to Israel promises memories to last a lifetime. •
FRANCE • More alluring than ever

As a fitting follow-up to its Ultimate New Year's Eve fête on the Champs-Elysées and at the Eiffel Tower, France invites visitors to join in a series of ongoing celebrations throughout 2000 and well into the 21st century.

Among the most notable commemorative programs are the Méridienne Verte and the Bastille Day 2000 Incredibile Picnic. On November 25, 1999, over 100,000 French school children and their teachers were invited to participate and witness the simultaneous planting of over 3,500 young trees marking the beginning of the Méridienne Vert, or Green Meridian, a 576 mile-long line along the Méridienne de Paris, running from Dunkerque to the north and descending south, via Paris, to Prats-de-Mollo, a village in the eastern Pyrénées close to the Spanish border. When completed in the late spring, this line of over 10,000 indigenous trees, including oaks, hornbeams, cedars, and olive trees, will traverse 8 regions, 20 departments and 337 cities and towns in France. Fields of poppies, clove, and other predominantly red flowers will be planted at 20 sites along the Méridienne Verte, and are expected to be in full bloom for the Incredibile Picnic, a huge national outing to be held along the Green Meridian on July 14, 2000.

On July 8, 2000, Paris will host “PériphéRock,” the Millennium edition of the annual “Fête de la Musique” featuring performances by scores of live rock-and-roll bands. The périphérique, the beltway of Paris, will for the first time be partially closed to traffic and transformed into a huge stage and nightclub where revelers will dance the day and night away to the sounds of top music groups from all over the world. The celebration will also continue well into the night in the city’s major squares and in the suburbs and throughout the country.

This year also marks the reopening of the Georges Pompidou Center, housing France’s National Museum of Modern Art, now tripled in size. The museum exhibits on two full levels a permanent collection of 1,400 works. The contemporary art collection, exhibited on level 4, includes works in the plastic arts, architecture and design from the 1960s to the present. Level 5 houses the modern art collection of 900 works dating from 1905 to the 1960s.

The restoration and expansion projects at the Louvre also reach fruition in 2000. Finishing touches this year include the completion of reorganized collections, including the Graphic Arts department, the Northern Schools 18th and 19th century paintings, and the Mediterranean Antiquities in the Denon Wing. The new Musée de la Publicité, housed in the Pavillon Marson of the Palace of the Louvre, is dedicated to advertising, featuring a collection of 10,000 posters from the 18th century to the present as well as thousands of television, film, and radio clips.

For the best buys, consider the La Carte Museum and Monument Pass, covering admission for 70 museums and monuments in Paris and its environs. It’s available for one, three, or five consecutive days for roughly $12, $25, and $37 US.

For more information visit www.2000enfrance.com.
Above & Beyond • Taking the road less-traveled

This season, consider destinations that offer a true departure from the norm and adventures that will expand your horizons, both geographically and personally. The volcanic island of Mauritius is distinguished not only for its exotic location and natural beauty, but for its unique heritage, history, and culture. Situated just north of the Tropic of Capricorn in the Indian Ocean, off the east coast of Madagascar, Mauritius is almost entirely surrounded by one of the largest unbroken coral reefs in the world.

The first attempt at actual colonization was made by the Dutch who arrived in 1598 and named the island Mauritius after Prince Maurice of Nassau, eventually abandoning their settlements in 1710. The French occupied the island between 1715 and 1818. The British takeover led to the importation of Chinese and Indian indentured laborers who were soon followed by traders of their own nationalities. In 1968, Mauritius gained independence from Britain and is now a sovereign Republic.

Today, visitors to Mauritius enjoy colorful reflections of the island's history in its languages, architecture, and cuisine. Local festivals reflect the variety and distinct flavor of this cultural melting pot, with religious ceremonies and fest days observing Hindu, Muslim, Chinese, and Christian traditions, among others.

The Maltese Islands offer an idyllic Mediterranean vacation to suit nearly any interest. Blessed with year-round sunshine and set in crystal clear waters, Malta and its sister islands of Gozo and Comino create the perfect setting for quiet relaxation, active adventure, or a bit of both. Malta's outstanding archeological and architectural sites "a living testimony to 6,000 years of history" serve as an impressive backdrop for all kinds of experiences, from the serene to the hypercharged. For lovers of music, theater, and the arts, Malta offers an abundant calendar of events. For the sports-oriented, the islands offer golf, tennis, sky-diving, horseback riding and a variety of watersports, from sailing and windsurfing to some of the best scuba diving in the Mediterranean.

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This year, why not take a trip to the truly wild side? International Wildlife Adventures, a Washington-based tour company invites intrepid nature enthusiasts to experience one of the world's most engaging wildlife events. Each year in the fall along the western shore of Canada's Hudson Bay, scores of polar bears gather around the bay near Churchill, Manitoba to await the moment when the water freezes so they can venture out to hunt seals. To make closer viewing of this natural phenomenon possible, the company is utilizing innovative Tundra Buggies® giant, soft tire vehicles that take explorers into the polar bears' domain. For those wanting an even more in-depth experience of the bears' world, there is a specially-designed Tundra Camp, a modular lodge on wheels set right on the shores of the Hudson Bay, serving as an excellent base for observation and photography.

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COLLARED GREENS

Story by Charles Bergman ~ Photographs by Steve Winter
Calling with loud, raspy screeches, a pair of great green macaws flew around the huge almendro tree several times before gliding onto a high branch. Deep within a nest cavity near the top of the tree, the pair's two chicks uttered hoarse coos, begging for food. Without entering the nest, both macaw parents began a soft murmuring exchange with the expectant young. At the base of the tree, Pam Wright and Ulisis Aleman waited, as they had all morning, hoping one of the parents would enter the nest hole and thus become easier to catch. Then, if all went well, they would outfit the two-and-a-half-foot-long bird with a radio collar and transmitter. Wright is the directress of and Aleman a long-time volunteer in a research project sponsored by the Tropical Science Center in Costa Rica. The information they gather may help determine the future of this macaw species in Central America.

Although *Ara ambiguа*, the great green macaw—also known as Buffon's macaw—is a magnificent bird by any standards, until recently this species has been a stepchild of Costa Rican conservation. A model among Latin American countries for its strong environmental policies, Costa Rica is home to an impressive system of national parks and reserves. But a look at a map of protected areas reveals that the land set aside—about 24 percent of the entire country—is primarily high mountain cloud forest and secondarily the beachy Pacific coast. Virtually none of the lowland tropical rainforests of northern Costa Rica near the Caribbean coast have received protection. Characterized by evergreens and broad-leaved trees, some reaching up as high as 200 feet, this disappearing wet lowland forest is the prime habitat of the great green macaw.

The situation probably owes something to the limited resources and economic realities of the region and to the sheer numbers of species to study and protect throughout Central America. Nevertheless, it is telling that a bird so large—the second-largest parrot in the Western Hemisphere—and endangered, according to the Convention on International Trade in Endangered Species (CITES), should have been overlooked. Local people knew the great green macaw (*lapa verde* in Spanish), but as recently as 1993 no description of the species' primary habitat, food sources, or nesting habits had appeared in the scientific literature.

That year, George Powell visited northeastern Costa Rica, near the Nicaraguan border. Then a conservation biologist for the Philadelphia-based RARE Center for Tropical Conservation, Powell was well known in Costa Rica for his research on the resplendent quetzal and his leadership in establishing the Monteverde Cloud Forest Reserve to protect the quetzal and other species. Powell also became interested in setting conservation priorities for the lowland rainforests, and he thought the great green macaw could serve as an indicator species, a kind of barometer of the health of the ecosystem.

Conferring with residents of the region, Powell launched a study of the parrot. Ulisis Aleman, a native of El Salvador but long a resident of Costa Rica, showed Powell his first great green nest, located on a farm for the cultivation of heliconia flowers, where Aleman worked. They found three more nests that year, and Powell returned the next year to set up a team and begin full-scale research. Today, while Powell continues to guide the work, Louisiana native Pam Wright directs project operations, leading a team of volunteers: Aleman and five women from five different countries, both Central and North American.

What makes the project unusual as well as successful—and has made possible the accumulation of much of the data—is the radio-collar technique developed by Powell. Together with biologist Robin Bjork, Powell pioneered the use of radiotelemetry to discover the seasonal movement patterns of the resplendent quetzal, and he was able to adapt the device to the macaws. Only one other study, conducted in Bolivia, has used radiotelemetry to study macaws. By 1999, thirty-seven great green macaws—nineteen adults and eighteen juveniles—had been equipped with transmitters.

Radiotelemetry has proved crucial in documenting the breeding ranges, foraging habits, and seasonal movements of the great green macaw. Such natural history information is a prerequisite of any sound conservation plan. The species' habitat is limited to lowland, primarily coastal, rainforests from eastern Honduras to northern Colombia. An

**The great green macaw project has a mission: to find out everything it can about the big parrot and save it from extinction. High tech is helping.**
In six years, the researchers have located fifty-one active great green macaw nests, although no more than nineteen have ever been in use in any one year.

Above, left: A parent bird peers from a particularly lofty nest cavity in an almendro tree. Veteran climber and macaw handler Ulisis Aleman quickly extracts the bird, center, and places it in a soft bag for its descent, right, to the hands of project leader Pam Wright.

isolated population of fewer than two dozen individuals survives near Guayaquil, in Ecuador. According to the 1989 Guide to Birds in Costa Rica, by E. Gary Stiles and Alexander F. Skutch, the species once nested throughout Costa Rica’s lowland forests. Through extensive fieldwork and local interviews, the macaw project has identified the major remaining breeding range of the birds in the country as an area roughly outlined by the Río Sarapiquí on the east and the Río San Carlos on the west; both these rivers flow into the Río San Juan, which forms part of the country’s border with Nicaragua. At about 2,600 square miles, this current range covers only 10 percent of the species’ original known range (see map, page 52).

During the first six years of the study, researchers located fifty-one active nests, although no more than nineteen were ever in use in any one year. Long-lived and slow-breeding, great green macaws take four or five years to mature and even then do not nest every year. Powell and Wright estimate that there are only about 35 breeding pairs and about 100 to 150 juvenile and other nonbreeding great greens in Costa Rica.

I visited the study area in the summer of 1998 and again in April 1999, when I met Pam Wright and her team at the cabin that serves as their research headquarters in Boca Tapada. A small agricultural town situated on the Río San Carlos, just twelve miles from the Nicaraguan border, it is reached by a dirt road that winds past huge plantations of pineapple, banana, and palm—the kind of cultivated landscape that is replacing the lowland rainforest in Costa Rica. Our plans were to stake out a great green macaw nest and try to capture one of the parent birds.

We drove for about forty minutes and then hiked for another half hour through largely treeless pasture to reach the nest. (Wright mentioned that just a generation ago, local people would see flocks of a hundred or more of the birds.) The nest cavity was high, about a hundred feet up a lone almendro tree that grew on a privately owned cattle ranch. Because macaws are intelligent and wary birds—not likely to approach their nest while a group of humans is milling about—Wright and Aleman, who had the trap apparatus, hid in some bushes at the base of the tree while the rest of us hunkered down farther off. Even then, the pair were skittish when they appeared, noisily circling as we waited and
Wright, above, records data as volunteer Tana Wood hoists a radio antenna that will help the team map the birds' movements. Left: Adult great green macaws average thirty inches in length and are the second largest of the macaw species, all of which are native to the Western Hemisphere.
storm clouds loomed. We had been stationed in the pasture for about four hours when they landed and finally neared the cavity.

As one of the adults slid over to the lip of the nest, Wright carefully reached for a rope at her feet. Wise to all the “moves” of the macaws, Wright held back when the bird made a quick ducking motion—a kind of head fake, she later joked—into the hole. Then, when the macaw swiftly slipped inside for real, Wright jerked on the rope. Attached to nearly invisible fishing line threaded through eye screws in the tree, the rope flicked a homemade trap of sticks and more fishing line over the nest hole. A piercing scream confirmed that the parent was inside with its two chicks.

Instantly Aleman began to hoist himself up the tree in harness and ropes. At the nest, and hanging far above ground, he used another stick-and-line device (this one looked vaguely like a lacrosse racket) to gingerly scoop the parent macaw from the nest while avoiding its powerful beak, which could snap a finger. He placed the bird in a sack and lowered it to the ground, where Wright and several volunteers handled the macaw with practiced efficiency. First they weighed it—it was three pounds—and checked for parasites and other health indicators. Then they fitted the bird with a brass collar and a radio transmitter. Trial-and-error work on captive birds with other collar designs had made clear that the collar had to be brass; macaws use their massive beaks to gnaw through any material that is less durable. The cylindrical transmitter on this bird’s collar was painted black and orange so that even when the transmitter died, the bird could still be identified. Because the antenna is inside the collar’s small brass cylinder, it cannot be chewed off. The macaw would now be known by its radio frequency, “76.8.”

To call a bird by its number is precise, if dull, but I found that none of the various names for this species prepares one for the beauty of the birds up close. This was especially true of the two chicks, which Aleman lowered one at a time for Wright to inspect and fit with identification bands. Their new plumage was particularly fresh and vibrant and shone like a forest of greens—lime to jade to emerald. The birds’ wings are blue and their tails a rainbow of yellow, red, and blue. In the young, the blue of the tail feathers is a gleaming turquoise. A shock of red feathers rims the beak like a bonnet, and one of the chicks had a splotch of cadmium yellow on its head. On their cheek patches the birds have small black feathers that form stripes, the patterns of which may vary with the individual. Biologist and macaw expert Charles Munn, who has studied macaws in Peru for many years, has shown that in scarlet macaws these facial markings are individualized, like fin-
The macaw chicks fledge, or learn to fly, when they are three to four months old, but they will remain with their parents for another year.

gprints. He suspects that the case is the same in great green macaws.

Wright and Aleman quickly returned all three birds to the nest. According to Aleman, who has seen all the nests, this one was typical in its roominess, at about four feet deep. The average nest, however, is a mere sixty to seventy-five feet off the ground. By observing nests, the team has learned a lot about the habits of great green macaws. A noisy courtship begins in earnest in November, with squawking, prancing, and strutting. By late January or early February, the female has laid one to three eggs. Only one parent, which the researchers assume to be the female (the sexes cannot be distinguished in the field), broods the eggs; the other delivers food. Once the eggs hatch, both parents forage and carry food back to the nest in their crops, regurgitating it for the chicks. Usually at the end of April, or about a hundred days after the eggs are laid, the young fledge—that is, they take their first flight. Still, the family will stay together for about another year.

Powell and Wright's macaw project has monitored eighteen nesting attempts and recorded an average success rate (chicks raised to the fledging stage) of 1.8 chicks per nest. This is slightly higher than the average for other macaws. Some researchers working with other endangered macaw species take a second egg and rear it by hand to increase the chances of the young's surviving and to augment the productivity of a nest. But Wright has found that more often than not, great green macaws fledge two healthy young on their own.

On another day, we visited the nest of radio-equipped macaw "29." Wright hoped to be able to put a radio collar on this bird's mate because she wanted to see whether pairs maintain their bond from year to year—a connection that is suspected but not documented. Situated much lower than the nest of "76.8," this nest was easier to watch. Macaw "29" and his mate ("29" had not incubated eggs, so Wright inferred it was male) worked as partners. They arrived together at the nest every two to four hours, fed the young, and always left together. Never silent, the birds announced their presence with screams, resonant and unmistakable even in a forest filled with natural sounds. Macaws are social and demonstrative. When not perched near the cavity and cooing constantly to the young, this pair would be high in a nearby tree, preening, grooming each other, beak nipping, and "chatting."

Like the other macaw family I visited, this one nested in an almendro. About 90 percent of the nests are located in this kind of tree. Scientifically known as *Dipteryx panamensis*, it is "emergent," with branches that poke through the high canopy of the forest, although on cattle ranches and in other cleared fields it stands stately and alone. The macaw project has shown that the life and future of the great green macaw are closely tied to this tree species. Not only do the macaws prefer the almendro for nests, they also avidly devour its fruit and seeds. A green legume about the size of an apricot, the fruit contains a large, hard seed, which is nevertheless easily crushed by the beak of a macaw. The tree is in fruit from October to

Left: A chick (sinking its already formidable bill into a woven bag) was fitted with an identifying leg band and returned to the nest. The pattern of black cheek feathers may be individual to each bird.
April, which corresponds with the great greens’ breeding season. At nests monitored by the project, 80 percent of all feeding observed during January has been on almendro. Wright noted that the birds seem to love the fruit; she has seen as many as thirty macaws feeding in a single tree. When the almendro is not in season, the macaws switch to another fruit, that of the *titor*, or *Sacoglottis trichogyna*, which forms the bulk of the macaws’ diet from April to June.

According to the radiotelemetry data, foraging and seasonal movements are closely connected. The research team uses ATVs, aerial surveillance, and plain bushwhacking to follow radio signals, and they have pieced together the pattern of the species’ movements. Great green macaws are elevational, rather than distance, migrants. When *titor* becomes scarce in the breeding range, a few birds stay and manage on what they can find, a few move into Nicaragua to look for food, but many move upslope. The family of bird “29” is typical. At the end of June, both adults and the one surviving juvenile (also radio-collared, and known as “8.7”) moved about twenty-four miles south of the nest site. The project members located them as they fed near the La Selva Research Station, at about 900 feet elevation, where *titor* is more densely distributed. Then, in September, the family migrated again, up to 2,100 feet in the mountains of Costa Rica’s Central Range. At this point, the birds were feeding on a wide variety of fruit, some thirty different species.

Like most species of parrot, great green macaws have suffered as a result of hunting and the pet trade, but their most serious problem is the loss of their habitat to agriculture. The fertile lowlands are especially coveted by agricultural interests, and economic pressure is brought to bear to clear land for tree and fruit plantations. A study of deforestation in Costa Rica conducted in the 1970s and 1980s revealed that forests were being lost at a rate of 3 percent a year. Between 1986 and 1992—until the year before the macaw project began—satellite images of the species’ breeding range showed a 35 percent loss.

The favored almendro tree once enjoyed a kind of de facto protection because its wood was too hard to be cut readily. As a result, many individual almendros have survived, often standing alone in otherwise cleared fields that are used for cattle grazing. In the 1990s, however, almendros have fallen victim to new and tougher saw blades. Since the macaw project began, 16 percent—or 8 of 51—of the nest trees the team has monitored have been chopped down.

The project has developed a macaw conservation plan that focuses on the protection of habitat. Only small sections of Tortuguero and Braulio Carillo national parks jut into the macaws’ breeding range. The project hopes to protect enough land in both the breeding area and the migration area to support at least fifty breeding pairs. In conservation

The future of the great green macaw is closely tied to the almendro tree. Not only do the macaws nest in the almendro, but they also avidly devour its fruit.

Now eight years old, Paquita, opposite, was a chick when her nest tree, an almendro, was cut down. Although young macaws are often sold to the pet trade, she was saved and raised by a local resident.

biology, that is the minimum necessary for a population to maintain its numbers in the short term.

In 1996 the Comisión Nacional Lapa Verde, made up of local residents, government representatives, planters, and even a few loggers, successfully lobbied for the setting of some limits on almendro harvesting. Along with project volunteers, the commission is active in an outreach program to inform local people of its work. The great green macaw is becoming a symbol of local pride.

As their natural history becomes better known, these birds may prove to be their own best ambassadors. This was brought home to me at the third nest I visited with the team. Wright and Aleman were hoping to radio-tag one of the young before it fledged. When we arrived, it was clear that one chick was indeed close to flying for the first time. It sat peering out at us from the nest cavity and watched with an almost comic attentiveness as Aleman scaled the almendro, scrambling over epiphytes and bromeliads growing on the tree trunk. When Aleman neared the hole, the young bird squawked and jumped—into the air.

We watched as it sagged into its maiden flight, pounded its wings as it plunged toward the ground, and then caught enough lift to rise, if unsteadily. Although this meant one less bird collared, we cheered and clapped; it was the first time Wright had seen a juvenile fledge. The young great green macaw wobbled aerially into a nearby copse of trees, where it disappeared in the dense leaves, green vanishing into green.
The Hidden Unity of Hearts

BY CARL ZIMMER

Every second or so of every minute of every hour of every day, something remarkable happens inside your body. The valves of your heart open, blood surges into its chambers, the heart contracts, and then blood comes blasting out, either to load up with oxygen in the lungs or to flow into the rest of your body. Every beat of your heart is the result of a precise choreography of electrical impulses and swirling fluids, a choreography without which you’d be dead in minutes.

Over the past several years, scientists have gone a long way toward figuring out how this complex and vital organ evolved. By comparing the hearts of living animals and unlocking the genes that build them, they have found that while there may be no physiological truth to the expression “my heart is in my throat,” that may be exactly where hearts began. They’ve also discovered that the change from simple tube to complex, chambered organ may have happened in an evolutionary flash.

The first foreshadowings of the heart reach back to at least 800 million years ago, when the first known multicellular fossils formed. A single cell can draw in oxygen and nutrients through its membrane, but once cells start huddling together, some will be cut off from the outside world. Cells can pass nutrients to one another across their membranes, but it’s a slow process that works only over tiny distances. An animal of any size needs a plumbing system.

You can find a simple (though elegant) version of plumbing in sponges, which are among the most primitive animals on the planet. The sponge is shot through with tunnels that branch into smaller and smaller tunnels. Lining the tunnels are cells with little hairs that wave back and forth, pumping water through the organism at a tremendous rate; as the water flows past, the cells extract oxygen from it and filter out particles of food. These tunnels enable a sponge to bring seawater directly to all its cells, making it, in a sense, a multicellular animal trying to live a unicellular life.

But evolution later produced more complex animals, with cells that could no longer fend for themselves. The bodies of these more complex organisms have cells of many different types, each dedicated to its own specialized work. A photoreceptor cell in a squid’s eye, for example, helps the squid see but doesn’t feed itself. These animals need a circulatory system to replenish their cells, and they need something to keep that system pumping. You can find hearts, or heartlike structures, beating in the bodies of many complex animals, including mollusks, arthropods, and chordates (among which are vertebrates such as ourselves.) Yet few of these hearts, other than those of vertebrates, resemble our own.

A fly’s heart, for instance, is a muscular tube that simply squeezes the insect version of blood (called hemolymph) into the body cavity, rather than being connected to a closed system of veins and arteries. The fly’s heartbeat is somewhat like the peristalsis in your digestive tract: a simple ripple of contraction. Unlike flies (and more like us), the earthworm has a closed vascular system, but instead of a heart, it has eleven contracting vessels, each of which pumps much as a heart does. The octopus

*Studies of an ox heart, by Leonardo da Vinci, ca. 1512*
(a mollusk) has two powerful, chambered hearts, each pumping blood through a set of gills.

For decades, biologists assumed that all these hearts, which look so different from one another, had evolved independently. But in recent years, research on how genes orchestrate the development of hearts within embryos has revealed a hidden unity. In the laboratory, scientists alter or remove particular genes in animals and then look at the consequences in the developing embryo. The deformities that result from these experiments help the researchers figure out a particular gene's usual role in development.

Much of this work has been done on mice, which have the advantage of being closely related to humans but which have some drawbacks as well; for one thing, their embryos grow inside a uterus and are difficult to observe. Other experiments have involved organisms that are less closely related to us yet easier to study, such as vinegar worms and fruit flies. A major breakthrough came in 1993, when Rolf Bodmer at the University of Michigan discovered the gene that controls the development of the fruit fly heart; a fly that lacks this gene never forms a heart at all. The gene was named tinman, after the Tin Woodman in the Wizard of Oz, who joins up with Dorothy and sets off for the Emerald City to ask the Wizard for a heart.

Tinman belongs to a special class of genes. Many genes carry instructions for making a single protein that has a specific job—to build fingernails or make hemoglobin, for example. But some genes make proteins that control other genes. Some act like master switches, triggering many different genes to work together to build a structure. Tinman is one such “master gene” for the fruit fly. Within a few years of its discovery, scientists found master genes for building hearts—named, far less poetically, Nkx genes—in mice as well.

What surprised scientists is just how similar the mouse's Nkx genes and the fruit fly's tinman are. When they compared the genes' sequence of base pairs (the bonds between the strands of DNA's double helix, which carry genetic information), many parts were practically identical. What's more, the genes that control Nkx genes, and the genes that Nkx genes control in turn, are also similar to the genes that play the same roles in flies. The only logical conclusion was that tinman and Nkx genes have a common origin in the common ancestor of insects and mammals, which scientists think was probably a flatwormlike animal that lived 700 million years ago or so. This creature most likely had a heart much simpler than any of its descendants has today—perhaps nothing more than a crude muscular tube capable of contracting regularly.

Genes also provide a hint as to where that first protoheart might have come from: the throat. The tinman and Nkx genes bear a striking resemblance to a gene that helps build the throat muscles in nematode worms. So here's a possible scenario for how the first heart evolved. Every now and then during cell division and reproduction, one gene (or, rarely, a group of genes) is accidentally duplicated. Perhaps this happened to the genes that induced throat formation in a lineage of primitive animals. At first, the second set of throat genes may have kept on doing their original job of helping to build the throat. Then, thanks to a mutation, the genes started switching on in cells in a different part of the animal's body. Instead of making a muscular tube that pumped blood, these genes began to make a muscular tube that pumped blood.

It's a long way from a simple tube to the chambers and valves of the vertebrate heart. A look at the history of vertebrates suggests the stage at which hearts became complex. Vertebrates probably descend from an ancestor similar to ascidians (chordates also known as sea squirts). In their larval form, ascidians have some anatomical features much like our own. They have, for example, a precursor to the backbone, a gristy rod in their backs known as a notochord. As adults, however, they root themselves to the seafloor to filter out food from the water, develop a throat with gill slits, and lose their notochord. An ascidian's heart is little more than a glorified stretch of blood vessel.

The oldest true vertebrate fossils date back 530 million years. Less than 100 million years later, the first fish evolved, and because the hearts of all fish alive today have chambered hearts and tightly synchronized contractions, biologists assume that their common ancestor—the first fish—did, too. As it does in living fish, the blood would have flowed past the gills to pick up oxygen and then continued on to the rest of the body. A new kind of cell layer, called the endocardium, would have lined the heart, thickening it and making it more powerful. Eventually the heart itself grew larger.

"The question is, how do you transform a simple tube into a vertebrate heart in relatively little evolutionary time?" asks Mark Fishman, a geneticist at Massachusetts General Hospital. "That's a remarkably ornate change."
To answer that question, Fishman and other researchers turned to genes—specifically to the genes of the zebrafish (Danio rerio), a species common in home aquariums but relatively new as a “model animal.” Because it’s a fish—not an insect, such as the fruit fly—the zebrafish has a multichambered heart. And unlike a tiny mouse embryo hidden inside its mother’s uterus, a zebrafish larva matures on its own. Even better for those who want to study hearts, its body is transparent.

When Fishman started studying the embryonic zebrafish heart, however, he wasn’t sure “if the heart would be decipherable, because the genes might be used more than once in development.” In other words, a gene involved in the formation of the heart might have had another job earlier in an embryo’s development, when the embryo was just a ball of cells. If Fishman created a mutation that made such a gene inactive, the embryo would never become anything more than that ball, and he’d never discover the gene’s normal role in building the heart.

“Fortunately, that turned out to be a false worry,” says Fishman. His team and others have found more than a hundred genes involved in heart development. After tinman-like genes have finished creating a simple tube, these other genes switch on, transforming the tube into the complex organ we’re familiar with. And some of the genes took Fishman by surprise. By knocking out a single one of them, his group could create a heart that was missing its ventricle but was otherwise normal; knocking out a different one produced a heart that was missing valves but nothing else. These genes seemed to be in charge of little modules of genes that worked together to build specific parts of the heart. Fishman ended up finding about a dozen heart-module genes. “It was more than we could have hoped for,” says the geneticist. “It meant we could dissect organ development, because we had individual elements that could be removed.”

Fishman also realized that the way these heart-module genes work in living fish might hold a clue to the evolution of vertebrate hearts. It’s possible that the complex, chambered heart didn’t change gradually, with many genes evolving minor mutations that changed their functions. Instead, each of the heart modules may have existed in earlier vertebrates, where they performed other, still-unknown jobs. Merely by tinkering with the master gene that controlled a module, evolution could have quickly invented a new structure for the heart. To picture the difference between these two kinds of evolution, imagine building a concrete bridge. If you build it by adding sand grains one at a time, it will take a lot longer than if you assemble it from large prefabricated blocks.

With powerful chambers, valves, and all the other parts of the vertebrate heart in place, the blood of an early fish could be pumped at higher pressures and therefore travel farther from the heart. And this souped-up circulatory system meant that fish could grow large enough to hunt down smaller prey. Thanks to a genetic revolution, Fishman suggests, vertebrates changed from lowly filter feeders into the ocean’s top predators.

There’s a built-in problem with the fish heart, though. It pumps blood through the gills, where the blood loads up with fresh oxygen before traveling through the rest of the body, nourishing muscles and organs as it goes. By the time it returns to the heart, it has used up a lot of the oxygen. The heart is like a waiter who is forced to eat only the scraps left at the end of a meal.

This design can cause trouble when a fish tries to swim fast: the harder it swims, the more oxygen is devoured by its swimming muscles, leaving even less to nourish the heart. But there are a couple of ways to get around this constraint. One is to divert blood back from the gills to the heart while it is still rich in oxygen. That’s what some fish have done, evolving coronary arteries that move blood through the heart tissues. Tony Farrell, a physiologist at Simon Fraser University in British Columbia, has found that the flow of blood through the coronary arteries of a trout triples during exercise, enabling the fish’s heart to keep pumping hard.

Another way to become a stronger swimmer may be to evolve lungs. Today lungs are found not only in land vertebrates but also in a few obscure fish lineages, such as gar, bichir, and lungfish. Many other species of fish have swim bladders, which they use to control their buoyancy. For a long time, paleontologists thought that lungs had evolved from swim bladders, helping fish survive in stagnant waters, where oxygen often ran low. But the fish themselves tell a different story. About 420
million years ago, evolution split jawed fish into two great branches: cartilaginous (such as sharks and rays) and bony (everything else, from lungfish and trout to sea horses). Sharks have neither swim bladders nor lungs, suggesting that both these useful organs must have evolved in bony fish after the split. Which came first? The most primitive branches of bony fish all have lungs, while swim bladders are found only in the teleost branch. The simplest explanation of the evidence is that the common ancestor of today’s bony fish had lungs and that lungs turned into swim bladders in the lineage that led to teleosts.

The oldest fossils of bony fish all come from marine waters, where fish presumably didn’t have to worry too much about running low on oxygen. So why did fish evolve lungs, when they had gills that seemed perfectly well adapted for getting oxygen from water? Colleen Farmer, a physiologist at the University of Utah, thinks that the evolution of lungs made fish better swimmers. In air-breathing fish, some of the blood that flows through the gills gets diverted to the heart, and when these fish swim hard, they tend to breathe more air. Farmer suggests that they’re trying to keep their hearts supplied with enough oxygen. And that, she proposes, may have been the initial pressure driving the evolution of the first lungs some 400 million years ago. “These lunged fish,” says Farmer, “were active predators cruising around the open ocean.”

The question then becomes why (and when) so many fishes lost their lungs. Farmer speculates that the change started when rising to the surface to breathe became risky. About 220 million years ago, the sky began to fill with predators—scaly-winged pterosaurs and, eventually, birds—that snatched up the fish they saw while flying over the water. Perhaps fish species that lost their lungs flourished, while those with lungs became rare.

Fortunately for humans, one lineage of lunged fish hauled ashore about 360 million years ago, eventually giving rise to land-dwelling amphibians, reptiles, and mammals. In the millions of years that followed, these vertebrates have retooled their hearts in multiple ways. Hummingbirds evolved rapid-fire hearts that can beat twenty-two times per second; frogs and squirrels evolved the ability to slow down their hearts during hibernation. Whales returned to the sea and evolved huge hearts—in the case of the blue whale, a heart capable of pumping sixty gallons per minute. And crocodiles, when underwater, can redirect the flow of blood to bypass their lungs entirely. What makes these transformations all the more amazing is that the basic genetic recipe for the vertebrate heart hasn’t changed much at all. When it comes to the heart, we all swim with the fishes.
AND THE BEAT GOES ON
A BRIEF GUIDE TO THE HEARTS OF VERTEBRATES

BY WARREN BURGGREN

Biologists would love to know just how the vertebrate heart evolved from the simple, two-chambered organ of early fish to the complex, multi-chambered hearts of birds and mammals, with their two atria (which receive blood from the veins) and two ventricles (which pump blood back out through the arteries). Unfortunately, soft tissues rarely make good fossils, so we are unlikely ever to know for certain. But we can construct a hypothetical scenario by looking at the wide variety of hearts found in animals alive today. Amphibians, reptiles, birds, and mammals have been following independent evolutionary paths for millions of years, of course, and no modern biologist would dare suggest that a frog or alligator is a step en route to an eagle or human being. However, comparing the hearts of living vertebrates—and specifically how they handle the transport of oxygen to the body’s tissues (one of the organ’s most important functions)—can provide insights into what the intermediate steps between one type of heart and another might be.

We start with the heart found in most fish today: a relatively simple organ, with one atrium, from which blood flows into a single ventricle.

After leaving the heart, blood picks up oxygen at the gills, but by the time the blood returns to the heart, most of its oxygen is gone. With the evolution of lungs came a partial separation of oxygenated from deoxygenated blood, ensuring a steady supply of oxygen to the heart and its more efficient distribution to the rest of the body. The division of the atrium into two chambers—evident in living lungfish—was an important step toward more complete separation.

In the heart of modern frogs and toads, we see the beginnings of distinct ventricular chambers as well. Although these animals have only one ventricle, its spongy walls help separate oxygenated and deoxygenated blood: oxygen-rich blood flowing in from the left atrium tends to get soaked up by the left ventricular wall; oxygen-poor blood from the right atrium is taken up by the right wall. When the amphibian ventricle contracts, it expels all the blood into a central artery, where the two flows are again kept largely separate by a long winding valve that spirals down the length of the artery, functionally dividing it into two channels. Most of the poorly
oxygenated blood travels through the channel that leads toward the lungs and skin, where it picks up a fresh supply of oxygen (in amphibians, the skin also functions as a gas-exchange organ). Most of the oxygenated blood ends up in the channel that leads out to other tissues in the body, providing them with nourishment. Partial division of the ventricle can be seen in the lesser siren (Siren intermedia), a salamander with a ridge of muscle rising up from the floor of the ventricle.

Division of the ventricle into more than one chamber is more complete in turtles, tortoises, and snakes. In addition to two atria, these reptiles have a three-chambered ventricle, however, and so don't fit neatly on our hypothetical continuum. Enter the varanids, or monitor lizards, a group that includes the huge Komodo dragon of Indonesia. Like those of other reptiles, the varanid's heart has a total of five chambers, but one of the ventricles is little more than a small pathway for the blood that traverses the heart. There is still some mixing of oxygenated and deoxygenated blood from the other two, larger ventricular chambers but much
The varanid heart introduces, for the first time, a way to deal with a vital but potentially dangerous component of the circulatory system: blood pressure. High blood pressure helps the heart pump harder to deliver more blood more quickly to working muscles and other tissues in the body. Unfortunately, these same pressures can “blow out” the lung's delicate vessels, which operate most effectively at lower blood pressures. With its two nearly separate ventricular chambers, the varanid heart can pump at two different pressures: low for blood to the lungs, high for blood heading out to the rest of the body. Perhaps not surprisingly, this efficient heart enables some of the monitor lizards to be truly frightening predators, able to capture very active prey.

THE COMPLETELY DIVIDED HEARTS OF BIRDS AND MAMMALS CAN PUMP BLOOD HARD AND FAST TO WORKING MUSCLES AND MORE GENTLY TO DELICATE LUNG MEMBRANES.
We turn next to crocodiles and alligators, in which the heart has two anatomically separate ventricles. When breathing air at the water's surface, these reptiles, like monitor lizards, pump blood at two different pressures. Once they slip beneath the surface, however, they do not breathe, and their hearts produce a single, intermediate pressure. While underwater, crocodiles and alligators perform another neat heart trick: blood that would have gone to their lungs (which become less useful during a dive, as their oxygen is depleted) is shunted, via an extra aorta emerging from the right ventricle, back toward the general body circulation.

In birds and mammals, the separation of the left and right sides of the heart is complete. This allows for high-pressure distribution of blood to the body, with no risk to delicate lung membranes. (For diving birds and mammals, this is a mixed blessing. Whether resting on the beach or diving for food [when the lungs are not ventilated], a seal or penguin must pump the same amount of blood both to its lungs and to the rest of its body.)

The next steps on our hypothetical continuum have yet to be determined. The human heart is no more the ultimate in cardiac design than was that of reptiles before mammals evolved. Perhaps in the future, our descendants will inhabit other parts of the solar system. Could the vertebrate heart evolve to handle life on a planet with less gravity or less oxygen than we have on Earth? Or with more? If not, space colonizers will have no choice but to recreate Earth's environment wherever they go.

Warren Burggren, a biologist, is dean of the College of Arts and Sciences at the University of North Texas.
Most people think of Brazil nuts as the huge pointy things in a can of mixed nuts. To a botanist, however, Brazil nuts represent only one species in a large and diverse family of flowering trees, the Lecythidaceae, which dominate some Amazonian rainforests. Several years ago in the central Brazilian Amazon, working in a plot that measured slightly less than half a square mile, my colleagues and I were able to identify some 7,800 plants belonging to 38 species in the Brazil nut family. (During the same study, but in a smaller plot—the size of two and a half football fields—we found 285 species of trees in numerous plant families. In Wisconsin, where I grew up, there are only 74 tree species in the entire state!) Brazil nut trees are symbols of the Amazonian forest, where, as Charles Darwin put it, plants and animals have evolved such varied and diverse forms as to throw a naturalist's mind into "a chaos of delight."

As in the orchid family, which also delighted Darwin, many species of the Brazil nut family have evolved flowers that are adapted to specific pollinators—mostly various kinds of bees. The trees' seeds are dispersed by birds, wild pigs, agoutis, bats, and monkeys, as well as by wind and water. We are just beginning to grasp the complexity of these relationships; unfortunately, our understanding comes at a time when tropical forests are threatened with destruction. Flower pollinators, seed-dispersing animals, and Brazil nut plants—all these organisms are part of the intricate living mosaic that is life in the Amazon.
POLLINATORS OF TREES in the Brazil nut family include the female carpenter bee (*Xylocopa frontalis*), above, shown as she is about to enter the flower of a sapucaia tree. Proceeding headfirst into the blossom, the bee collects sterile pollen to feed her larvae. As she does so, she brushes against fertile pollen, picking it up on her head and back. When the bee flies to a distant tree, she will deposit this pollen on another flower’s stigma. Opposite page: Orchid bees (*Euloema peruviana*) visit an *Eschweilera pedicellata*, or *mahot* tree. For several months during the dry season, each flower cluster on the tree produces a single bright pink blossom daily. Once they have discovered a flowering tree, the bees return each day to gather nectar, visiting each cluster in rapid succession, apparently having memorized the locations of individual trees. Stamens in one area of the blossom are modified for producing the nectar sought by the bees; stamens in a second location produce fertile pollen that clings to the insects. A longitudinal cross section of a *mahot* flower, left, shows the bee’s extraordinarily long proboscis reaching around the flower’s inner curves to the nectar while the insect receives a dusting of fertile pollen on its thorax and head.
LIBERATING BRAZIL NUT SEEDS
by gnawing through the fruit's hard, thick casings, the red-rumped agouti, left, seeks a meal. Although the fruit's woody casing may have evolved to protect the seeds from predation, its opening is too small to allow them to fall out. The tree therefore depends on animals to open the fruits. Agoutis feed on some of the seeds immediately and cache others for future consumption; uneaten seeds germinate about a year later. The brown capuchin monkey, a seed predator, can recognize which fruits are about to open on a Cariniana micrantha tree, above. Tearing them from the stems, the monkey bangs them against thick branches to get at the small, nutritious seeds. Some fruits open on their own while still in the tree, releasing their seeds. Aided by winglike appendages, the seeds are carried away by the wind.
TRAVELING BY AIR EXPRESS, a sapucaia seed is transported by Palla's spear-nosed bat, above. The seeds are attached to a durable fruit casing by a cord with a fleshy outgrowth, or aril, at its base that bats find appetizing. The bats may later drop the seeds or discard them while roosting far from the mother tree. Right: The flowering and fruiting of the "monkey's bailing cup" coincide with annual floods produced by the rising Amazon. When the cup-shaped fruits open, the seeds drop into the water and, buoyed by their corky coats, are carried by the current.
Cuttlefish Say It

A mesmerizing repertoire of quick changes in skin color and texture qualifies cuttlefishes as masters of communication and disguise.

A fleet of tiny creatures swim the length of a shallow tank at the Marine Biological Laboratory at Woods Hole, Massachusetts, passing above yellow sand, then brown sand, then variegated pebbles, and finally a bed of white shells. These newly hatched animals, each no larger than a thumbnail, undergo instant and seemingly magical transformations as they travel the route, their skin color shifting from yellow to a tasteful khaki, to mottled black and white, to a uniform soft white. Protean masters of disguise, the apogee of marine crypsis, these young creatures are cuttlefishes, and according to their devotees, we should be so lucky.

Virtual reality pioneer Jaron Lanier is among the many people entranced by the fact that cuttlefishes seem to wear
With Skin
By Marguerite Holloway
Camouflaged against the reef, a male *S. plangon*, above, hovers over the female in a classic "mate guarding" pose (Australia). Opposite page, top: A male *S. pharaonis* defends a female from another suitor (Thailand).

their thoughts on their skin. “This is what virtual reality is about, the ability to directly express your images,” he says with obvious envy. Indeed, he asserts, the purpose of technology “is to turn people into cuttlefish.” A single cuttlefish can become speckled, ocellate, stippled, lineate, whorled, black, white, brown, gray, pink, red, iridescent—all in different combinations and all in less than a second. It can hold zebra stripes for hours or send waves of color flickering across its skin. It can make half its body white while the other half displays lines. Its skin can pucker into ripples and spines and bumps, then suddenly go smooth as polished stone. And that’s just the common cuttlefish (*Sepia officinalis*); each of the hundred or so other species has its own repertoire of quick changes.

Cuttlefishes—which, like snails and scallops, are mollusks—are highly advanced invertebrates, a distinction they share with several cephalopods, a class that includes squids and octopuses. But while cuttlefishes are closely related to these other ink-sputting, color-flexing creatures, they remain more mysterious, largely because they are for the most part so hard to observe in their natural habitats. Researchers have recently ventured into the field with night-vision video cameras and other high-tech equipment, but most of what we know about cuttlefishes still comes from the laboratory, where, often clustered together in tanks, these cephalopods—which are probably solitary by nature—continue to yield surprises. In the past few years, scientists have found that cuttlefishes can detect water motion in the same way that fishes do, that their large eyes (which have W-shaped pupils) can see polarized light, and that their reproductive behaviors and modes of communication are quite complex.
Cuttlefishes range enormously in size, from the two-inch _Metasepia pfefferi_ to the three-foot-long _Sepia apama_. But all have eight arms and two tentacles, the latter usually remaining retracted unless the cuttlefish is feeding. Like other cephalopods, cuttlefishes seem to grow quickly, mate once, and then die; most live for no more than eighteen months. Like squids and octopuses, cuttlefishes have a funnel for jet propulsion, but unlike the other two, they also have an internal, oval-shaped bony chamber that fills with gas. The result is that, as well as being able to swim and squirt backward and forward, they can gracefully hover, rise, and fall.

Found in tropical and temperate oceans everywhere except in the Americas, cuttlefishes favor mostly near-shore environments such as coral reefs, mangrove swamps, and fields of sea grass and algae. Although they are an important source of food for many people, no data have been compiled on whether they have been endangered by overharvesting, and demand for them has been growing in Asia and the Mediterranean. Still, even if they can't always escape nets, cuttlefishes can stay hidden from their other predators: sharks and teleosts (a range of bony, jawed fishes). This ability probably evolved between 370 million and 190 million years ago, when teleosts began taking over coastal environments and forcing some mollusks into deep water, where hydrostatic pressure made their shells cumbersome. So the cephalopods (with the exception of the chambered nautilus) shed their shells and slowly moved back to compete with, and to avoid, the fish.

The secret to cuttlefishes' capacity to fade into the background lies in several special types of muscle groups and cells: papillae, which allow the animals to deform their skin so they can assume the texture of seaweed or a bumpy rock; chromatophores, which contain pigment; and two kinds of reflecting cells, iridophores and leucophores, which influence color. In the common cuttlefish—the most extensively studied species because it is rather easily found in the eastern Atlantic Ocean,

A single cuttlefish can send waves of color flickering across its surfaces. Or pucker its skin into spines and bumps, then suddenly go smooth as polished stone.
An S. pharaonis, below, raises its arms combatively (Thailand). A cuttlefish’s astonishing range of color and texture can be seen in two photographs of Metasepia pfefferi, opposite page.

The English Channel, and the Mediterranean Sea—the chromatophores are yellow, red, orange, and dark brown to black, with a density of about 30,000 per square inch. The muscles around these sacs of pigment expand or contract in response to “messages” from the brain as it processes visual information. This neural control allows cuttlefishes and other cephalopods to transform their appearance rapidly; chameleons, on the other hand, control coloration through hormones traveling in the blood—a much slower process.

Iridophores are made of stacks of very thin layers of chitin that diffract (cause interference patterns in) light, giving rise to shimmering blues, greens, and silvers. Recent research by Roger T. Hanlon, of the Marine Biological Laboratory, suggests that iridophores also may be under indirect neural control, through the action of the neurotransmitter acetylcholine. Leucophores, found in some cuttlefish species, some octopuses, and in one type of squid, are flat, branched cells that, like sequins, reflect all colors.

The mesmerizing array of hues and patterns resulting from these specialized cells is important not only for hiding but for communication. Cuttlefishes, as well as squids and octopuses, have a rich repertoire of signals for defense, hunting, reproduction, and warning—and perhaps for types of communication not yet understood. In S. officinalis, for instance, the so-called Intense Zebra display warns other males to stay away. This and other dermal changes are often accompanied by a complex set of postures and arm movements. Hanlon and his colleague John B. Messenger, of the University of Sheffield in England, have described fifty-four components of the common cuttlefish’s “vocabulary,” including such postures as Drooping Arms, Flanged Fin, Wrinkled First Arms, and Extended Fourth Arm.
Deciphering this vocabulary has been challenging—and has just become more so. Watching female cuttlefishes choose mates, Jean G. Boal, of the University of Texas Medical Branch (UTMB) at Galveston, recently discovered that they shied away from males making aggressive Zebra displays. Instead, the females seemed interested in males that had just mated, which suggests that the females were responding to a chemical cue from the male. Sure enough, Boal and Sherry Painter, also at UTMB, found that cuttlefishes recognized a pheromone that Painter had recently isolated from a marine snail, a cephalopod relative. “Mollusks, in general, use pheromones to coordinate their behavior because they are not all that mobile,” explains Boal. “It serves as a communicator over much longer distances than visual signals could ever work.”

Boal’s studies have also revealed that cuttlefishes cannot recognize each other individually. But, she explains, the lack of recognition works perfectly for them. If, say, a male encounters another male and responds aggressively, he’ll repeat the behavior after swimming around the tank and bumping into the same male a minute later. “I talked to many people who were very disappointed: ‘Oh, cuttlefish are stupid, huh?’” Boal recalls, laughing. Cuttlefishes probably live far apart in the wild, except when they gather en masse to mate, so they have no real need to recognize individuals: “If two males have a fight,” says Boal, “the loser can leave and is not likely to bump up against that male again. He has a whole blooming ocean out there.”

And because cuttlefishes, like almost all cephalopods, die before their eggs have hatched, there is no reason for them to recognize their young.

The question of intelligence is what attracted Boal to cuttlefishes in the first place. “No matter how you measure it,” she points out, “their brain is larger than an octopus brain.” Her current experiments on learning suggest that both cephalopods do well with spatial learning; cuttlefishes seem to learn their way around a maze with the same facility as octopuses. Such savvy comes as no surprise to cuttlefish aficionados, who can sit entranced in front of a tank for hours, feeling the creature’s curiosity or (making allowances for the perils of anthropomorphism) what seems to be its passing interest in the human observer. “I think that’s part of the allure of cuttlefish,” says John W. Forsythe, a biologist at UTMB’s National Resource Center for Cephalopods in Galveston, a sort of Cuttlefish Central that supplies the animals to aquariums and researchers.
to their full extent and grab the prey, pulling it back into a beaked mouth. Another *pharaonis* flashes bright yellow for an instant; that’s a color Forsythe hasn’t seen before in this species. Mealtime continues fast and furious; the tank is clean within minutes. “They’re the most awesome predators. I’m very thankful they don’t get to be six feet,” says Forsythe, adding that if crabs had been on the menu, the waters would have roiled. “They’re the master crab destroyers of the universe.”

Cuttlefishes are indeed perfectly honed hunters. Everything about their physiology enhances their search for shrimp, crabs, and fish; their huge eyes, for instance, are as sophisticated as those of vertebrates. Although they seem unable to see in color (unlike most of the fishes that feed on them), their eyes can detect polarized light, allowing them to easily locate transparent or camouflaged prey. Thirteen or fourteen muscles control their eyes, while humans’ eyes are controlled by only six muscles and octopuses’ by seven. The extra muscles allow cuttlefishes to see pretty much everything, because they can move their eyes to compensate for the position of their bodies and can cause their lines of vision to converge for optimal perception of depth. Why they have W-shaped pupils remains a mystery, however; Forsythe suspects it allows them to see backward and forward at the same time.

Cuttlefishes can sense movement in other ways as well. Bernd U. Budelmann, of UTMB’s Marine Biomedical Institute, has determined that cuttlefishes have tiny hair cells that detect the directional flow of water, enabling them to sense and interpret changes in currents or water movement up to sixty feet away. And they are also outfitted with statocysts (organs similar to the vestibular structure, or inner ear, in vertebrates), which allow them to maintain orientation. So whether they’re swimming forward, jetting in reverse, or just hovering, cuttlefishes can figure out which way is up. “They’re like cats—built to right themselves,” explains Forsythe. And then, with some of the fervor that cuttlefishes seem to evoke, he blurs out, “They’re so cool!”

Every day Forsythe gets e-mails from people obsessed with these animals, people who want a cuttlefish as a pet so that they can sit and stare into its mesmerizing eyes and commune with a creature that can project the workings of its colorful mind. Jaron Lanier may be right. The day may come when we catch up with the mollusks and can make our skin dance with the patterns of our thoughts.
Australia’s Rock Stars

For the giant cuttlefish of southern Australia, Spencer Gulf is the place to spawn.

By Simon Foale and Mark Norman

From April to July of most years, the northwest coast of Spencer Gulf in the state of South Australia is the setting for one of the most colorful and vibrant biological events: the spawning of Sepia apama, the giant cuttlefish. These animals, which measure up to three feet, can be found along the entire south coast of Australia. But the greatest concentration (as many as thousands per acre) is found only on the few rocky reefs between the industrial port of Whyalla and Point Lowly, ten miles northeast. This distinction may be related to the scarcity of rocky seafloor seventeen feet of land, where the water is as shallow as six feet. Because sites for laying eggs may be limited, males often rove from boulder to boulder in search of a good spot that isn’t already being used. Having found one, the males can then court females that come looking for a place to lay their eggs. Males compete for females by swimming alongside their opponents and trying to make themselves look as large and frightening as possible. They flare out their ornately decorated arms, which bear bannerlike webs, and also produce a mesmerizing pattern—an inverted V of black stripes in constant motion—on the side of the body facing their rival. When rival males are unevenly matched in size, the smaller one invariably swims away before too long. If they are evenly matched, however, the showdown can sometimes escalate into violence; most individuals sport the evidence of past brawls, such as bite marks, missing tentacles, and scratches and scars of varying severity. In any case, the winner gets the female.

Giant cuttlefish copulate head to head, with the male using the tip of an arm to transfer a spermatophore (sperm packet) to a pouch under the female’s mouth. Many males

A male giant cuttlefish (Sepia apama), left, swims out to meet the challenge of another male. Right: Another giant cuttlefish decks itself out in camouflage.
Every now and then, however, much smaller males manage—through stealth and disguise—to mate with females. By pulling in their arms and bannerlike webs and taking on a mottled coloration, they achieve a typically female appearance. These small males may even approach females that are guarded by large males. Seemingly cued to the aggressive visual displays of sizable competitors, a large guarding male will readily accept the approaches of an apparent female. Then, when the guard is busy fending off some other big brute, the small “sneaker” male makes his move to mate with the female. The small male’s disguise appears to work even during mating; large males have been observed to tolerate copulations between a female they’re guarding and a sneaker male dressed up as a female.

During the three-month breeding season, a female can lay several hundred eggs in a number of separate clutches. Before laying them on the undersides of boulders or in crevices—away from currents and large predators—she uses her arms to draw the eggs out of their gill cavity and pass them under her mouth to fertilize them. With her head in a crevice and the rest of her body protruding into the open, the female may produce a pair of large black eyespots on the back of her mantle; possibly a deterrent to would-be predators. Egg laying is a hazardous business. Each egg is glued to the boulder individually, and eggs are frequently caught on the spines of urchins, which take shelter in large numbers on the undersides of boulders and
Eggs can catch on the spines of urchins sheltering under the same boulders used by the giant cuttlefish.

are among the many predators known to feed on the eggs. When the female S. apana is not laying eggs, she and her guard can be seen close to their boulder, with the male usually hovering a little above his mate. Even then, challengers often attempt to get to the female by using their tentacles to “scoop” the male up and away from her. About five months after being laid, the eggs hatch into free-swimming, miniature cuttlefish; by then, the adults will have long since dispersed or died.

Recent interest in fishing for Spencer Gulf’s giant cuttlefish may threaten the spawning aggregations. For many years, a small number of giant cuttlefish (10 tons’ worth a year) were harvested for use as bait, without apparent impact on the spawning population. In 1996, however, a new Asian market for cuttlefish was discovered, and fishing efforts exploded. More than 200 tons were taken in the 1997 season alone. After lobbying by local divers and conservationists, the South Australian state government placed a temporary ban (for 1998) on fishing for these animals in the gulf. Catches at the start of the 1999 season were so low that the fishery was quickly closed to protect remaining stock. In advance of the 2000 season, fisheries scientists released research findings that support permanent closure of the region to fishing. The fate of the giant cuttlefish now lies in the hands of politicians and other decision makers.

A giant cuttlefish tries to grab a fishing line with its tentacles, which have pads of strong suckers on their tips.

Simon Fode studies the indigenous use of marine resources and the ecology of target species. Much of his time has been spent in the tropical Pacific; he is currently a research scientist in the Solomon Islands for the World Wildlife Fund. Mark Norman, a research fellow at the University of Melbourne, has studied cephalopod diversity, evolution, and behavior for many years, in the course of which he has discovered more than 150 new species of octopus.

Giant cuttlefish are voracious predators, feeding on a variety of fish and crustaceans. Dinner, on this occasion, is a rock crab.
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45. Visit Florida

46. Zeiss Company
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forms of authority or seek certain forms of knowledge— injunctions that cannot be congenial to any scientist.)

Similarly, no statement in Genesis 1 speaks about inequality between the sexes, but Adam uses Eve’s status as both subsequent and partial to hint at such a claim in Genesis 2: “And Adam

After all, we read the Bible as a source of moral debate and instruction, not as a treatise in natural history.

said, This is now bone of my bones, and flesh of my flesh: she shall be called Woman, because she was taken out of Man” (Gen. 2:23).

Haydn’s text divides the creation myth of Genesis 1 into three sensible and dramatic units. We usually view the six-day sequence as a story of successive additions, but I think that such a reading seriously mistakes the form of this particular tale. Creation myths, based on limits to both our mental powers and the structural possibilities of material objects, can “go” in only a few basic ways, and Genesis 1 invokes the primary theme of successive differentiation from initial chaos, not sequential addition. The universe begins in undefined confusion (“without form and void”). God then constructs a series of separations and consolidations to mark the first four days. On Day 1, he divides light from darkness. Haydn’s amazing overture violates many contemporaneous musical traditions of tonality and structure to depict this initial chaos. The composer then, at the end of the first chorus, describes the creation of light with a device both amazingly simple and (to this day) startlingly evocative: a series of crashing chords in bright and utterly unsophisticated C major. (A virtual cliché therefore ends with Haydn’s most famous text and tune, “The heavens are telling the glory of God”—the heavens, that is, because no animals have yet been formed!

Part 2 describes the work of Days 5 and 6, the creation of animals: creatures of the water and air on Day 5 and of the Earth, including humans, on Day 6. Soloists and chorus alternate as in Part 1. Haydn’s music exudes beauty, power, and exultation, but he also describes whimsical, earthy, and ordinary events—a combination that captures the essence of the humanistic (or should I say naturalistic) spirit by acknowledging that glory and fascina-
Bob and Marie Bergh love to travel. Since their first trip with the Museum in the early 1980’s, they have participated in eight Discovery Tours, to destinations as diverse as the British Isles, the Black Sea, Scandinavia, the Caribbean, Greenland, Antarctica, the North Pole, the Middle East, India and Southeast Asia.

Exploring the world on Discovery Tours, Bob and Marie have become increasingly aware of the significance of the Museum’s work. This is why they recently decided to provide for the Museum’s future through a Charitable Gift Annuity.

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A Gift Annuity is a way to support the Museum and provide lifetime income to one or two people. When low-yield stock is used to fund the plan, capital gains tax is avoided. Marie offers a tip to Natural History readers: “We learned about the Museum’s Gift Annuity program through this magazine, and we encourage you to find out about it, too!” Here are the sample rates and benefits for one person with a $10,000 gift:

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For more information, please call (800) 453-5734 or reply by mail to: Office of Planned Giving, American Museum of Natural History, Central Park West at 79th Street, New York, New York 10024-5192

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The final exultation of joy for the glorious diversity of the Earth and its life—"praise the Lord, utter thanks, Amen"—runs twice, first as an alternation of passages for a quartet of soloists and the full chorus, and then, even louder, for the full chorus alone. This acceleration or promotion—more an emotional device than a compositional beauty per se, but mastery of such devices also marks a composer's skill—always leaves me feeling that we should mount even higher, over nature: "And God said, Let us make man in our image, after our likeness; and let them have dominion over the fish of the sea, and over the fowl of the air, and over the cattle, and over all the earth, and over every creeping thing that creepeth upon the earth. . . And God blessed them, and God said unto them, Be fruitful, and multiply, and replenish the earth, and subdue it" (Gen. 1:26, 28).

Instead, following the creation of land animals, Haydn's text, in a non-biblical interpolation, suggests an entirely different reason for the creation of men and women. In Genesis 1, God fashions us to have dominion over everything else. But in Haydn's text, the world needs us simply because God's noble efforts remain unfulfilled if the great work must end with the tawny lion and the sinuous worm. In nearly six full days of hard labor, God has stuffed the Earth with a glorious series of diverse and wonderful objects. But he then realizes that one omission precludes the fulfillment of his greatest being; that, grateful, could God's power admire, with heart and voice his goodness praise."

I don't want to make either this recitation or Haydn's text sound too saccharine or devoid of complexity. The humanistic tradition does not deny the dark side but rather chooses to use these themes as warnings for potential correction rather than as statements about innate depravity. Thus, Haydn does not entirely neglect the common biblical subject (so prominent in Genesis 2) of the dangers inherent in know-
ing too much. But he certainly reduces the point to a bare reminder, just before the final chorus, the tenor soloist sings a quick passage in the least impassioned narrational style of "dry recitative" (with only keyboard and continuo as accompaniment): "O happy pair and happy still might be if not misled by false conceit, ye strive at more than is granted and desire to know more than you should know." Modern listeners might also be discomfited by Eve's promises of obedience to Adam in their second duet (from Milton, not from Genesis 1), even though her inspiration follows Adam's promise to "pour new delights" and "show wonders everywhere" with every step they take together upon this newly created world. We can't, after all, impose the sensibilities of 2000 upon 1798. And who would want to defend 2000 before any truly just court of universal righteousness?

But while we identify Haydn's text as a creation myth in the most expansive and optimistic spirit of love and wonder for all works of Earth and life, we must also confront a historical puzzle. Haydn began his work in 1796, and the first public performance took place in 1799 (with Haydn conducting and none other than Antonio Salieri, the much and unfairly maligned villain of Amadeus, at the fortepiano). Such an expansively optimistic text seems entirely out of keeping with the conservative gloom that spread throughout Europe after the excesses of the French Revolution, culminating in the guillotining of the guillotiner Robespierre in 1794. Moreover, the spread of the Romantic movement in music and art, for all its virtues, scarcely sanctioned such old-fashioned joy in the objective material world.

The apparent solution to this problem includes an interesting twist. Haydn wrote The Creation as a result of inspiration received during trips to London, particularly in 1791, when he heard (and felt overwhelmed by) the
power of Handel's oratorios. This source has always been recognized, and the pleasure of singing The Creation lies at least partly in the wonderful Handelian anachronism included amidst the lush Classical and near-Romantic orchestration. But Handel's posthumous influence may have run far deeper. The source of Haydn's text has always presented a mystery. Who wrote it, and how did Haydn obtain the goods and the rights? (We know that Haydn's friend Baron Gottfried van Swieten translated the text into German from an English original, but whence the original?) The latest scholarship indicates that the text may have been originally written for Handel more than forty years earlier (Handel died in 1759) but never set by the greatest master of the oratorio and therefore still available for Haydn two generations later.

Such an earlier source would solve all problems of content, for if Haydn's libretto really dates from the 1740s or 1750s, then all incongruities disappear. The text becomes a document composed during the heart of the Enlightenment, an intellectual and artistic movement that embodied all the optimism of the age, all the pleasure in nature's beauty, all the faith that a combination of human reason and moral potential might ensure both goodness and justice. The text of The Creation reflects this hopeful world, when Linnaeus worked in Uppsala, classifying all plants and animals for the glory of God and the knowledge of men, while Ben Franklin promoted the virtues of fire departments, public libraries, and universities in Philadelphia. The Enlightenment may have veered toward naïveté in its optimism about human and worldly possibilities, but the goals still seem attainable, and we will never get there if we lose the hope and spirit. Ya gotta believe.

The difficulty of this task (so well epitomized, in some great words of another famous Enlightenment thinker, as the realization, for all people, of our inalienable rights of "life, liberty, and the pursuit of happiness") requires that all facets of human achievement be mobilized in the great work. We will surely need the benefits of science, if only to feed and keep healthy all the people that science has permitted us to rear to adulthood. We will also need, and with equal force, the moral guidance and ennobling capacities of religion, the humanities, and the arts, for otherwise the dark side of our personalities will win, and humanity may perish in war and recrimination on a blighted planet.

Art and science provide different and legitimate takes on the same set of "There is grandeur in this view of life," wrote Darwin. And as Haydn said, "The heavens are telling the glory of God." saving subjects, and we need both approaches. Thus, as a scientist who has devoted an entire career to the study of evolution (but who also fancies himself a serious and competent avocational choral singer and not just an occasional duffer at a Saturday-night piano bar), I see no contradiction, but only harmony, in integrating the final line from a great work of science (a statement that Darwin chose to make in personal terms of poetic awe) with Haydn's inspirational choral work based on an Enlightenment version of a creation myth that seems to employ (in its different way) the same subject of Darwin's scientific studies. The factual truth of evolution cannot conflict with the search for meaning embodied in a good creation myth. "There is grandeur in this view of life," Darwin wrote. And as Haydn said, "The heavens are telling the glory of God."

The task before us remains so daunting that we need to find tools even beyond the integration of science, morality, and the other separate patches that construct what I like to designate as the coat of many colors called wisdom. We also need symbols to intensify and epitomize this grand effort that must ultimately lead us all to hang together or to hang separately (a great pun by the Enlightened Mr. Franklin). Given my propensities and proclivities, I do not know how, in this symbolic sense, I could have spent the inception of the millennium in a more meaningful way. And so, Mrs. Ponti, my truly beloved fifth-grade teacher, I dedicate this version of "what I did on my . . ." to your memory and to the inspiration that you so freely provided with your dedication and skill.

I consecrated the day that symbolized the end of history to the opposite service of praising its optimistic beginnings, by joining a group of colleagues who had worked long and hard to prepare a performance of the greatest musical work ever written about the joyful and glorious inception of an order that can end (on our time scale) only if we fail to unite the spirits of Darwin and Haydn, thereby potentiating all the saving graces of our nature. We express this union in many ways. The closing words of Genesis 1 do not represent my personal choice, but who can doubt the nobility of the sentiments, and what person of goodwill can fail to be horrified by the prospect (and therefore be inspired to devote some personal effort toward prevention) that one species might eviscerate something so wonderful that we did not create and that was not fashioned for us? "And God saw every thing that he had made, and, behold, it was very good."

Stephen Jay Gould teaches biology, geology, and the history of science at Harvard University. He is also Frederick P. Rose Honorary Curator in Invertebrates at the American Museum of Natural History.
Anthropology and American Ancestry

New controversies have opened old wounds over how scientists have historically treated Native Americans.

In July 1996 two young men wading through the shallows along the Columbia River near Kennewick, Washington, stumbled across a skull partly buried in the sand. Thinking it was that of a murder victim, they called the police. A forensic anthropologist named James Chatters concluded that the skull looked Caucasoid. After an almost complete skeleton had been collected, radiocarbon dating indicated that it was more than 9,000 years old and thus one of the oldest and most complete skeletons ever found in the New World. As a result, under the Native American Graves Protection and Repatriation Act of 1990, the U.S. government seized the bones and was planning to turn them over to a coalition of local Indian tribes. The Indians, believing that scientific study of the remains was an act of sacrilege, said they would bury the skeleton where no scientist would ever find it. A group of distinguished anthropologists, seeking the opportunity to study the bones and analyze the so-called Caucasoid features of the skull, sued. “So began the furious controversy over Kennewick Man,” David Hurst Thomas writes in his remarkable and groundbreaking book *Skull Wars*.

The Kennewick controversy provides an apt introduction for *Skull Wars*, because it embodies all the contradictions and passions generated by anthropologists’ efforts to unravel the Native American past of our continent. This highly readable history of American anthropology is proof that a work of scientific scholarship can be set forth in straightforward, elegant English prose free of jargon. As a founding trustee of the National Museum of the American Indian, a member of the National Academy of Sciences, and a former chairman (now a curator) of the anthropology department at the American Museum of Natural History, David Hurst Thomas was well positioned to write this book.

This is no dusty history. The author tells stories of grave robbing in the dead of night, of researchers decapitating Indians after battles in order to send their heads back to museums for study, of the elevation of scientific materialism above people’s deepest religious values. He recounts tales of anthropologists who collected living people for study, as his own museum did a century ago, with six Eskimos from Greenland.

The book’s foreword is written by Vine Deloria Jr., a Standing Rock Sioux activist and educator, who says that his “rage was almost incandescent” as he read Thomas’s manuscript about what had been done to Indian people in the name of science. The choice of
Deloria to write the foreword may seem odd, since he rejects the central tenet of American anthropology—that human beings migrated from the Old World to the New. Yet giving Deloria the opportunity to speak is very much in keeping with Thomas’s goal, which is to present both sides fairly. On the other hand, he’s no wimp. He states his own views forcefully, and some Indian activists, including Deloria himself, come in for pointed criticism.

Skull Wars is much more than a litany of scientific injustices. Thomas recounts, for example, how American anthropologists led the way both in debunking racist theories that “ranked” human beings and in developing the powerful idea that all cultures—even the so-called primitive ones—are equally complex and important. Although U.S. anthropologists did much to save and protect Native American cultures and peoples, their record is mixed: Franz Boas, often called the father of American anthropology, robbed Indian graves but also denounced his discipline's embrace of racial determinism. Smithsonian anthropologist Frank Hamilton Cushing pushed his way into the Zuni Indians’ sacred ceremonies but also fought passionately for the rights of the Zuni against those who were trying to steal their land and water.

The battle over Kennewick Man marks another chapter in the sometimes bitter history of relations between anthropologists and American Indians. Using this fracas as an example of how not to practice archaeology, Thomas makes an eloquent plea to heal the breach: “If archaeologists—of all people—can draw some lessons from the past,” he writes, “perhaps we can rediscover a more human side to our science and come to value once again the importance of face-to-face relationships with those whose ancestors we wish to study.”

Do we have a model for how archaeologists and Native Americans can work together? According to Thomas, we do: a project in southeastern Alaska’s Tongass National Forest, where archaeologists and spelunkers have been mapping and excavating the hundreds of caverns and fissures in the limestone bedrock of Prince of Wales Island. In 1993 Terry Fifield, the island’s USDA Forest Service archaeologist, joined the team; he soon moved to Klawock, one of the eleven local Haida and Tlingit villages, and regularly attended the council meetings, making a point of sharing news of discoveries. The first finds—41,600-year-old bear bones and 17,565-year-old seal bones—dated back to the “very peak of the Ice Age.” When researchers found human remains in the same caverns, Fifield immediately asked the advice of tribal elders. After much discussion, writes Thomas, “they finally agreed that the potential increase in knowledge about their oldest ancestors overwhelmed all other concerns.” Subsequent radiocarbon dating of the bones and tools proved that they were as old as Kennewick Man and of immense value to archaeology.

The Tongass remains were discovered at the same time as Kennewick Man. Today the Kennewick bones are mired in controversy and legal maneuvering, while the Tongass bones have been quietly and intensively studied, yielding a trove of information. As Thomas proposes, “One of these cases may well define the future (if any) of twenty-first century archaeology. The question is: Which one?”


Robert Anderson is a freelance science writer based in Los Angeles.
Jacobson's Organ and the Remarkable Nature of Smell, by Lyall Watson (W. W. Norton, 2000; $24.95; 256 pp.)

Most of us know that smells are picked up by the nose, relayed to the brain's olfactory bulbs, and translated as, say, a whiff of perfume, or the stink of skunk. Few know about the transmission of subtler sexual, pheromonal, and other chemical odors via the vomeronasal organ, or Jacobson's organ (named after the Danish anatomist who discovered it in 1809), to an entirely different part of the brain—the hypothalamus. Science writer Watson explores the scent-sensing mechanisms that have evolved not just in humans but throughout the animal kingdom.

Millions of Monarchs, Bunches of Beetles: How Bugs Find Strength in Numbers, by Gilbert Waldbauer (Harvard University Press, 2000; $24.95; 264 pp.)

According to entomologist Waldbauer, insects, spiders, and many other animals live cheek by jowl to defend themselves against enemies, to find mates and food, and to cope with extremes of weather. He cites, among many colorful examples, a group of daddy longlegs that formed a huge cluster, about 70,000 strong; their mass of long, threadlike legs created a thick pelt that deflected the wind and slowed the loss of moisture.

Medicine Quest: In Search of Nature's Healing Secrets, by Mark J. Plotkin (Viking, 2000; $24.95; 214 pp.)

Ethnobotanist Plotkin ranges far afield to report on the race to discover and bottle natural remedies, from eriostatin (a protein from Asian pit vipers that appears to inhibit the spread of melanoma cells) to myrrh (a fragrance used as an antibiotic in the ancient world).

Defending the Cavewoman and Other Tales of Evolutionary Neurology, by Harold Klawans (W. W. Norton, 2000; $24.95; 224 pp.)

Klawans plays the double role of detective and neurologist as he attempts to figure out the genesis of his patients' symptoms, which range from alexia and other aphasias to "painful-foot-and-moving-toe syndrome."

Walking With Dinosaurs: A Natural History, by Tim Haines (Dorling Kindersley, 2000; $130; 288 pp.)

Although published to accompany the BBC television series of the same name, this book by zoologist Haines can stand alone. It contains an abundance of eerily lifelike images of extinct dinosaurs, marine reptiles, pterosaurs, and early mammals, all based on the "animatronics" of the film. The you-are-there text is lavishly supplemented with graphics and with brief essays filled with scientific background information.


Selecting from the letters Jane Goodall wrote between the ages of seven and thirty-two, editor Dale Peterson has presented an intimate and vivid portrait of the British primatologist who went out to East Africa at the age of twenty-three, became the assistant to Louis Leakey in his studies of apes, and remained there to conduct her own (now world-famous) research on chimpanzees.

Wanderlust: A History of Walking, by Rebecca Solnit (Viking, 2000; $24.95; 318 pp.)


Two very different books extol the benefits of walking. Solnit's eclectic compendium covers everything from human bipedal beginnings to religious pilgrimages. Rousseau's meditations affirm that "these hours of solitude and meditation are the only ones in the day during which I am fully myself and for myself, without diversion, without obstacle, and during which I can truly claim to be what nature willed."

On Tycho's Island: Tycho Brahe and His Assistants, 1570-1601, by John Robert Christianson (Cambridge University Press, 2000; $34.95; 451 pp.)

For twenty years, Tycho Brahe, a sixteenth-century Danish astronomer and patron-practitioner of science, maintained an international research community on the island of Hven, granted to him by King Frederick II. Participants (among them Johannes Kepler) were trained in the use of new instruments and innovative methods of observation and experimentation, and many of them contributed to the scientific revolution that culminated in the Enlightenment.

Events

APRIL 3
The John Burroughs Association holds its annual meeting at 10:30 A.M. Bernd Heinrich, author of _Mind of the Raven_, will receive this year's award for nature writing. For tickets to the awards luncheon, call (212) 769-5169.

APRIL 4
At 7:00 P.M., Marc Hauser, professor of psychology at Harvard University and author of _Wild Minds: What Animals Really Think_, discusses new ideas about animal intelligence, gleaned from evolutionary theory and cognitive science.

APRIL 10
As part of the “Frontiers in Astrophysics” series, Robert Kirshner, of the Harvard-Smithsonian Center for Astrophysics, gives a talk at 7:30 P.M. entitled “The Runaway Universe: Measuring the Universe with Supernovae.”

APRIL 11
In his 7:00 P.M. talk, geneticist Steve Jones draws on his new book, _Darwin’s Ghost: The Origin of Species Updated_, to survey what’s been happening in evolutionary biology since 1859.

APRIL 11, 18, AND 25
The first three speakers in a series of 7:00 P.M. talks on the state of genetic research are molecular biologist and 1989 Nobel laureate Harold E. Varmus (“How Genetics Is Transforming Medicine”), cell biologist and 1999 Nobel laureate Günter Blobel (“The Empowered Cell”), and legal scholar Bartha M. Knoppers (leading a panel discussing “Ethical and Legal Implications of Genetic Medicine”). For information, call (212) 769-5176.

APRIL 13 AND 14
The Center for Biodiversity and Conservation is cosponsoring, with the Wildlife Conservation Society’s Metropolitan Conservation Alliance, a two-day symposium entitled “Nature in Fragments: The Legacy of Urban Sprawl.” To register, call (212) 769-5200. For additional information, go to research.amnh.org/biodiversity/Sprawl/Symposium2k.html.

APRIL 15 AND 16
From 1:00 to 4:00 P.M. during “Dinosaur Weekend,” sponsored by the Museum and Discovery Kids, children between the ages of six and eleven can participate in paleontologic activities in the Fossil Halls.

APRIL 17
As part of the “Distinguished Authors in Astronomy” series, writer Andrew Chaikin gives a talk at 7:30 P.M. entitled “The Apollo Odyssey.”

APRIL 21
At 7:00 P.M., a musical visualization program, conceived by computer scientist and musician Marty Quinn in collaboration with University of New Hampshire scientists, evokes 110,000 years of Earth’s climatic history.

APRIL 25
Dave Mattson, of the U.S. Geological Survey, discusses his twenty-five years of research on Yellowstone’s threatened grizzly bear in a 7:00 P.M. talk.

APRIL 28
At 7:30 P.M., storyteller Diane Wolkstein, using a combination of voice, gesture, and song, presents a 4,000-year-old Sumerian epic in a performance entitled “The Story of Inanna: Queen of Heaven and Earth.”

DURING APRIL
“Full Moon,” an exhibition of photographs from the archives of NASA’s _Apollo_ missions, is on display in the new Rose Center for Earth and Space. The works were compiled and printed by artist Michael Light.

For information about this month’s weekend multicultural programs, “Native Cultures of the Americas: A New Generation,” call (212) 769-5315.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100. Visit the Museum’s Web site at www.amnh.org. Space Show tickets, retail products, books, and Museum memberships are now available online.
Going Online

In McAllen, Texas, a buff-bellied hummingbird sits in the cup-shaped nest she has anchored to a clothespin. These diminutive birds usually choose the elbow of a branching twig as the nest's base, but this one used a familiar human artifact instead. The nest itself is constructed from plant fibers, lichens, shredded bark, and blossoms, bound together with spider silk.

Other species of hummingbird pass through southern Texas during migration, but the buff-bellied hummingbird resides year-round in the Rio Grande valley. The birds' nests are commonly hidden in low shrubs; this one, however, was boldly established in the open courtyard of an apartment building.

An elderly resident called the local media when she discovered the nest. After the aspirin-sized eggs had hatched and the hummingbirds had left, the woman gave the nest, clothesline and all, to the photographer’s business partner, who displays it in a place of honor in her own backyard.—Richard Milner

Photograph by Steve Bentsen
Explore the World with Discovery Tours

Since 1869, the American Museum of Natural History has sponsored thousands of scientific expeditions around the globe in an effort to unravel the world’s greatest mysteries. It is this passion to discover and to understand that inspires Discovery Tours, the Museum’s educational travel program.

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*Most of our land programs are limited to 15-25 travelers.

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- **Northern Australia: In Quest of Rock Art and Natural Treasures**
  - June 23-July 7, 2000
  - $6,990

- **China and the Yangtze River**
  - September 6-24, 2000
  - September 27-October 13, 2000
  - From $6,690 to $7,290
  - (Airfare from L.A. included)

- **Exploring the Prehistoric Caves and Medieval Castles of Southern France**
  - September 14-26, 2000
  - $4,990

- **The Enduring Spirit of Tibetan Buddhism: Bhutan, Ladakh, and Sikkim**
  - September 24-October 13, 2000
  - $6,990

- **Elephant Walk: Zimbabwe, Zambia, and Botswana**
  - September 12-28, 2000
  - $8,590

**CRUISES**

- **Life on the Mississippi: Memphis to New Orleans**
  - April 15-22, 2000
  - From $695 to $5,785

- **The Isles of Britain and Ireland Aboard the Caledonia Star**
  - June 10-23, 2000
  - From $6,540 to $11,700

- **North America’s Great Lakes: Toronto to Chicago**
  - June 30-July 8, 2000
  - From $3,690 to $5,190

- **Voyage to the North Pole: Aboard the Icebreaker Yamal**
  - July 23-August 6, 2000
  - From $16,950 to $22,950

- **Journey to the Top of the World: From the Northwest Passage to Greenland Aboard the Clipper Adventurer**
  - August 15-27, 2000
  - From $4,380 to $7,920

- **Magnificent Passage: A Journey of Discovery from Paris to Rome Aboard the Seabourn Goddess II**
  - August 20-September 2, 2000
  - From $6,995 to $14,195
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**PLANE TRIPS**

- **From Early Man to Contemporary Civilization: Dordogne Valley, the Iberian Peninsula, and Bilbao**
  - September 21-October 4, 2000
  - $4,475 to $6,275

- **Under Sail in the Western Mediterranean: Journey from Sicily to Southern Spain Aboard the Sea Cloud**
  - October 14-27, 2000
  - From $6,270 to $10,620

- **Egypt and the Nile Aboard the M/S Sovereign**
  - October 15-29, 2000
  - $5,990

- **Circumnavigating South Georgia and the Falkland Islands Aboard the M/S Explorer**
  - November 20-December 9, 2000
  - From $7,990 to $12,890

- **Splendors of Antiquity: Egypt, Israel, Syria, Cyprus, and Lebanon Aboard the Clelia II**
  - November 30-December 13, 2000
  - $5,995 to $12,995

Prices based on double occupancy. Single rates available on all tours. All prices, dates, and itineraries are subject to change.
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FEATURES

IN THE COMPANY OF HUMANS
There is no question that we are drawn to wild animals. But are they ever drawn to us?

BY JOHN TERBORGH

DIG IT, AND THEY WILL COME
In the underground world of dung beetles, the strong, well-armored males always win the females—or do they?

STORY BY DOUGLAS ELMEN
ILLUSTRATIONS BY UTAKO KIKUTANI

LIFE ON A LEAF
All summer long, a tree's green foliage hosts burgeoning communities of tiny fungi. In autumn, the guests become the undertakers.

BY PETER J. MARCHAND

SEARCHING FOR THE WILD BACTRIAN CAMEL
If truly wild camels exist, biologists want to study them. But first they must find them in the trackless waste.

BY JOHN HARE
ILLUSTRATION BY RODICA PRATO
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TO THE EDITOR

The Not-Always-Frozen Ground Squirrel
“The Natural Moment” (3/00) reports that Arctic ground squirrels “can withstand temperatures below 30°F for months at a time, to all appearances frozen solid.”

In fact, however, even when the animal’s “core” body temperature is as low as 27°F, its head and anterior body do not get colder than 32°F. Moreover, for roughly eighteen hours every two to three weeks, the squirrel’s body warms to between 97° and 100°F. During these episodes, the animal generally remains in the curled posture of hibernation, sleeping 67 percent of the time. Brain waves, absent when the animal is deeply torpid, return spontaneously. Normal metabolic levels may be necessary for protein synthesis at brain synapses.

J. Lee Kasaun
University of California
Los Angeles, California

Historians Need Scientists . . .
Stephen Jay Gould brings some welcome clear thinking to bear on Ernst Haeckel’s faked embryo pictures (“Abschleudlich! Atrocious!” 3/00).

Admittedly, some of those sensational press stories from 1997 that Gould criticizes were based on interviews with me. So the errors in them may reflect my (former) ignorance of the fact that German embryologists in Haeckel’s own day recognized his fabrications. As a biologist, I read the Haeckel pictures as scientific hypotheses. For their part, historians of science sometimes defend Haeckel by saying he was only attempting to idealize what he believed to be true of natural forms. Maybe so, but in that case, his drawings are not science.

The problem may be that academic history of science looks at the cultural and political factors that surround scientists but not in detail at the science itself. Professional scientists need Gould’s scientifically informed brand of the “history of ideas.”

Michael K. Richardson
Saint George’s Hospital Medical School
London

Rhythm and Blooms
How does a plant sense that the time is right for flowering? After years of sleuthing, molecular biologists are beginning to find out.

On the Trail of a Hat
It gave spirit to Harry Truman, charm to Albert Einstein, and identity to Charlie Chan. But the Panama hat really comes from Ecuador.

. . . and Scientists Need Philosophers
Charles T. Snowdon’s review of Wild Minds: What Animals Really Think (3/00) presents the following six-step argument: (1) When looking into mirrors, great apes (gorillas, chimpanzees) react to marks surreptitiously placed on their faces. (2) They couldn’t react in that way without understanding the image in the mirror to be their own. (3) One can perceive an image to be of oneself only if one has self-awareness. (4) Great apes thus have self-awareness. (5) Monkeys in the same circumstances do not react to marks on their faces. (6) Monkeys, therefore, do not have self-awareness.

Statement 6 follows only if statement 3 presents a necessary rather than a sufficient condition for self-awareness. Some humans from technologically undeveloped cultures, for example, do not recognize images of themselves in photographs. What follows about their self-awareness? Nothing.

Concepts such as self-awareness need more analysis than they are typically given by scientists studying animal cognition. Philosophers have been doing that kind of analysis for quite some time.

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John Terborgh ("In the Company of Humans") is James B. Duke Professor at Duke University’s Nicholas School of the Environment and codirector of the university’s Center for Tropical Conservation. For nearly three decades, he has managed the Cocha Cashu Biological Station in Peru’s Manu National Park. His research there has focused, at different times, on primates, birds, jaguars, and forest dynamics. His 1999 book Requiem for Nature (Island Press) was reviewed in the September 1999 issue of Natural History. Another recent work, Continental Conservation, coedited with Michael E. Soulé (Island Press, 1999), lays out the principles for designing nature preserves. His current project is another coedited volume entitled Making Parks Work. It is little wonder that he sometimes seeks refuge in a screened tent deep in the forest.

As a graduate student, Douglas Emlen ("Dig It, and They Will Come") was looking for a splashy beetle with big horns to study. When biologist William Eberhard showed him a box of tiny black dots and said, “These are the beetles you should work on,” he was reluctant. Now, a decade later, he is very glad he took the advice. Onthophagine dung beetles—in addition to having impressive horns (if you look very closely) and interesting mating behavior—are nearly ubiquitous, which makes them perfect for studying both in the laboratory and in the field. They have taken him to Panama, Ecuador, Australia, and several parts of the United States. Emlen hopes next to explore species in which gender roles are reversed—that is, in which the females wear the horns. Emlen is assistant professor in the Division of Biological Sciences at the University of Montana in Missoula.

Trained in earth sciences and ecology at the University of New Hampshire, field biologist Peter J. Marchand ("Life on a Leaf") has devoted his career to the ecology of forests, tundra, and, more recently, desert. A visiting professor at Colorado College and a regular contributor to Natural History, Marchand has focused on cold-season phenomena. His latest book, Autumn: A Season of Change (University Press of New England), will be published this year. Describing himself as “broken loose from the halter of academic specialization to rummage freely, like a bear in a garbage dump, for the biological spoils” that interest him the most, Marchand travels throughout Europe and North America when he’s not in Arizona, which he now calls home.

Born in Great Britain, John Hare ("Searching for the Wild Bactrian Camel") acquired his practical knowledge of domesticated camels in Africa, beginning in Nigeria, where he served as an administrator in late colonial times and during the early years of independence. He subsequently worked for the BBC and in international publishing before again encountering camels, this time as an employee of the United Nations Environment Programme in Kenya. In this issue, Hare describes his most recent adventure investigating wild camels in Asia. Earlier explorations are recounted in his book The Lost Camels of Tartary: A Quest into Forbidden China (Little, Brown, 1998). In 1997 Hare founded the Wild Camel Protection Foundation, with Jane Goodall as patron, and proposed establishing the Lop Nur Nature Sanctuary to save the animals, whose lands are threatened by development. China signed on to this project in March 1999, and Hare has now raised more than $800,000 to help make it a reality.

“I have always had a fascination with the geology and landforms of the Great Rift Valley,” says photographer Gerry Ellis ("Scorch and Soda"). Ellis’s interest evolved into a project commissioned by the World Wildlife Fund to document the ecosystems of African rift lakes. While growing up in the Pacific Northwest, Ellis often hiked into the foothills around Mount Rainier. He now travels to remote corners of the world to photograph endangered wildlife. His photographs have appeared in BBC Wildlife, Natural History, Terre Sauvage, Audubon, GEO, and National Geographic, as well as in more than a dozen books. For the featured image, Ellis used a Nikon F4 and a wide-angle lens while flying low over the lake in a single-engine plane.
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Phoebe Diary

A naturalist takes an intimate look at the family over the door.

IN THE FIELD

Almost two hundred years ago, John James Audubon attached a light silver thread to the legs of a pair of eastern phoebes that were nesting in a cave on his father's estate in Pennsylvania. This early experiment in American bird banding paid off: Audubon was delighted to see the birds he had marked return the next year. A few of these fly-catching songbirds may still nest in caves; others use more traditional sites, building their nests under clifh overhangs. But today, like barn swallows and adaptable imports such as house sparrows and rock doves, many eastern phoebes raise their young near humans and their structures; under bridges, in barns, or beneath the eaves of houses.

My first intimate contact with these dark- to smoky-gray birds with the white bibs was in 1951, when my family moved to Maine. A pair nested in our three-seater outhouse. Later I nailed a small piece of board onto the underside of a beam in the barn. Phoebes built there the next spring, and they continue to do so today. Probably most farmsteads close to woods in the Northeast and Midwest host a pair of phoebes. For five months of the year at my current home in rural Vermont, my family and I enjoy watching a near-tame mated pair raise two successive broods of four to five young. Phoebes help mark my annual cycle, one that begins, come spring, with their arrival back "home" from their wintering grounds in the southern United States.

My diary for March 24, 1998, records that year's first intimations of the phoebes' return. A warm wind that day was rapidly melting the remaining snow. Down in the bog, the first red-winged blackbirds were yodeling, and a robin sang in the evening. I went to sleep hearing the wind.

I awoke suddenly in the night, almost sure I had heard a phoebe. But I could see only darkness through the skylight above my bed. I went back to sleep thinking this would be a great night to migrate. If I were a phoebe, I might ride home on the wind.

The next night, from the maple tree just outside the bedroom window, I heard it again, a phoebe's excited "dchirzeep, dchirzeep" call. There was just the faintest glow of dawn in the sky, and I jumped out of bed to look. Perched barely five feet from the window, the phoebe wagged its tail up and down (a characteristic move), stretched a wing, and continued calling. I made a cup of coffee, took notes, and waited for dawn.

Daylight revealed two birds. Phoebes typically refurbish an old nest or build a new one on top of the old. This pair wasted no time inspecting the two spots where they had nested in previous years. One was the bend in the drainpipe by the bedroom window, the other a one-inch ledge just above the back door. Each time one of the pair landed on one of the old nests, it made a soft chittering call and vibrated its wings. Quickly the pair decided on the back-door site.

The male's dependable greeting starts the day, every day, for two months. The "song" can be described as a short, high buzz-whistle or can be likened to the sound of a zipper pulled rapidly up and down. The song consists of thirty-two syllable "fee-bee, fee-bay" phrases per minute, all delivered with clocklike regularity.

From April 2–4 it was overcast and spitting snow, and the phoebes were uncharacteristically silent. When I awoke on April 5 to find the ground covered with an inch of snow, I feared for their lives. Phoebes belong to the tyrant flycatcher family and are adapted for capturing insects on the wing. They have favorite perches from which they sally forth to snatch their airborne prey. But there had been no insects aloft for days. I was surprised to see one of the phoebes on the ground under my truck, apparently searching for insects there. I was even more struck to see one bird first hover nearby, then pick at, and finally eat the suet I had hung from the porch railing for woodpeckers. Although their predation is usually triggered by the movement of insects in flight, the phoebes had, when necessary, improvised to find food.

The end of that week brought milder weather, and my diary indicates that the pair was present but quiet: "Only soft whisper calls near the nest." On April 9 the female, with her mate in attendance, began gathering billfuls of mud and bright green moss for the nest, making trip after trip with speed and apparent urgency. Phoebes are unusual among songbirds in refurbishing old nests and in using mud to cement the structure onto the smallest of platforms.

The eggs were not laid until the last week of April, as the weather warmed up, serviceberry bloomed, and maples, poplars, birches, and beeches were leafing out. That week, five species of warblers arrived. The phoebes seemed intent and wary, the
female incubating and the male aggressively guarding the nest and eggs. Males have good reason to mount a defense, and I have intervened more than once myself when the nest was threatened. One morning, when the phoebes had fallen silent, I noticed a cowbird hanging around. Brown-headed cowbirds lay their eggs in the nests of other species, usually small songbirds that are duped into raising the alien young while their own offspring perish. I was sure the cowbird, a female, was targeting the phoebes, and apparently they knew it too. Five minutes after the cowbird was gone, they erupted into a song that continued unabated for five minutes. Several years earlier I had removed a chipmunk that repeatedly tried to get at the nest, persisting even in the face of the phoebes' frantic attempts to repel it. The pair's vocal response was similarly vigorous.

These events and the fact that the birds are so accustomed to our household—they never even flush when we go in and out the squeaky door, and they use our vehicles as perches—lead me to wonder about this species' choice of nest sites. They may not only be adapting to new situations but also benefiting from the human presence. Some tropical bird species rear their young near wasp nests and depend on the insects to repel predators. Perhaps humans perform the same service for phoebes.

After about sixteen days of incubation, five young hatched in mid-May. In addition to filling the nestlings' demands for food, the adults kept the nest meticulously clean, at first by eating the chicks' fecal pellets and later by carrying them off for disposal far from the nest. By the last week in May, when the young were rapidly feathering out, pellets started to accumulate under the nest, on our back steps. That meant the chicks would soon fledge. Sure enough, on June 1, at about 6:00 A.M., I heard excited chirp calls and then saw one of the young fluttering away, with the parents accompanying it. Another chick was on the ground by the back door. I picked it up. It closed its eyes and feigned death, but when I put it on the woodpile, it quickly revived and scampered off. By afternoon, when all was quiet around the house, I heard the adults in the nearby woods. When I investigated, I found all five young perched in a row about fifteen feet up in a leafy ironwood tree.

The next dawn, the male was back, singing by the house. While shaving, I heard the pair's nest chatter that says "Here is the place." With not a day wasted, the phoebes were at the nest site. They were still feeding their fledged young, but in two more days the female had relined the nest and then immediately started laying a second clutch of eggs. On July 11 the second brood of four nestlings fledged.

The phoebe pair spends little time around the house after late July. In mid-September we commonly hear and see the pair, but only for a day or two. As the foliage brightens and the forest turns silent, they leave. I always miss these lively housemates until they return the following spring.

Bernd Heinrich is a professor of biology at the University of Vermont in Burlington.
Peering Into the Past

To understand the concept of light-speed, just bring it closer to home (plate).

One of the most basic concepts of modern cosmology is also one of the most baffling for sky watchers: the finite speed of light. Again and again, in hushed tones that suggest embarrassment at not "getting" something so fundamental, people have told me they know that looking out across space is the same as looking back in time—but how can that be?

Much of astronomy is anything but intuitive, and the idea that the speed of light is finite does indeed lead to mind-bending implications and conclusions. Unfortunately, astronomers' usual way of explaining what they call lookback time only further obscures its meaning.

Their explanation goes like this: Traveling at a speed of 186,282 miles per second, the light from the Sun takes a little over eight light-minutes to reach us. The light from Proxima, the next-nearest star, takes about four years; the light from the Andromeda Galaxy, the most distant object visible with the naked eye, more than two million years. And so it goes, farther and farther out in space, further and further back in time, until you are suitably overwhelmed with just how vast and strange this universe of ours really is. But this explanation, I think, only succeeds in putting more distance—literally—between you and the universe. Perhaps it would be easier to grasp the relationship between space and time if we brought the universe closer to home.

It's spring, so let's imagine that we're at a baseball game. From where we're sitting in the bleachers, we can watch the Sun setting and, on the opposite horizon, the full Moon rising. The Sun is slightly more than 8 light-minutes away. The Moon is 1.25 light-seconds away. But what about the batter poised at the plate?

Crack! We hear the sound of bat on ball a moment after we see the batter swing and make contact. Since we're sitting in the bleachers, maybe 400 feet from home plate, the sound takes about a third of a second to reach our ears, and we think nothing of the time lag. We're used to the fact that sound takes time to reach us—that when we hear something, it actually happened moments ago. Sound waves and light waves are not the same thing, but for our purposes in this little gedankenexperiment, the comparison is useful. We take for granted that we hear things in the past. The fact is, we see things in the past, too, but that lag isn't as obvious.

As it happens, if you do the math, the speed of light translates into an easy-to-remember formula: light travels one foot in about a billionth of a second. So at 400 feet from home
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plate, you’re seeing the batter 400-billionths of a second in the past because it took that amount of time for the light striking your eyeballs to get there from the batter. That may not sound like much, but it’s something: a quantifiable window into the past.

But let’s look around the ballpark some more. The left fielder who’s maybe 100 feet in front of you? He’s about 100-billionths of a second in the past. The cotton candy vendor, two rows over? She’s 20-billionths of a second in the past. The loud guy with the cigar sitting in front of you? He’s only 3-billionths of a second in the past. Your hand in front of your face waving away the cigar smoke? It’s 1-billionth of a second in the past, even though it’s part of your body.

But that’s just your past: to the guy with the cigar, the batter is 397-billionths of a second in the past; to the vendor keeping one eye out for a home-run ball, the batter is 380-billionths of a second in the past; and to the left-fielder, the batter is 300-billionths of a second in the past—

In other words, where you are in space is where you are in time. The two concepts don’t just coexist, they co-relate. You can’t have one without the other. There can be no now without a here.

This was one of the insights to come out of Einstein’s special theory of relativity, and it certainly provides plenty of fodder for philosophical contemplation. But from a sky watcher’s point of view, it can add a whole new dimension to appreciating what’s out there. The next time you look up at the night sky and struggle to make sense of your place in the universe, just remember that you’re struggling to make sense of your time in the universe, too. And if that doesn’t help, try telling yourself this: Play ball!

Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens (Penguin, 1999).

THE SKY IN MAY

By Joe Rao

The (In)visible Planets Sometimes an astronomically useful word becomes prematurely obsolete—for instance, “combust.” It was once used as an adjective, referring to a planet or star seemingly extinguished by the Sun’s light. This month, every one of the planets that can be seen by the naked eye (Mercury, Venus, Mars, Jupiter, and Saturn) will be combust at one time or another, and during an interval between May 9 and 21, all five will effectively be hidden from our view because of their proximity to the Sun. The exceptional clustering starts May 3–4, when the five planets, the Sun, and the Moon will be contained in a 27° span of sky. Then, on May 5, at 4:04 A.M., the span containing them will shrink to only 25.9°. At 6:30 A.M. on May 17, after the Moon moves out of the arrangement, the remaining six celestial bodies will be contained within a span of just 19.5°.

Whenever an unusual gathering of the planets occurs, it is nearly always accompanied both by a sense of wonder and by outright fear. In 1186 A.D., for instance, a similar celestial event prompted predictions of natural disasters and produced widespread panic in Europe. But absolutely nothing happened.

Will the upcoming planetary conjunction affect Earth, bringing about volcanic eruptions, earthquakes, and floods, as today’s doomsayers predict? Even if all five planets were exactly in line with the Earth and at their closest possible distance to us, their combined gravitational force would equal only 1/6460 of the Sun’s average tide. Bottom line: The Great Celestial Alignment of 2000 should have no effect on Earth.

Mercury is invisible early in the month as it passes behind the Sun (superior conjunction) on May 9. It then slowly emerges in the evening sky. Beginning May 22, look for it as a very bright star (magnitude -1) very low in the sky near the west-northwest horizon about an hour after sundown.

Venus is too close to the Sun during May to be seen.

Mars bids evening observers adieu during the first week of May, as it disappears in the bright evening twilight.

Jupiter and Saturn are both in conjunction with the Sun in May (Jupiter on the 8th and Saturn on the 10th), rendering the planets invisible for most of the month. They slowly emerge from the bright morning twilight during the final days of May. Carefully scan the east-northeast horizon with binoculars about half an hour before sunrise, and both planets will be visible within 1.1° of each other. This is their first conjunction since 1981. Jupiter will appear as a bluish white disk about seven times brighter than yellowish Saturn.

The Moon is at new phase on May 4 at 12:12 A.M. First quarter is on May 10 at 4:00 P.M. Full Moon occurs on May 18 at 3:34 A.M., and last quarter on May 26 at 7:55 A.M.

All times are given in Eastern Daylight Time.
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This year, make summer travel an adventure for all your senses. Here, a guide to mapping out memorable natural and cultural exploits in eastern North America, home to some of the most scenic spots in the world.

New Brunswick

FOLLOW YOUR QUEST FOR NATURAL WONDER to New Brunswick, one of Canada's most alluring provinces. Located on the country's east coast, it borders Maine to the west, and the province of Quebec to the north. Most notably, New Brunswick is also bordered on three sides by water: Chaleur Bay to the north, the Gulf of St. Lawrence and the Northumberland Strait to the east and, perhaps most significantly, the Bay of Fundy, all along the southern coast.

Many of New Brunswick's most picturesque byways follow along the coast of the Bay of Fundy. From the streets of cosmopolitan cities to historic, seaside towns and villages, the Bay of Fundy region is a unique coastal getaway.

The waters here invite fishing, sailing, and kayaking. Charming towns and cities offer eclectic galleries and boutiques and fine dining on fresh, succulent seafood. Whale watching is also a favorite activity here, where a variety of species put on a spectacular, unrehearsed daily show.

The Bay of Fundy itself is one of the world's most captivating natural phenomenons, an awe-inspiring display of truly monumental proportions. Considered one of the Marine Wonders of the World, the Bay of Fundy is a place of natural wonder, on par with the rainforests of Brazil and the Great Barrier Reef of Australia.

The bay is an amazing force of nature. Twice a day, one hundred billion tons of seawater surge in and out of the Bay of Fundy, enough to fill the Grand Canyon to the brim. The bay's unique funnel shape pushes and squeezes the incoming tides to incredible heights, up to 48 feet in some places. The tides here are the highest and most dramatic in the world. They create a spectacular panorama of carved coastlines and headlands as well as a rich ecosystem that supports an unusual abundance of wildlife.

Because of the size and frequency of the tides, there are certain notable attractions that are visible only at low tide, like the Hopewell Rocks. The Ocean Tidal Exploration Site at The Hopewell Rocks is the icon of New Brunswick's Outdoor Network. It is comprised of National and Provincial Parks, natural sites and amazing trails. In 1998, the Hopewell site was tripled in size and enhanced to include a new interpretive center with food services, multimedia exhibits, a gift shop, and visitor services, as well as an extensive trail network and viewing decks. In 1999 the site was the winner of Attractions Canada's Best New Site and British Airway's Tourism for Tomorrow award.

Visitors to the Bay of Fundy are warmly invited to observe over 350 million years of natural history while exploring towns that reflect the region's multifaceted native and colonial history. The city of Saint John is the Fundy City, an ideal starting point for travel along the New Brunswick coast. A journey along the city's steep streets reveals over 400 years of history. Many of the city's most interesting boutiques, cafés, and historic properties are connected by a convenient indoor walkway system. The bustling farmer's market here is the oldest in the country.

A rich blend of English and French-Acadian traditions gives the city of Moncton a distinct cultural flare. Fine dining and accommodations, vibrant nightlife and renowned shopping centers make Moncton a great stop along any New Brunswick itinerary. Moncton's Capitol Theatre, restored to its 1920s vaudeville grandeur, provides a stunning venue for live entertainment. The city's music scene offers something for everyone, from classical concerts to jazz, country and Acadian pop-rock. Naturalists will be equally entertained by the dramatic Tidal Bore of the Petitcodiac River, another of the province's famously beautiful waterways.


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New York

Niagara Falls is perhaps New York's most famous natural wonder.

**THIS STATE OFFERS A VARIETY OF ROUTES FOR summer vacationers with natural beauty in mind. In New York, a Scenic Byway is officially defined as a highway designated by the federal government and New York State that reflects regionally significant resources. New York's Scenic Byways system invites unhurried tourists to fully experience the unique features of each of the state's scenic regions.**

The Seaway Trail has been a historically important travel corridor for thousands of years. The waters of Lake Erie, the Niagara River, Lake Ontario and the mighty St. Lawrence River supplied Native Americans and early European explorers with food and transport. Later, as shipbuilders created larger vessels, lumber, grain and commodities to serve the world's populations began to move along this great seaway. The great battles of the War of 1812 were fought on these waters. Forty-two signposts note points significant to that struggle. Today, the 454 miles of this unique freshwater shoreline offer well-marked roads to villages, harbors, fishing ports and family attractions. Overnight accommodations range from hotels and inns to cottages and campgrounds.

Some of America's finest sportfishing can be enjoyed along the Seaway Trail. Marinas, state and public boat launches, professional charters and guides are ready to serve you on two Great Lakes and many marvelous bays and streams including Oak Orchard Creek, the Salmon River, a growing wild fishery on the Black River and ice fishing on the St. Lawrence. More than 600 waterfront services line the Nautical Seaway Trail. Trailwide tournaments offer large prizes.

More than two dozen lighthouses stand guard along the trail's freshwater coastline. Several have public museums: Dunkirk, Old Fort Niagara, Thirty-Mile Point, Charlotte-Genesee, Old Sodus and Tibbetts Point, and Buffalo Main Light, which has a walking trail of interest. Museum sites show and tell of shipwrecks and lives saved, the evolution of water travel, and the life of the seagoing adventurer. Oswego Lighthouse can be seen from the ramparts of Fort Ontario, a site sought by the British, French and Americans.

Old Fort Niagara in Youngstown is a National Historic Site, dating to 1679. Original stone buildings backdrops a "living" museum featuring the pageantry of daily military drills and demonstrations by costumed soldiers. Special events include reenactments of early 18th century barracks life. The Seaway Trail Guide to the War of 1812 is an excellent self-touring companion to 42 locations and events of that era.

A diverse wildlife population awaits birdwatchers, photographers, walkers, bicyclists and nature lovers. The region boasts New York's first three Important Bird Areas designated by the National Audubon Society. At three zoos, numerous state parks and wildlife management areas, botanical gardens and habitats trailwide, see a doe and fawns, hear wolves howl, watch elk wade in water, and visit western New York's only rainforest. The Seaway Trail Wildguide to Natural History details the diverse habitats and seasons and describes 127 sites of natural interest.

For more information about travelling New York State's Seaway Trail and its year-round events and festivals, call 1-800-SEAWAY-T.

The Adirondack North Country byways follow nature's contours, paralleling ancient river valleys and geological fault lines, and winding through the lake country and glacial lowlands, rugged mountain passes, and terraced plateaus.

Each byway promises great views and unlimited photo opportunities. North Country roadways also trace history's contours, introducing travelers to tales of Iroquois hunters, soldiers, pioneers, loggers, miners, trappers, painters, writers and philosophers. Exciting travel opportunities await along each Adirondack byway.

The Champlain Trail Scenic Byway runs along one of the most popular attractions in the Adirondacks—Lake Champlain. The valley's unique charm is captured in its history, recreation opportunities, quaint towns and villages. Running the length of the 121-mile Lake Champlain, the Champlain Trail features miles of sandy beaches, quaint historic villages and unique glimpses of the Adirondack Mountains. Begin your travels along the trail on Route 4 in Schuylerville, then head north to Fort Edward. The Old Fort House Museum was once an important outpost during the French and Indian War. As you travel into Ticonderoga, look for a right turn on Route 74 that heads east toward Fort Ticonderoga. The fort, a national historic landmark, offers a museum, guided tours, artillery demonstrations, encampments, and file and drum corps.

The Colonial Trail offers a memorable 200-mile scenic driving tour, linking the historic Mohawk Valley with colonial fortresses, two of the largest bodies of water in the North Country region, natural health.
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Jim Bowie’s Letter & Bill Buckner’s Legs

In history, sports, and evolutionary biology, a good story with heroic overtones may overpower the facts.

By Stephen Jay Gould

Charlie Croker, former football hero of Georgia Tech and recently bankrupted builder of the new Atlanta—a world of schlocky, soulless office towers, now largely unoccupied and hemorrhaging money—seeks inspiration, as his world disintegrates, from the one item of culture that stirs his limited inner self: a painting (originally done to illustrate a children’s book, “the only book Charlie could remember his father and mother ever possessing”) by N.C. Wyeth of “Jim Bowie rising up from his deathbed to fight the Mexicans at the Alamo.” On “one of the happiest days of his entire life,” Charlie spent $190,000 at a Sotheby’s auction to buy this archetypal image for a man of action. He then mounted his treasure in the ultimate shrine for successful men of our age: above the ornate desk on his private jet.

In his latest novel, A Man in Full, Tom Wolfe describes how Croker, his prototype for redneck moguls, draws strength from the inspirational painting:

And so now, as the aircraft roared and strained to gain altitude, Charlie concentrated on the painting of Jim Bowie . . . as he had so many times before . . . Bowie, who was already dying, lay on a bed . . . He had propped himself up on one elbow. With his other hand he was brandishing his famous Bowie knife at a bunch of Mexican soldiers . . . It was the way Bowie’s big neck and his

jaws jutted out toward the Mexicans and the way his eyes blazed defiant to the end, that made it a great painting. Never say die, even when you’re dying, was what that painting said . . . He stared at the indomitable Bowie and waited for an infusion of courage.

Nations need heroes, and Jim Bowie did die in action at the Alamo, along with Davy Crockett and about 180 fighters for Texian (with the i then included in the name) independence, under the command of William B. Travis, an articulate twenty-six-year-old lawyer with a lust for martyrdom combined with a fearlessness that should not be disparaged, whatever one may think of his judgment. In fact, I have no desire to question Bowie’s legitimate status as a hero at the Alamo at all, but I do wish to explicate his virtues by debunking the legend portrayed in Charlie Croker’s painting and by suggesting that our admiration should flow for quite different reasons that have never been hidden but that the legend leads us to disregard.

The debunking of canonical legends ranks as a favorite intellectual sport for all the usual (and ever so human) motives of one-upmanship, aggressivity within a community that denies itself the old-fashioned expression of genuine fisticuffs, and the simple pleasure of getting details right. But such debunking also serves a vital
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scholarly purpose in identifying and correcting serious pitfalls in our favored styles of argument. Evolution has tuned our brain for special sensitivity in the recognition of patterns. The further development of human consciousness extended this inherent sensitivity into a propensity for organizing patterns as stories and then for explaining the world in terms of the narratives expressed in these tales. For reasons both behind and beyond the cultural particulars of individual groups, humans tend to construct their stories along a limited number of favored pathways that seem to grant both useful sense and satisfying meaning to the confusion (and often to the tragedy) of life in our complex surrounding world.

Stories, in other words, “go” in only a limited number of strongly preferred ways, under the controlling influence of two particularly deep biases: first, a theme of directionality (linked events proceeding in an ordered sequence, not an aimless wandering—back, forth, and sideways—to nowhere) and, second, a sense of motivation or definite reasons (whether we judge them good or bad) propelling the sequence. When a particular story treats the action of our own species, these motivations will be rooted directly in human purposes. But tales about nonconscious creatures or inanimate objects must also provide a surrogate for valor (or dishonorable intent, for dystopian tales)—as in the “virtue” of evolutionary principles that dictate the increasing general complexity of life or the “lamentable inexorability” of thermodynamics in guaranteeing the eventual burnout of the Sun. In summary, and at the risk of oversimplification, we prefer to explain pattern in terms of directionality and causation in terms of valor.

I will refer to the small set of primal tales based upon these deep biases as canonical stories. Our strong propensity for expressing all histories, be they human, organic, or cosmic, in terms of canonical stories would not entail such enormous problems for science (but might be viewed instead as simply humorous in exposing the foibles of Homo sapiens) if two properties of mind and matter didn’t promote this potentially harmless idiosyncrasy into a pervasive bias actively derailing our hopes for understanding events that unfold in time. (The explanation of temporal sequences defines the primary task of a large subset among our scientific disciplines: the so-called historical sciences of geology, anthropology, evolutionary biology, cosmology, and many others. Thus, if the lure of canonical stories blights our general understanding of historical sequences, much of what we call science labors under a mighty impediment.)

As for matter, many patterns and sequences in our complex world owe their apparent order to the luck of the draw within random systems. (We flip five heads in a row once every thirty-two sequences, on average. Stars clump into patterns in the sky because of these causes because the lure of canonical stories leads us to entertain only a small subset within the full range of legitimate hypotheses for explaining the recorded events. Even worse, since we cannot observe everything in the blooming and buzzing confusion of the world’s surrounding richness, the organizing power of

Sam Houston ordered Jim Bowie to destroy the Alamo and withdraw, but Bowie decided to defend it.

Death of Bowie, by Louis Eyth, ca. 1878
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canonical stories leads us to ignore important facts readily within our potential view and to twist or misread the information that we do manage to record. In other words—and to summarize my principal theme in a single statement—canonical stories predictably drive facts into definite and distorted pathways that validate the outlines and necessary components of these archetypal tales. We therefore fail to note important items "in plain sight," while we misread other facts by forcing them into preset mental channels even when we retain a buried memory of actual events.

This essay will illustrate how canonical stories have predictably relegated crucial information to misconstruction or invisibility in two great folktale of American history: Bowie's letter and Buckner's legs, as oddly (if euphoniously) combined in my title. I will then extend the general message to argue that the allure of canonical stories acts as the greatest impediment to better understanding throughout the realm of historical science, one of the largest and most important domains of human intellectual activity.

1. Jim Bowie's letter. How the canonical story of "All the brothers were valiant, and all the sisters virtuous" (a familiar quotation that first appears on the tomb of the Duchess of Newcastle, who died in 1673 and now lies in Westminster Abbey) has hidden a vital document in plain sight. The Alamo of San Antonio, Texas, was designed not as a fortress but as a mission built by eighteenth-century Franciscans. Today the Alamo houses exhibits and artifacts, most recalling the death of all Texian defenders in General Antonio López de Santa Anna's assault on March 6, 1836, after nearly two weeks of siege by forces outnumbering the Texans by at least ten to one. This defeat and martyrdom electrified the Texian cause, which triumphed less than two months later, when Sam Houston's men captured Santa Anna at the Battle of San Jacinto on April 21 and then forced the Mexican general to barter Texas for his life and liberty.

The Alamo's exhibits, established and maintained by the Daughters of the Republic of Texas and therefore more partisan than the usual (and, to my mind, generally admirable) fare that the National Park Service provides in such venues, tells the traditional tale, as I shall do here. (Mexican sources, no doubt, purvey a different but equally traditional account from another perspective.) I shall focus on the relationship of Bowie and Travis, for my skepticism about the canonical story focuses on a fascinating letter, written by Bowie and prominently displayed in the Alamo's official presentation but strangely disregarded to the point of invisibility.

In December 1835, San Antonio fell to Texian forces in fierce fighting with Mexican troops under General Martin Perfecto de Cos. On January 17, 1836, Sam Houston ordered Jim Bowie and some thirty men to enter San Antonio, destroy the Alamo, and withdraw the Texian forces to more defensible ground. But Bowie, after surveying the situation, disagreed for both strategic and symbolic reasons and decided to fortify the Alamo instead. The arrival, on February 3, of thirty additional men under the command of William B. Travis strengthened Bowie's decision.

But tension inevitably developed between two such different leaders: the forty-year-old, hard-drinking, fearlessly independent but eminently practical and experienced Bowie and the twenty-six-year-old, troubled, and vainglorious Travis, who had left wife and fortune in Alabama to seek fame and adventure on the Texian frontier. (Mexico had encouraged settlement of the Texian wilderness by all who would work the land and swear allegiance to the liberal constitution of 1824, but the growing Anglo majority had risen in revolt, spurred by the usual contradictory motives of lust for control and love of freedom, as expressed in anger at Santa Anna's gradual abrogation of constitutional guarantees.)

Bowie commanded the volunteers, while Travis led the "official" army troops. A vote among the volunteers overwhelmingly favored Bowie's continued leadership, so the two men agreed upon an uneasy sharing of authority, with all orders to be signed by both. This arrangement became irrelevant, and Travis assumed full command, when Bowie fell ill with clearly terminal pneumonia and a slew of other ailments just after the siege began, on February 23. In fact, Charlie Croker's favorite painting notwithstanding, Bowie may have been comatose or even already dead when Mexican forces broke through on March 6. He may have made his legendary last "stand" in supine position, propped up in his bed with pistols in hand, but he could not have mounted more than a symbolic final defense, and his legendary knife could not have reached past the Mexican bayonets in any case.

The canonical story of valor at the Alamo features two incidents, both centered upon Travis, with one admitted as legendary by all serious historians and the other based upon a stirring letter, committed to memory by nearly all Texas schoolchildren ever since. As for the legend, when Travis realized that no reinforcements would arrive and that all his men would surely die if
they defended the Alamo by force of arms (for Santa Anna had clearly stated his terms of no mercy or sparing of life without unconditional surrender), he called a meeting, drew a line in the sand, and then invited all willing defenders of the Alamo to cross the line to his side, while permitting cowards and doubters to scale the wall and make their inglorious exit (as one man did). In this venerable legend, Jim Bowie, too weak to stand, asked his men to carry his bed across the line. Well, Travis may have made a speech at the relevant time, but no surviving witness (several women and children and one slave) ever reported the story. (The tale apparently originated about forty years later, supposedly told by the single man who accepted Travis's option to escape.)

As for the familiar letter, few can read Travis's missive with a dry eye, while even the most skeptical of Alamo historians heeds honor upon this document of February 24, carried by a courier (who broke through the Mexican lines) to potential reinforcements but addressed to “The People of Texas and All Americans in the World.” (For example, Ben H. Proctor describes Travis as “egotistical, proud, vain, with strong feelings about his own destiny, about glory and personal mission . . . trouble in every sense of the word,” but judges this missive “one of the truly remarkable letters of history, treasured by lovers of liberty everywhere.” [See Proctor's pamphlet The Battle of the Alamo, published by the Texas State Historical Association in 1986.]

I am besieged, by a thousand or more of the Mexicans under Santa Anna—I have sustained a continual bombardment & cannonade for 24 hours & have not lost a man—The enemy has demanded a surrender at discretion, otherwise, the garrison are to be put to the sword, if the fort is taken—I have answered the demand with a cannon shot, & our flag still
waves proudly from the walls—I shall never surrender or retreat. Then, I call on you in the name of Liberty, of patriotism & everything dear to the American character, to come to our aid, with all dispatch—The enemy is receiving reinforcements daily & will no doubt increase to three or four thousand in four or five days. If this call is neglected, I am determined to sustain myself as long as possible & die like a soldier who never forgets what is due to his own honor & that of his country—VICTORY OR DEATH.

Although a small group of thirty-two men did arrive to reinforce the Alamo, their heroic presence as cannon and bayonet fodder could not alter the course of events, while a genuine force of potential difference (several hundred men stationed at nearby Goliad) never came to Travis’s aid, for complex reasons still under intense historical debate. Every Texian fighter died in Santa Anna’s attack on March 6. (According to the usual legend, all the men fell in action. But substantial, if inconclusive, evidence indicates that six men may have surrendered at the hopeless end, only to be summarily executed by Santa Anna’s direct order. The probable presence of Davy Crockett within this group accounts for the disturbing effect and emotional weight of this persistent tale.)

As something of an Alamo buff and as a frequent visitor to the site in San Antonio, I have long been bothered and intrigued by a crucial document—a letter by the Alamo’s other leader, Jim Bowie—that seems to provide quite a different perspective on the siege but doesn’t fit within the canonical legend and hardly receives a mention in any official account at the shrine itself. Bowie’s letter thus remains “hidden in plain sight”—sitting in its own prominent glass case right in the main hall of the on-site exhibition. This curious status as prominently displayed but utterly passed over has fascinated me for twenty years and provided the inspiration for this essay (despite the almost absurdly long gestation time). I have, in three visits to the Alamo spanning fifteen years, bought every popular account of the battle for sale at the extensive gift shop. I have read these obsessively and can assert that Bowie’s letter, while usually acknowledged, receives short shrift in most conventional descriptions.

Let us return to a statement in Travis’s celebrated letter—“the enemy has demanded a surrender. . . . I have answered the demand with a cannon shot”—and fill in some surrounding events. The basic outline has not been disputed. When Santa Anna entered town with his army and began his siege on February 23, he unfurled a blood-red flag—the traditional demand for immediate surrender, with extermination as the consequence of refusal—from the tower of the Church of San Fernando. Travis, without consulting his co-commander, fired the Alamo’s largest cannon, an eighteen-pounder, in defiant response, just as he boasted in his famous letter written the next day.

The complexities that threaten the canonical story now intrude. Although Santa Anna had issued his uncompromising and blustering demand in a public display, many accounts (filled with different details but all pointing in the same credible direction) indicate that he also proposed a parley for negotiations with the Alamo defenders. (Even if Santa Anna didn’t issue this call, the canonical story takes its strong hit just from the undisputed fact that Bowie, for whatever reason, thought the Mexicans had suggested a parley. In various versions of the story, Santa Anna’s forces also raised a white flag—the equally traditional signal for a parley—either accidentally or purposefully and either before or after Travis’s cannon shot, or else a Mexican soldier sounded the standard bugle call for an official invitation to negotiations.)

A healthy and practical Bowie might have negotiated an honorable surrender at no great cost to the Texian cause.

In any case, Bowie, who by most accounts was furious at Travis for the impetuous bravado and clearly counterproductive nature of his purely symbolic cannon shot, grabbed a piece of paper and wrote, in Spanish and signed with a faltering hand (for Bowie was already ill but not yet prostrate and still capable of leadership), the “invisible” letter that just won’t mesh with the canonical story and therefore remains “hidden” on prominent display at the Alamo. I cite the full text of Bowie’s letter, in the translation given in Clifford Hopewell’s biography James Bowie: Texas Fighting Man (Eakin Press, 1994):

Because a shot was fired from a cannon of this fort at the time a red flag was raised over the tower, and soon afterward having been informed that your forces would parley, the same not having been understood before the mentioned discharge of cannon, I wish to know if, in effect, you have called for a parley, and with this object dispatch my second aide, Benito James, under the protection of a white flag, which I trust will be respected by you and your forces. God and Texas.

I don’t want to exaggerate the meaning of this letter. I cannot assert a high probability for a different out-
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come if Bowie had remained strong enough to lead and if Santa Anna had agreed to negotiations. Some facts dim the force of any speculation about a happier outcome that would have avoided a strategically senseless slaughter with an inevitable military result and would thus have spared the lives of 180 Texians (and probably twice as many Mexicans). For example, Bowie

**Bostonians incurred the Curse of the Bambino in 1920, when the Red Sox sold Babe Ruth’s contract.**

did not display optimal diplomacy in his note, if only because he originally wrote “God and the Mexican Federation” in his signatory phrase (indicating his support for the constitution of 1824 and his continued loyalty to this earlier Mexican government) but, in a gesture that can only be termed defiant, crossed out “the Mexican Federation” and wrote “Texas” instead.

More important, Santa Anna officially refused the offer of Bowie’s courier and sent back a formal response promising extermination without mercy unless the Texians surrendered unconditionally. (Moreover, we cannot be confident that the Texians’ lives would have been spared even if the Alamo’s defenders had surrendered without a fight. After all, less than a month after the fall of the Alamo, Santa Anna executed several hundred prisoners—the very men who might have come to Travis’s aid—after their surrender at Goliad.)

In the confusion and recriminations between the two commands, Travis then sent out his own courier and received the same response but, according to some sources, with the crucial addition of an informal statement that if the Texians laid down their arms within an hour, their lives and property would be spared, even though the surrender must be technically and officially unconditional. Such, after all, has always been the way of war, as good officers balance the need for inspirational manifestos against their even more important moral and strategic responsibility to avoid a “glory trap” of certain death. Competent leaders have always understood the crucial difference between public proclamations and private bargains.

Thus, I strongly suspect that if Bowie had not become too ill to lead, some honorable solution would eventually have emerged through private negotiations, if only because Santa Anna and Bowie, as seasoned veterans, maintained a high mutual regard beneath their strong personal dislike, whereas I can only imagine what Santa Anna thought of the upstart and self-aggrandizing Travis. In this alternative and unrealized scenario, most of the brothers would have remained both valiant and alive. What resolution fits better with our common notions of morality and human decency: more than four hundred men slaughtered in a battle with an inevitable result (thus providing an American prototype for a claptrap canonical story about empty valor over honorable living) or an utterly non-heroic, tough-minded, and practical solution that would have erased a great story from our books but restored hundreds of young men to the possibility of a full life, complete with war stories told directly to grandchildren?

Finally, one prominent Alamo fact (though rarely mentioned in this context) provides strong support for the supposition that wise military leaders usually reach private agreements in order to avoid senseless slaughter. Just three months earlier, in December 1835, General Cos had made his last stand against Texian forces at exactly the same site—within the Alamo! But Cos, as a professional soldier, raised a white flag and agreed to terms with the Texian conquerors: he would surrender, disarm, withdraw his men, retreat southwestward over the Rio Grande, and not fight again. Cos obeyed the terms of his bargain, but after he had crossed the Rio Grande to

Boston Red Sox first baseman Bill Buckner in 1986 against the Detroit Tigers; his three-run double in that game helped put the Red Sox in the World Series.
safety, Santa Anna demanded his return to active duty. Thus, the same General Cos—alive, kicking, and fighting—led one of the companies that recaptured the Alamo on March 6. Travis would have cut such a dashing figure at San Jacinto!

2. Bill Buckner's Legs. How the canonical story of "But for this" has driven facts that we can all easily recall into a false version dictated by the needs of narrative. Any fan of the Boston Red Sox can recite chapter and verse of a woeful tale, a canonical story in the land of the bean and the cod, called the Curse of the Bambino. The Sox established one of Major League Baseball's most successful franchises of the early twentieth century. But the Sox won their last World Series way back in 1918. A particular feature of all subsequent losses has convinced Boston fans that their team labors under an infamous curse, initiated in January 1920, when Boston owner Harry Frazee simply and cynically sold the team's greatest player—the best left-handed pitcher in baseball but soon to make his truly indelible mark on the opposite path of power hitting—for straight cash needed to finance a flutter on a Broadway show and not for any advantages or compensation in traded players. Moreover, Frazee sold Boston's hero to the hated enemy, the New York Yankees. This man, of course, soon acquired the title Sultan of Swat: the Bambino, George Herman "Babe" Ruth.

The Red Sox have played in four World Series (1946, 1967, 1975, and 1986) and several play-off series since then, and they have always lost in the most heartbreaking manner—by coming within an inch of the finish line and then self-destructing. Enos Slaughter, of the rival St. Louis Cardinals, scored from first on a single in the decisive game of the 1946 World Series. In 1975 the Sox lost game 7 after a miraculous victory in game 6, capped by Bernie Carbo's three-run homer to tie the score, and won in

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extra innings by Carlton Fisk when he managed to overcome the laws of physics by body English and cause a ball that he had clearly hit out of bounds to curve into the left-field foul pole for a home run.

And so the litany goes. But all fans will tell you that the worst moment of utter incredibility—the defeat that defies any tale of natural causality and must therefore record the operation of a true curse—terminated game 6 in the 1986 World Series. (Look, I’m not even a Sox fan, but I still don’t allow anyone to mention this event in my presence; the pain remains too great!) The Sox, leading the Series 3–2 and requiring only this victory for their first Ring since 1918, entered the last inning with a comfortable three-run lead. Their pitcher quickly got the first two outs. The Sox staff had peeled the foil off the champagne bottles but, remembering the curse, had not yet popped the corks. The Mets management had already, and graciously, flashed “Congratulations Red Sox” in neon on the scoreboard. But the faithful multitude of fans, known as Red Sox Nation, remained glued to their television sets in exquisite fear and trembling.

And the curse unfolded, with an intensity and cruelty heretofore not even imagined. In a series of scratch hits, bad pitches, and terrible judgments, the Mets managed to score two runs. (I mean, even a batting-practice pitcher, even you or I, could have gotten someone out for the final victory!) Reliever Bob Stanley, a good man dogged by bad luck, came in and threw a wild pitch to bring the tying run home. (Some, including yours truly, would have scored the pitch as a passed ball, but let’s leave such contentious irrelevancies aside for the moment.) And now, with two outs, a man on third, and the score tied, Mookie Wilson steps to the plate.

Bill Buckner, the Sox’s gallant first baseman and a veteran with a long and distinguished career, should not even have been playing in the field. For weeks, manager John Mcnamara had been benching Buckner for defensive purposes during the last few innings of games with substantial Red Sox leads, for after a long and hard season, Buckner’s legs were shot and his stride gimpy. In fact, he could hardly bend down. But the sentimental Mcnamara wanted his regular players on the field when the great (and seemingly inevitable) moment arrived, so Buckner stood at first base.

I shudder as I describe the outcome that every baseball fan knows so well. Buckner’s ignominious moment occurred when Mookie Wilson’s easy, tapped ball went right between Buckner’s legs to the outfield, allowing a runner on third to score.

Stanley, a great sinker-ball pitcher, did exactly what he had been brought in to accomplish. He threw a wicked sinker that Wilson could only tap on the ground toward first base for an easy out to cap the damage and end the inning with the score still tied, thus granting the Sox hitters an opportunity to achieve a comeback and victory. But the ball bounced right through Buckner’s legs into the outfield as the man on third hurried home with the winning run—not to the side of his body, and not under his lunging glove as he dived to the right or left for a difficult chance, but right through his legs! The seventh and concluding game hardly mattered. Despite brave rhetoric, no fan expected the Sox to win (hopes against hope, to be sure, but no real thoughts of victory). They lost.

This narration may drip with my feelings, but I have presented the straight facts. The narrative may be good and poignant enough in this accurate version, but this factual tale cen-
story fails to fall into place, usually as a consequence of human error or malfeasance. “But for this” can brook no nuances, no complexity, no departure from the central meaning and poignant tragedy that an entire baleful outcome flows absolutely and entirely from one tiny accident of history.

“But for this” must therefore drive the tale of Bill Buckner’s legs into the only version that can validate the canonical story. In short, poor Bill must become the one and only cause and focus of ultimate defeat or victory. That is, if Buckner fields the ball properly, the Sox win their first World Series since 1918 and eradicate the Curse of the Bambino. But if Buckner bobbles the ball, the Mets win the Series instead, and the curse continues in an even more intense and painful way. For Buckner’s miscue marks the unkindest bounce of all, the most improbable, trivial little error sustained by a good and admired man. What hath God wrought?

Except that Buckner’s error did not determine the outcome of the World Series—for one little reason, detailed above but all too easily forgotten. When Wilson’s grounder bounced between Buckner’s legs, the score was already tied! (Not to mention that this game was the sixth and, at worst for the Sox, the penultimate game of the Series, not the seventh and necessarily final contest. The Sox could always have won game 7 and the entire Series, no matter how the negotiations of God and Satan proceeded over Bill Buckner, the modern incarnation of Job, in game 6.) If Buckner had fielded the ball cleanly, the Sox would not have won the Series at that moment. They would only have secured the opportunity to do so if their hitters came through in extra innings.

We can easily excuse any patriotic American without credentials as a professional historian (or any casual visitor, for that matter) for buying into the canonical story of the Alamo—“All the brothers were valiant”—and not learning that a healthy and practical Bowie might have negotiated an honorable surrender at no great cost to the Texian cause. After all, the last potential eyewitness has been underground for well over a century. We have no records beyond the written reports, and historians cannot trust the account of any eyewitness, for the supposed observations fall into a mire of contradiction, recrimination, self-interest, aggrandizement, and the quintessentially human propensity for spinning a tall tale.

But any baseball fan with the legal right to sit in a bar and argue the issues over a mug of the house product should be able to recall the uncomplicated and truly indisputable facts of Bill Buckner’s case with no trouble at all—often, with the force of eyewitness memory, either exulting in impossibly fortuitous joy or groaning in the agony of despair and utter disbelief before a
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I almost wince when I see the first appearance of vertebrates on land described as a conquest. television set. (To fess up, I should have been at a fancy dinner in Washington, but I “got sick” instead and stayed in my hotel room. In retrospect, I should not have stood in bed.)

The subject attracted my strong interest because within a year after the actual event, I began to note a pattern in the endless commentaries that have hardly abated, even fifteen years later— 

for Buckner’s tale can be made relevant by analogy to almost any misfortune under a writer’s current examination, and Lord only knows we experience no shortage of available sources of pain. Many stories reported, and continue to report, the events accurately—and why not, for the actual tale packs sufficient punch, and any fan should be able to extract the correct account directly from living and active memory? But I began to note that a substantial percentage of reports had subtly (and quite unconsciously, I’m sure) driven the actual events into a particular false ver-

sion: the pure “end member” of ultimate tragedy demanded by the canonical story “But for this.”

I keep a growing file of false reports, all driven by requirements of the canonical story, claiming that but for Buckner’s legs, the Sox would have won the Series—forgetting the inconvenient complexity of a tied score at Buckner’s ignominious moment and sometimes even forgetting that the Series still had another game to run. This misconception appears promiscuously, both in hurried daily journalism and in rarefied books by the motley crew of poets and other assorted intellectuals who love to treat baseball as a metaphor for anything else of importance in human life or the history of the universe. (I have written to several folks who made this error, and they all responded honorably with a statement like “Omigod, what a jerk I am! Of course the score was tied, Jeez [sometimes bolstered by an invocation of Mary and Joseph as well], I just forgot!”)

For example, a front-page story in USA Today of October 25, 1993, discussed Mitch Williams’s antics in the 1993 World Series in largely unfair comparison with the hapless and blameless Bill Buckner:

Williams may bump Bill Buckner from atop the goat list, at least for now. Buckner endured his nightmare Oct. 25, 1986. His Boston Red Sox were one out away from their first World Series title since 1918 when he let Mookie Wilson’s grounder slip through his legs.

Or this, from a list of Sox misfortunes published in the New York Post on October 13, 1999, just before the Sox met

the Yanks (and lost, of course) in their first full series of postseason play:

Mookie Wilson’s grounder that rolled through the legs of Bill Buckner in Game 6 of the 1986 World Series. That happened after the Red Sox were just one out away from winning the World Series.

For a more literary view between hard covers, consider the very last line of a lovely essay written by a true poet and devoted fan to introduce a beautifully illustrated new edition of Casey at the Bat, the classic poem by Ernest L. Thayer about failure in baseball:

Triumph’s pleasures are intense but brief; failure remains with us forever.
mothering nurturing common humanity. With Casey we all strike out. Although Bill Buckner won a thousand games with his line drives and brilliant fielding, he will endure in our memories in the ninth inning of the sixth game of a World Series, one out to go, as the ball inexplicably, ineluctably, and eternally rolls between his legs.

But the nasty little destroyer of lovely canonical stories then pipes up, in his less mellifluous tones: “But I don’t know how many outs would have followed or who would have won. The Sox had already lost the lead; the score was tied.” Factuality embodies its own form of eloquence, and gritty complexity often presents an even more interesting narrative than the pure and archetypal “end member” version of our canonical stories. But something deep within us drives accurate messiness into the channels of canonical stories—the primary impossibilities of our minds upon the world.

To any reader who now raises the legitimate issue of why I have cluttered a magazine of natural history with two stories about American history that bear no evident relevance to any overtly scientific question, I simply restate my opening and general argument: human beings are pattern-seeking, storytelling creatures. These mental propensities generally serve us well enough, but they also, and often, derail our thinking about all kinds of temporal sequences—in the natural world of geological change and the evolution of organisms as well as in human history—by leading us to cram the real and messy complexity of life into simplistic channels of the few preferred ways that human stories “go.” I call these biased pathways canonical stories, and I argue that our preferences for tales about directionality (to explain patterns), generated by motivations of valor (to explain the causal basis of these patterns), have distorted our un-
derstanding of a complex reality where different kinds of patterns and different sources of order often predominate.

I chose my two stories on purpose—Bowie's letter and Buckner's legs—to illustrate two distinct ways that canonical stories distort our reading of actual patterns: first, in the tale of Jim Bowie's letter, by relegating important facts to virtual invisibility when they cannot be made to fit the canonical story (even though we do not hide the inconvenient facts them-...
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The flow of that water—in brooks, streams, rivulets, rivers, and lakes—frames much of what makes Kentucky so lush and alluring.

The hills and hollows of the state’s Eastern Highlands region were formed by water. Here “The Gap” refers to the Cumberland Passage, where Daniel Boone first entered this beautiful landscape.

The Daniel Boone National Forest pays homage to both the man and the land he discovered. At Cumberland Falls State Park, visitors are invited to ride the waterfall known as the “Niagara of the South.” In the evening, some lucky travelers experience the natural wonder of a “moonbow,” a rare nighttime rainbow that occurs in only two places in the world, the other located on the continent of Africa.

Kentucky’s Bluegrass Heartland’s region is not only the birthplace of bourbon but the best place to raise a thoroughbred or a carpet of grass so famous it has lent its name to the Bluegrass State, as well as a beloved American musical movement. The Heartland is home to both of Kentucky’s most vital urban centers, Louisville and Lexington.

On the banks of the Ohio River in Louisville, a block from Waterfront Park, lies the city’s new 13,000-seat stadium, Louisville Slugger Field, home to the RiverBats—a AAA affiliate of the Cincinnati Reds.

Lexington, Kentucky’s largest non-river city, is the Horse Capital of the World and home to the world-renowned Kentucky Horse Park. This premier facility celebrates one of nature’s most majestic creatures—in equine art and history museums, galleries, theaters, and equestrian events. This May, the park hosts “Imperial China: The Art of the Horse in Chinese History,” the largest exhibition to travel from China to the U.S.

Historic Richmond, south of Lexington, was Daniel Boone’s site for his wilderness outpost, the birthplace of Kit Carson, and home of the fiery abolitionist Cassius Marcellus Clay. Civil War buffs will want to take the Battle of Richmond driving tour. The Richmond Area Arts Center, housed in an 1887 church on Lancaster at Water Street, is another great stop. Nine miles southeast of town lies the Central Kentucky Wildlife...
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In the city of Newport, visitors to Kentucky can now experience something they never dreamed the state could offer—oceanic adventures. Opened just last year, the Newport Aquarium has quickly become one of the nation's most amazing attractions, with one million gallons of fresh and salt water creating an ideal habitat for 11,000 marine animals. More than 60 exhibits showcase sharks, American alligators, King penguins and fish from all over the world. This state-of-the-art facility features five underwater walkways. These seamless acrylic tunnels, designed specifically for this site, offer visitors an unobstructed view of the colorful creatures that surround them. Three areas feature acrylic flooring, providing a look down into the jaws of sharks and alligators. Visitors can also see one of the country's largest open-air shark exhibits: 380,000 gallons of water teeming with 25 tropical sharks. For more information about Oceanic Adventures-Newport Aquarium, call 888-491-FINS or visit www.newportaquarium.com.

In South Central Kentucky, visitors are invited to marvel at the state's Scenic Wonderlands. For millions of years, waters have forged vast holes in the land here, making this region an internationally renowned destination. Mammoth Cave National Park is the gateway to the largest known cave system in the world. The entire area around the 52,000-acre national park is full of caves to explore. Eleven different tours are offered each day, including a tour for the disabled. Park rangers lead explorations of breathtaking sites with playful names like Fat Man's Misery, Bottomless Pit and Grand Central Station. These caves reveal a wealth of information about the region's natural history and have offered up more than a few prehistoric artifacts. Nearly 30 miles of the Green and Nolin Rivers wind their way through the park, offering some of the best canoe runs in the state. The river here supports an unusual diversity of fish, including five species found nowhere else in the world.

In nearby Horse Cave, The American Cave Museum is an environmental education center offering exhibits on the cultural and natural resources associated with caves. A guided nature walk into the Hidden River Cave reveals the river flowing more than 100 feet beneath the earth as well as the remnants of an early hydroelectric system. Closed as a tourist attraction in 1943, Horse Cave has been successfully restored, even luring back the rare blind cavefish.

Bowling Green's Lost River Cave, known locally as "Dead Man's Cave," offers boat tours through what many claim to be the world's shortest and deepest river. This river valley was evidently formed by the collapse of a large cave system, creating over 23 acres of unique topographical features. While in the Lost River Cave and Valley area, take time to enjoy the beautiful nature trails, lined with over fifty varieties of trees and flowers, and visit the Butterfly House, the summer home of several colorful species.

Yet another not-to-be-missed stop in the Scenic Wonderlands region is the Big South Fork National River and Recreation Area, a wilderness plateau with fantastic geological formations, and a train ride right out of your imagination. The area offers an accommodating range of resorts, campgrounds and marinas surrounding two of the finest pleasure boating and fishing lakes in the Eastern United States: Lake Cumberland and Dale Hollow Lake. The region's inviting Shaker towns, located at South Union, is one of two restored Shaker sites in Kentucky.
Car aficionados won’t want to miss the impressive National Corvette Museum in Bowling Green. In addition to its 68,000 square-foot display floor and 200-seat Chevrolet Theater, the museum also features an outdoor amphitheater for a variety of concerts and events, including the annual Corvette Celebration, held each Labor Day weekend. Also in Bowling Green, on the campus of Western Kentucky University, lies the fascinating Kentucky Museum, tracing the state’s rich history through historic artifacts, fine and decorative arts, toys, games, folkcrafts and photographs.

Kentucky’s Western Waterlands teem with opportunities for outdoor exploration. Kentucky Lake and Lake Barkley, connected by a free-flowing canal, together form one of the largest manmade bodies of water in the country. The Land Between the Lakes (LBL) is a 40-mile-long peninsula, home to a notable National Park and World Biosphere Reserve, ideal for camping, fishing, and boating.

Paducah, the last of the large Kentucky cities on the Ohio River’s trek south, has more historic markers than any other city in the state. Since the opening of the Museum of the American Quilter’s Society in 1991, Paducah has become known as “Quilt City, USA.” Changing exhibits of antique and contemporary quilts are displayed in three galleries.

Kentucky’s plentiful natural resources are distilled in its signature spirit—bourbon. The Reverend Elijah Craig is credited with developing what would become known as bourbon whiskey in Georgetown, Kentucky, in 1789. Today, his legacy lives on along The Bourbon Trail, a self-guided tour of seven distilleries: Austin Nichols (Wild Turkey); Four Roses; Heaven Hill; Jim Beam; Labrot & Graham; Buffalo Trace; and Maker’s Mark.

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This year, Kentucky hosts the Millennium’s first great International exhibition.

Dynasty (1027-771 BC) as well as the subsequent dynasties through the Qing (1644–1911). Roughly 20 percent of the artifacts on display have never been exhibited in the United States. In fact, many of these items have never before been permitted to leave China.

More than an artistic display, the exhibit will explore the historical, cultural and political significance of the horse in the unification of China and the exchange of equestrian culture with the Western world via the Silk Road. It also looks at advancements in horsemanship, training and techniques and the use of the horse in leisure activities.

The exhibit features items selected from museums throughout Shaanxi Province, capital of China for more than a millennium and home of the terra-cotta army of China's first emperor. To qualify to host an international exhibition of this magnitude, the museum had to meet extremely high standards. This truly magnificent show is considered by many officials in Kentucky to be the most significant international cultural event in the state's history.

The Kentucky Horse Park is located at Interstate 75 Exit 120, four miles north of Lexington. For more information about this exhibition, call the Kentucky Horse Park at 800-568-8813 or visit its Web site at www.imh.org. For information on travel to Kentucky, call 800-225-8747 or visit www.kentuckytourism.com

This special editorial/advertising supplement was created by the Natural History Special Sections Department and did not involve the magazine’s editorial staff.  WRITER Kathryn Brennan  DESIGN Mindy Phelps Stanton
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On the Rebound

Blown down, a blade of grass uses the wind's energy to bounce back.

One of the biggest events in the history of terrestrial plants took place 420 million years ago. Before then, all plants hugged the ground, as mosses and liverworts do today. Once plants had built strong stems and trunks, they could stand upright and reach for the sun. But they faced new dangers. To support their own weight, they had to be stiff. Yet they also had to keep from snapping in a strong wind, and if they evolved to be more flexible, they might flop over like wet noodles. Different plants arrived at different solutions to this dilemma. Many trees, for instance, have built-in weak spots in their branches. As a result, a windstorm is more likely to prune a tree than to bring it crashing down.

Some of the most elegant ways to fight the wind can be found in grass. A blade of grass—whether wheat, oat, rye, or the fescues growing in suburban lawns—consists of a slender, hollow, cylindrical stem rigid enough to stand upright. Its hollow shape allows grass to grow much taller than a solid-stemmed plant with the same amount of tissue. Blown by a gust of wind, however, the blade bends, putting a lot of stress on its thin stem walls. Sometimes the stress is too much, and the blade buckles. (To see for yourself how thin-walled cylinders buckle under stress, try bending a plastic straw.) Farmers are all too familiar with the problem, which they call lodging; a thunderstorm can destroy a valuable field of wheat or rye by knocking it flat to the ground.

Most of the time, though, grass stands up straight again once a gust of wind has passed. Cornell University botanist Karl Niklas and his coworkers study the mechanical properties of grass, including those that help the plant avoid buckling. They have found that thin disks, stretching at regular intervals across the inside of the stem, prevent the hollow blade from collapsing at the bending point. Made of a springy material and light (accounting for only 2 percent of the blade's total weight), the disks act like bedsprings: the more they are squeezed, the more they push back against the walls of the stem. That outward force keeps the grass from caving in on itself.

Niklas has discovered an extra benefit to this design. As a blade bends, it changes shape: the cross section of an erect stem is circular, while one taken at the bending point is oval. If that oval becomes too compressed, the stem will collapse. But as the internal disks crumple, Niklas found, their springy tissue stores up some of the wind's energy. When the wind lets up, the disks uncrumple, releasing the pent-up energy. In the process, the stem regains its cylindrical shape and rebounds to its upright position. Grass doesn't sway in the wind so much as it springs.

The leaves surrounding the stem provide additional resistance to buckling. Sprouting from thin, crescent-shaped sheaths that grow alongside the disks and run partway around the plant's circumference, the leaves act like a girdle, their sheaths bracing the stem and absorbing some of the wind's impact.

If grasses are so well engineered to resist the wind, why is lodging such a worry for farmers? The problem is that wheat and other crop grasses have been bred to bear bigger and bigger seed heads. The plants are now so top-heavy that they've overwhelmed their natural antibuckling design. One solution might be to breed grasses with more resilient disks in their stems. Another might be to breed them shorter, so that the seeds at their tips wouldn't exert so much force when the blades bend.

Plant breeders aren't the only people who could benefit from a greater understanding of the biomechanics of grass. Some engineers, inspired by Niklas's research, want to design broom bristles that act like grass: with every sweep, the bristles would bounce back upright on their own.

Carl Zimmer is the author of At the Water's Edge: Macroevolution and the Transformation of Life, available in paperback from Touchstone.
Take Two Beers and Call Me in 1,600 Years

Ancient Nubians and Egyptians had a way with antibiotics.

By George J. Armelagos

Some twenty years ago, Debra Martin placed a bit of bone from a mummy under a microscope and discovered that a person who lived in Nubia (northern Sudan) during the fourth century A.D. had apparently ingested tetracycline, a broad-spectrum antibiotic that entered the arsenal of modern medicine only in the 1950s. Finding a pair of designer sunglasses on the mummy would hardly have been more startling. And the discovery was purely serendipitous.

Today Martin is a professor of anthropology at Hampshire College in Amherst, but at the time she was a graduate student in biological anthropology at the University of Massachusetts. As part of her training, she was visiting a research laboratory at Henry Ford Hospital in Detroit, Michigan, to learn techniques for making thin sections of bones from archaeological finds. Normally she would have relied on a standard microscope, and the tetracycline would have gone undetected. But because the standard microscope was unavailable, another researcher suggested Martin try one that used ultraviolet light.

At one specific wavelength, ultraviolet light causes tetracycline to fluoresce with a unique yellow-greenish color. In the lab, researchers under the direction of Harold Frost were using tetracycline to measure the rate of bone formation. Tetracycline tends to bind with calcium and phosphorus, which make up more than 80 percent of the mineral portion of mature bone. (Patients who are taking the drug are advised not to drink milk or take antacids containing calcium, since the tetracycline will bind to the calcium and lose its antibiotic effectiveness.) Any tetracycline circulating in the body may bind with calcium that is being deposited in the bone, “labeling” (tagging) the bone with its indelible signature. In the laboratory study, people who were scheduled to have bone removed during biopsy or amputation were asked to take tetracycline at intervals before the surgery. Bone deposits formed during this period could then be identified and measured.

When Martin returned to the University of Massachusetts, where I was then teaching, she told me of her discovery, and we began to explore several issues: Was this really tetracycline? If so, was it incorporated into the bone during the subject’s lifetime 1,600 years ago, or could it have been produced by organisms that invaded the remains after death?

If it was ingested by ancient Nubians in their food or medications, what was its source?

That we really were dealing with tetracycline was demonstrated by James Boothe, a chemist who had worked on the initial commercial applications of the antibiotic for American Cyanamid. He was able to extract it from our Nubian bone and show that it could still kill bacteria. More recently, Mark Nelson at Paratek Pharmaceuticals has been determining its precise molecular structure (there is actually a whole family of tetracyclines in nature).
Evidence that the tetracycline was incorporated during the lifetime of the Nubian mummy came from its osteons, which are microscopic cylindrical building blocks of cortical bone (such as the outer layers of bone shafts). In response to physical stresses, bone tissue undergoes a continual process of fine-tuning. Bone cells called osteoclasts break down small amounts of bone mineral, which other cells, called osteoblasts, then replace. The result is the formation of new osteons. It takes about four months for any one osteon to become fully mineralized, and tetracycline may be incorporated during the process. When we examined bone from the Nubian mummy, we found that some osteons had layers of mineral containing tetracycline alternating with layers without tetracycline. Such a pattern could have developed only during life, not if the tetracycline was somehow introduced later; it indicated that while these particular osteons were forming, the individual was ingesting tetracycline intermittently. In most of the osteons we examined in the mummy, however, we found that tetracycline was present in all the layers, suggesting that during the four months it took for these osteons to mineralize, this individual had continuously ingested the antibiotic.

To determine the extent of tetracycline use by ancient Nubians, three undergraduate researchers in our lab at Emory University—Kristi Kohlbacher, Jennifer Cook, and Kristy Collins—painstakingly sampled thousands of osteons from our original mummy and from seventy-seven other Nubian and Egyptian remains dating from about the same era. All but four of the seventy-eight individuals showed some degree of exposure to tetracycline, and no significant differences by age or sex were evident. Even the remains of two of the three infants contained tetracycline, showing that it was passed to them in their mothers’ milk.

Following the publication of these findings in the 1980s, other researchers began to report evidence of tetracycline in African prehistory. Physical anthropologist Megan Cook (then at the University of Toronto) and her colleagues, for example, found that the mummified remains of all twenty-five individuals recovered from Dakhla Oasis in Egypt, dating from the Roman period (A.D. 400–500), showed tetracycline labeling. The patterns were consistent with doses occurring at two- to three-week intervals. And Ann Grauer and I have recently reported evidence of tetracycline in bone from a Jordanian site that dates from the second century B.C. through the fourth century A.D.

But none of this told us why the antibiotic was showing up in the ancient bones. In nature, tetracycline is produced by streptomycetes, moldlike fungi. Development of tetracycline-resistant pathogens is a major concern in the antibiotic’s clinical application. We determined that tetracycline was produced by a fungus typical of the Mediterranean Basin, but we were puzzled by its presence in the mummy. Even if the tetracycline was ingested, the antibiotic may have been introduced into the bone through trauma, such as a break in the skin.

So we turned to an ancient Egyptian tomb in Thebes to examine this issue. Members of our team, including our lab manager, Emil, and the late Bob Mountjoy, an underwater archeologist, retrieved a mummy from the tomb that was radiocarbon-dated to 2009–1998 B.C. (ca. 2000 years B.C.E.). The mummy was previously studied in detail, and we were interested in examining the bone density, structure, and mineral content. We also examined the layers of bone mineral formed during the lifetime of the mummy—osteon structures formed at regular 20- to 25-month intervals. As we had in the Nubian mummy, we found that osteons from this ancient Egyptian mummy showed evidence of exposure to tetracycline. We found that tetracycline was incorporated at the same level throughout the mummy’s life, suggesting that the individual ingested the antibiotic daily, which contradicted the idea that trauma and prior antibiotic use were the cause of tetracycline incorporation. Researchers have long believed that tetracycline residues in bones were introduced through trauma or other artificial processes, but our evidence suggests that other factors are at play.

Tetracycline was first introduced into medicine to treat bacterial infections. It was not until the 1960s that it was suggested that tetracycline could be used in medicine by ingestion. However, tetracycline is a powerful antibiotic, and it is not often prescribed for acute bacterial infections in modern medicine. Its use has been restricted to situations where other antibiotics are not effective or are not appropriate, such as tetracycline-resistant bacteria. As a result, tetracycline is not used in the treatment of colds and other bacterial infections in modern medicine.

The tetracycline-resistant bacteria that have emerged are a major concern in the antibiotic’s clinical application. We determined that tetracycline was produced by a fungus typical of the Mediterranean Basin, but we were puzzled by its presence in the mummy. Even if the tetracycline was ingested, the antibiotic may have been introduced into the bone through trauma, such as a break in the skin. River water can also contain tetracycline, and it is possible that tetracycline was introduced into the bone through this route. Even if the tetracycline was introduced into the bone through trauma, it is still possible that the tetracycline was ingested by the individual, and that the tetracycline was introduced into the bone through the blood stream. We determined that tetracycline was produced by a fungus typical of the Mediterranean Basin, but we were puzzled by its presence in the mummy. Even if the tetracycline was ingested, the antibiotic may have been introduced into the bone through trauma, such as a break in the skin. River water can also contain tetracycline, and it is possible that tetracycline was introduced into the bone through this route. Even if the tetracycline was introduced into the bone through trauma, it is still possible that the tetracycline was ingested by the individual, and that the tetracycline was introduced into the bone through the blood stream. We determined that tetracycline was produced by a fungus typical of the Mediterranean Basin, but we were puzzled by its presence in the mummy. Even if the tetracycline was ingested, the antibiotic may have been introduced into the bone through trauma, such as a break in the skin. River water can also contain tetracycline, and it is possible that tetracycline was introduced into the bone through this route. Even if the tetracycline was introduced into the bone through trauma, it is still possible that the tetracycline was ingested by the individual, and that the tetracycline was introduced into the bone through the blood stream. We determined that tetracycline was produced by a fungus typical of the Mediterranean Basin, but we were puzzled by its presence in the mummy. Even if the tetracycline was ingested, the antibiotic may have been introduced into the bone through trauma, such as a break in the skin. River water can also contain tetracycline, and it is possible that tetracycline was introduced into the bone through this route. Even if the tetracycline was introduced into the bone through trauma, it is still possible that the tetracycline was ingested by the individual, and that the tetracycline was introduced into the bone through the blood stream. We determined that tetracycline was produced by a fungus typical of the Mediterranean Basin, but we were puzzled by its presence in the mummy. Even if the tetracycline was ingested, the antibiotic may have been introduced into the bone through trauma, such as a break in the skin. River water can also contain tetracycline, and it is possible that tetracycline was introduced into the bone through this route. Even if the tetracycline was introduced into the bone through trauma, it is still possible that the tetracycline was ingested by the individual, and that the tetracycline was introduced into the bone through the blood stream. We determined that tetracycline was produced by a fungus typical of the Mediterranean Basin, but we were puzzled by its presence in the mummy. Even if the tetracycline was ingested, the antibiotic may have been introduced into the bone through trauma, such as a break in the skin. River water can also contain tetracycline, and it is possible that tetracycline was introduced into the bone through this route. Even if the tetracycline was introduced into the bone through trauma, it is still possible that the tetracycline was ingested by the individual, and that the tetracycline was introduced into the bone through the blood stream.
bacteria commonly found in soils. These slow-growing cells do not do so well in the wet, acidic soils where most bacteria flourish, but they have the edge in hot, dry, and neutral-to-alkaline environments. Ten-year-old spores survive in dry sand and are easily cultured.

Initially we thought that during famine or drought, the ancient Nubians and Egyptians might have been forced to eat moldy grain. (Even one or two grams of tetracycline consumed by humans in a single day will produce fluorescence in bone.) The warm, dry, alkaline environment of storage bins made of mud could have been an ideal environment for streptomycetes. But we learned that when they are growing well, streptomycetes actually produce little tetracycline. Given the degree of tetracycline labeling in the Nubian and Egyptian remains, we had to consider other possibilities. The key turned out to be beer, known as bosa in much of present-day Africa.

Searching through both ancient and later texts, Everett Bassett, Margaret Keith, and other members of our team realized that in the region’s grain processing, there was an important link between bread baking and beer brewing. Egyptian art also shows baking and brewing in constant association. In fact, baked bread is an essential part of the traditional beer recipe still used today by villagers who live along the Nile.

The beer produced in ancient times, according to Barry Kemp, author of *Ancient Egypt: Anatomy of a Civilization*, was quite different from the modern commercial product: “It was probably an opaque liquid looking like a gruel or soup, not necessarily very alcoholic but highly nutritious. Its prominence in the Egyptian diet reflects its food value as much as the mildly pleasurable sensation that went with drinking.” University of Cambridge archaeologist Delwen Samuel and his colleagues from the British brewery Scottish and Newcastle have undertaken extensive research on brewing and baking in ancient Egypt. They analyzed the remains of food left in tombs as offerings and the residues of beer and crumbs of bread encrusted on pottery shards and vessels. They even examined floor sweepings from tombs and living areas.

Successful brewing depends on the use of a grain that provides enough sugar for fermentation. In modern recipes, grain is made to germinate and is then heated and dried to halt the process. Known as malting, this proce-
bread forms a crust but is removed from the oven before the center has had a chance to cook, allowing the yeast to grow in the warm, slightly cooked dough. The partially baked bread is then broken up and added to a broth of malted grain to make the beer.

We theorized that airborne streptomycete spores were captured in the ancient brewers' dough during its exposure to the air and that the streptomycetes then produced tetracycline while the yeast grew in the partially baked bread. To investigate brewing's capacity to give rise to tetracycline, Daniel Popowich and Brennan Posner, undergraduates at Emory University, added streptomycetes during two experiments with the traditional process. In the first, they added a small colony of streptomycetes to the just-baked bread; in the second, they added the streptomycetes to the mixture of malted grain and bread. The second technique was the more successful and produced significant amounts of tetracycline.

The fermenting brews of ancient times, we concluded, provided the somewhat harsh environment in which the streptomycetes were stimulated to yield tetracycline in quantity. Nowadays, companies that make pharmaceuticals deliberately control and limit certain nutrients as a way of forcing streptomycetes to make tetracycline.

Given that the ancient Nubians and Egyptians were getting doses of tetracycline, another question is whether this afforded them any medical benefits. In Food: The Gift of Osiris, William J. Darby and coauthors provide archaeological, historical, and ethnographic accounts of beer's use as a mouthwash to treat the gums, as an enema, as a vaginal douche, as a dressing for wounds, and as a fumigant to treat diseases of the anus (the dried remains of grains used in brewing are burned to produce a therapeutic smoke). This shows that even in the distant past, Egyptians and their neighbors appreciated beer's medicinal qualities.

Today tetracycline remains the drug of choice in the treatment of both acne and gingival disease. Researchers studying gum disease originally assumed that the tetracycline worked because of its antibiotic qualities. But tetracycline also appears to inhibit collagenase, an enzyme that breaks down collagen. There has been a concerted effort to produce chemically modified tetracyclines (CMTs) that have this effect but not the antibiotic qualities. In addition, both tetracycline and CMTs have proved to be very effective in inhibiting matrix metalloproteinases, enzymes involved in a number of bone and connective-tissue diseases, such as rheumatoid arthritis, osteoarthritis, periodontal disease, osteoporosis, and even cardiovascular disease. The ingestion of tetracycline may thus have had real medical benefits for ancient Nubians and Egyptians.

As we enter the new millennium, many people are concerned that our own use and abuse of antibiotics in medicine, agriculture, and even manufactured products has been encouraging the rise of antibiotic-resistant bacteria. When we reported the discovery of tetracycline in ancient bones in the journal Science, we wondered whether, owing to long-term ingestion of the antibiotic, the Nubian and Egyptian populations might have suffered an increase in disease caused by resistant bacteria. To test this, we have examined the bones in our sample for signs of periosteal reactions—roughened surfaces that form as a result of bone infection. We have found no evidence that infections became more intense during the centuries represented by the bones, as would be expected if more resistant bacteria had evolved. But during our own lifetimes, 1,600 years later, many of us may well fall victim to bacteria that are resistant to all the known antibiotics. If we do, our bones will reveal this to archaeologists of the future.

George J. Armelagos is a professor of anthropology at Emory University in Atlanta.
Sometimes wild animals are attracted to people. They seem to weigh the risks of associating with us and conclude that under certain circumstances, hanging out with *Homo sapiens* is the safest thing to do.

In *The Biophilia Hypothesis*, biologist Edward O. Wilson addresses the psychological and evolutionary reasons humans are attracted to animals. My own experience as a field biologist has exposed me time and time again to convincing evidence that many humans are indeed powerfully drawn to animals. For more than three decades, I have spent part of every year in the Peruvian Amazon, where I have been privileged to visit villages belonging to half a dozen premodern tribes. Nearly every household has included pets, and even though many of these pets ultimately wind up in the supper pot, the villagers treat them with obvious affection. Among the animals selected are birds of assorted sizes and habits, tortoises, iguanas, and mammals (especially primates but also peccaries, agoutis, and coatimundis). Many have been captured as juveniles, usually by hunters who shot the mother; the young are then raised by humans, who sometimes even suckle them until they can be weaned.

This story has a flip side, however. Under certain circumstances, wild animals are drawn to people. Not always do they flee or recoil from hu-

By John Terborgh
Reclining Nude,
by Tommy Dale Palmore, 1976
Happy, Crazy
American
Animals and a
Man and Lady at
My Place, by
John Wilde,
1961

moms; instead, it has often seemed to me, the
animals quietly observe them as if attempting to judge
their intentions. Then, if the people appear to be
nonthreatening, various kinds of interactions be-
come possible.

But before I begin to elaborate on why animals
may choose to associate with humans, perhaps I
should review the circumstances in which animals
of different species are drawn to one another. In the
forests around the Cocha Cashu Biological Station
in Peru’s Manu National Park, such associations are
common. In one type, called the beater syndrome,
one species unintentionally makes food available to
another by creating a disturbance as it moves
through the habitat. The beater syndrome is a form
of commensalism—the unilateral transfer of bene-
fits from one species to another at little or no cost to
the benefactor.

One of the beneficiaries of the beater syndrome
in Manu is the rare huanganapesco, known in Eng-
lish as the rufous-vented ground cuckoo. In
Quechua, the language of the Incas, pescco means
the animals' hooves. Meanwhile, overhead, several woodcreepers cling to tree trunks, ready to snatch insects that take wing to avoid being trampled.

A more intimate form of commensalism, termed the cleaner syndrome, involves direct body contact between the associates, implying both trust and recognition. Viewers of nature programs on television are familiar with the cleaner wrasse, a small coral reef fish that makes a living by nipping parasites off larger fish. The most famous terrestrial cleaner syndrome involves the colorful tick birds of the African savanna. These birds forage exclusively on the backs and legs of large mammals, where they dine on parasites, principally ticks. The Amazonian counterpart of Africa's tick bird is the giant cowbird, which forages independently most of the time but deticks capybaras and tapirs when opportunity knocks. Obviously comfortable with the relationship, capybaras (the largest living rodents) are un-

The costs of joining a flock, school, or herd can be lower when the group is composed predominantly of other species.

fazed when cowbirds alight on their heads and begin to peck around their eyes and ears.

Sometimes birds of a feather flock together for less transparent reasons, as one unplanned "natural" experiment showed. Years ago, as a graduate student at the University of California, Berkeley, ornithologist Pete Myers was studying sanderlings—the pale little sandpipers that frenetically chase waves up and down beaches along both coasts of North America. During the first winter of his study, based at California’s Point Reyes National Seashore, Myers observed that sanderlings, when not foraging, roosted amicably in large flocks on sandbars. But when the tide was propitious, they spread out along the beaches and set up individual territories, chasing away any rival sanderlings that ventured too close. This behavior provided gratifying confirmation of the then-new theory of optimal foraging, which held that the highest feeding rate could be attained by individuals that maintained exclusive rights to a foraging area. In this case, the area was a strip of beach about a hundred yards long.
The following year, Myers encountered an entirely unanticipated situation. Instead of spreading out and confronting their neighbors in hostile face-offs, foraging sanderlings bunched together in tight little flocks. Many birds feeding in a small area quickly deplete the prey, however, lowering individual foraging success and compelling a flock to keep moving in quest of fresh sites. Clearly the birds were paying a price for their newfound togetherness. The question was, What had inspired them to change their behavior so profoundly?

Myers soon discovered that a merlin (a small falcon) had taken up residence that winter at Point Reyes. Although the merlin was usually out of sight, the sanderlings never forgot that a predator was in the vicinity. Membership in a flock meant that each individual gained the advantage of more eyes and ears to detect the approaching predator.

The costs of joining a flock, school, or herd can be lower when an animal joins a group composed predominantly of other species. Consorting with aliens, as it were, offers all the advantages of foraging in a group, while it minimizes competition with other individuals of the same species. This probably explains why flocks of birds consisting of many species, but no more than a few individuals of any one, are so commonplace around the world.

By now, the reader is surely wondering what all this has to do with what I call homophilia (literally, a friendly feeling toward humans) in animals. In fact, it has a great deal to do with the rest of my story, which begins with trumpeters.

Distant relatives of cranes, trumpeters are long-legged, chicken-sized birds that glean fallen fruit from the ground. Unlike other birds that live on the forest floor, trumpeters are not particularly shy and readily habituate to the presence of humans. One day, while observing monkeys feeding in a giant fig tree, I understood why.

Shortly after the monkeys began to eat—sloppily dropping nearly as much fruit as they consumed—a group of trumpeters showed up on the forest floor beneath them. Soon an agouti (a large tropical rodent) appeared and began to feed among the trumpeters, which were unperturbed by its presence. Before long, a group of collared peccaries joined the crowd. Again the trumpeters showed no reaction at all.

I later learned that various terrestrial mammals routinely join feeding trumpeters, presumably to benefit from various loud alarm calls that the birds make against such animals as jaguars, bush dogs, eagles, and snakes, as well as from their habit of posting sentinels whenever other group members are feeding. To the trumpeters, I realized, a person is just one more large but nonthreatening mammal come to join the group.

All these animals appear able to recognize a good thing when they see it, and my many years at Manu have convinced me that our little research station—by providing opportunities for safety that
some animals decide to take advantage of—is a bit like the group under that fig tree. The station's unobtrusive buildings bring the scientists into unusually close contact with the inhabitants of the surrounding forest. Every year, certain individual birds and mammals linger near the station, often strolling in open view through the clearing or perching right in front of a building, hardly more than an arm's reach away.

Among them is one that stands out above the rest. It is a bird, the tinamous, whose familiarity is both comforting and sometimes frustrating. The tinamous are a diverse group of birds, found in the Americas from Mexico to Argentina. They are often found in tropical forest habitats and are known for their distinctive cries and bold behavior.

The species that have shown such boldness are extraordinarily diverse in their habits and diets and thus seem to have no common denominator. Among those that have been drawn into our midst are tinamous—plump, partridge-like birds notorious for their shyness. A small path that leads from one group of our buildings to another apparently cuts through areas frequented by these birds. Observing that humans passed by at frequent intervals without adverse consequences, several tinamous grew so comfortable with our presence that they would sometimes stand in the middle of the path and fail to budge when someone approached. Occasionally I found it necessary to make a verbal request before a tinamou would step aside so that I could pass.

Over the years, I have sometimes sought refuge from the hubbub of the station in a screened tent in the forest. One morning, after I had sat down at my desk, a movement in the tent caught my eye. It was one of the "tame" tinamous. The bird did not seem to be the least bothered about sharing the cramped space of the tent with me. It calmly strolled around inside for a few minutes and then let itself out through a crack at the bottom of the door.

Tinamous have demonstrated the flexibility of animal behavior in other ways as well. Several years ago, we kept chickens at the research station. (We were studying ocelots at the time and needed chickens to lure the cats into our traps.) I happened to glance idly at a group of foraging chickens one day and was thunderstruck to see two tinamous scratching and pecking among them. They were doing two things tinamous never do (or so I had thought): participating in a social group of foraging birds and exposing themselves to an open sky that might have contained raptors. This scene of interspecific amity was repeated day after day as the tinamous took advantage of the safety in numbers provided by our chickens.

One of the habituated birds I remember best was a piping guan—a chicken-sized bird normally found only in the highest treetops—that chose to nest only two yards from a building under construction. As the guan calmly sat on her nest, a team of carpenters erected beams and nailed them into place almost eyeball to eyeball with the unflappable bird. Even the chainsaw didn't disturb her. Eventually the guan's three eggs hatched into downy chicks, and for many days afterward she remained within a few yards of our buildings while she tended her growing brood.

Birds have not been the only creatures at our site to seek the company—or at least the nearness—of humans. Perhaps the most remarkable were Howeird and Moreweird, two subadult male red howler monkeys. Howlers are among the most distinctive and characteristic primates of the New World tropical forest. The adults' roars are often so loud and startling that first-time visitors are
The Fifth Trumpet Call I, by Mary Frank, 1984

... convinced they are in the immediate presence of a jaguar. In reality, however, few animals could be less threatening than these languid vegetarians that spend much of every day lounging in the canopy digesting leaves.

One extraordinary day a number of years ago, primatologist Patricia Wright was doing her laundry when a furry red limb suddenly intruded into her field of vision. Looking up with a start, she confronted a howler monkey backing down the very tree to which the washboard was attached. Transfixed in surprise, Pat stood motionless as the monkey proceeded down to the ground under the washboard, where it set about eating soil that had been soaked in wash water. So unconcerned was the howler by Pat’s presence that at one point it rested its hand on her shoe.

Howler monkeys are well known to engage in geophagy, or earth eating, though the reason they do it remains unclear. One idea is that the soil pro-
vides certain mineral elements lacking in their diet of fruit and leaves. Another hypothesis is that clay minerals in the soil help alleviate the effects of some of the toxins that must inevitably be ingested by an animal that consumes leaves.

After Howeird had broken the ice with Pat, he began to hang around the station buildings, often resting in the rafters under the open roof when Pat was inside. Although she never fed him, Howeird persisted in following her around. When she went to her tent for the night, Howeird was right behind. Not wishing to spend the night with a monkey in her tent, Pat would quickly slip in and zip the door behind her. Undiscouraged, Howeird would climb up a small tree that overhung her tent and spend the night there.

After several days of this behavior, another subadult male howler, duly named Moreweird, joined Pat and Howeird. The three of them were nearly inseparable until the day the two monkeys just vanished into the forest, never to be seen again. Their departure was as unexpected as their arrival. Pat, who enjoyed imagining that true love had brought the howlers out of the forest to her, was soon forced to accept that the attraction was something more mundane: the two monkeys departed right after her bottle of lemon-scented detergent ran out and was replaced by one of a different brand. A dejected Pat had to admit that they didn't love her after all; they only loved her detergent.

Last year, something nearly as remarkable happened—less amusing but deeply touching. At lunch one day, a student announced a very unusual sighting: a lone huangana. Finding one of these big peccaries all by itself and away from its herd was unprecedented in our experience. The student had encountered the animal half a mile to the north of the station and noted that it appeared sick and lame. Late that afternoon, another researcher met the same animal only 300 feet from the station. It had been standing in the middle of Trail 1, the main thoroughfare between the station and our port on the Manu River. When confronted by the approaching human, the huangana hobbled a few feet off the trail and stood there while the researcher passed by.

The next day several people saw it, always standing at the edge or in the middle of Trail 1. The animal could not have selected a busier place to reside; many people, often in noisy groups, go back and
forth to the port every day. Yet the huangana chose to settle precisely here. For the first few days it seemed to be in decline, limping badly and responding listlessly to the blandishments of nervous researchers who didn’t want to get too close to a potentially dangerous animal.

Why would the sick and lame peccary have walked half a mile to our camp in an enfeebled condition if it hadn’t wanted to be near us?

After perhaps a week, the huangana appeared more alert and was steadier on its feet, although I don’t know what it could have been finding to eat during all that time. Had the animal wanted to distance itself from further contact with humans, it could easily have done so. But it remained in the middle of Trail 1 by day, and by night, we discovered it quietly bedded down just a few feet from an investigator’s tent.

I can think of no other way to interpret the huangana’s behavior except to imagine that it “wanted” to be close to humans. Why else would it have walked half a mile in an enfeebled condition to be near us?

The huangana is a prime example of a species that seeks safety in numbers. Its archenemy, the jaguar, never launches a frontal attack on a herd, because adult peccaries defend themselves with long, saberlike tusks that could easily disembowel a big cat. Instead, the jaguar stalks the herd in the hope of being able to assault a juvenile or a peripheral individual and subdue it before the others react. A lone huangana is thus in a very vulnerable situation. From a jaguar’s point of view, such an animal is a freebie.

Our peccary must have decided that the risk of consorting with humans was less than the one it faced by remaining alone in the forest. Perhaps it had noticed that the jaguar was seldom in the vicinity of the station. Whatever its reasoning, the huangana was right. Its vigor and agility steadily improved until, one day, a herd of its species crossed Trail 1 and our peccary was gone.

As a scientist, I am admonished to be unrelenting in my skepticism and to demand the highest standards of evidence before drawing conclusions. Above all, I should resist any temptation to construct anthropomorphic interpretations. What I have recounted here are anecdotes—isolated occurrences of an essentially unrepeatable, and thus scientifically untestable, nature.

Nevertheless, having spent a lifetime observing animals in the wild, I have come to the conclusion that many birds and mammals are highly observant, that they are able to weigh very abstract risks, and that they can reach conclusions based on the assessed balance of those risks and then take appropriate action.

Night and day, the Amazonian rainforest teems with predators. No animal, except perhaps a top carnivore, can afford to be unmindful of the omnipresent threat of predation. If animals can be said to think about anything, heading the list must be how to conduct their lives in a way that minimizes exposure to predators—since, of course, only living animals can pass along their genes.

Whether a particular bird or mammal is territorial or social is commonly regarded as characteristic of the species. Pete Myers’s sanderlings, however, demonstrated a capacity for radically altering their behavior in direct response to an increased threat of predation. So did the habituated timidus at our research station when they perceived that by consorting with chickens, they could forage in the open at reduced risk. Monkeys are similarly opportunistic in their choice of companions. Never at ease when alone, bachelor males routinely seek the company of other species of monkey. Howeird and Moreweird apparently decided that Pat could provide some sort of protection against predators. To be alone is to be vulnerable, because no animal is able to maintain vigilance 100 percent of the time.

I am not suggesting that animals have the same intrinsic affinity for people that E. O. Wilson claims people have for animals. But when under the threat of predation, many animals do have an affinity for other animals, whether of their own or of different species. Having been taught as a child that nearly all animals instinctively avoid people, I was pleasantly surprised to learn that a child that nearly all animals instinctively avoid people, I was pleasantly surprised to learn that animals can occasionally overcome their inhibitions and see us as benign. My colleagues and I at Manu are gratified when the birds and mammals with which we share the forest choose to draw near, even if it is only to use us as foils against their enemies.
Dig It, and They Will Come

By Douglas Emlen

Kick aside a pile of fresh horse droppings, and a small cloud of flies is sure to explode around you. Maggots squirm in the nutritious sea of manure, and beetles scurry this way and that. Among the crowd of insects are the ones I have been studying for the past ten years: beetles in the genus Onthophagus. Small (often no bigger than the eraser on a new pencil) and sluggish, these beetles are easy to overlook as your eyes fix on other, faster, more brightly colored species or on beetles that are industriously pushing balls of dung away from the pile. But if you look closely, especially right where the dung meets the soil, you will be rewarded with a look at some of the most bizarre and—at their scale—formidable creatures on Earth.

There are 2,000 named species of onthophagine dung beetles, and certainly half again as many waiting to be described. They inhabit every continent except Antarctica and can be found as readily in tropical rainforests as in temperate pastures, African savannas, and the Australian outback. They feed on almost every type of dung imaginable, from cow to kangaroo and toad to tapir.

Despite this variety of habitats, all these beetles do basically the same thing: they fly to pieces of dung and dig tunnels in the soil below it. The females then pull small pieces of dung into the tunnels, fashion them into balls, and lay one egg inside each ball. A few days later, when the eggs hatch, the young larvae feed on the dung in relative peace, shielded from the competitive aboveground world.

The bodies of onthophagine beetles reflect their subterranean lifestyle. Durable, ovoid digging machines, they have a smooth, rigid exoskeleton and sharp, toothed forelegs, which they use to dig into sun-scoured clay and other hard soils. Like the front end of a bulldozer, a dung beetle’s head is flattened into a broad plate that can push soil up and out of the tunnel; lying safely beneath this protective shield are its delicate organs of taste and vision.

The exceptions to this streamlined body plan are the knobs, barbs, and spikelike outgrowths that protrude from the males. You might need a magnifying glass to see these “horns” clearly, but in many species they rival the antlers of bull moose in both shape and proportion. The largest males produce the biggest horns (small males and females generally have none). In some species, such as O. nigriventris, they may be longer than the rest of the body.

Why produce such extravagant horns? They make it difficult even to fit into a tunnel, let alone run, turn, or maneuver inside one. My work has led me to conclude that the tunnels themselves—and the need to guard the females breeding inside them—are key to the evolution of the horns.

With the help of glass observation chambers, video cameras, and plenty of patience, my team at the University of Montana and researchers at several other institutions have been watching these beetles inside their tunnels. The first thing we learned was that provisioning the eggs is a laborious process. One female in the species O. acuminatus made more than fifty separate trips to the surface to collect enough dung to make just one brood ball; over the course of several days, a female might make five to twenty such balls.

Illustrations by Utako Kikutani

After excavating tunnels, female Onthophagus acuminatus beetles drag in dung within which to lay their eggs. Large, horned males guard the tops of the tunnels, attempting to keep out rivals, while smaller, hornless males may reach a female by digging side tunnels of their own.

A female dung beetle in her tunnel is sure to attract suitors big and small.
Immediately before and during egg laying, the female essentially lives under the ground. This presents the male of the species with a challenge: to mate with the female, he must get inside the tunnel. It also presents him with an opportunity: once inside, if he can keep rival males away, he can mate repeatedly with the resident female and be the only one to fertilize her eggs.

And this is precisely what many males endeavor to do. The first hurdle is the tunnel entrance. Standing guard here, the resident male will try to fight off other males that attempt to enter. In a typical contest, the resident male braces himself against the tunnel walls and uses his head and long horns to block entry or to push the rival out. An intruding male, for his part, tries to squeeze past the resident male. By wedging his head beneath the other beetle and pushing or twisting, the challenger may create a gap into which he propels himself. The resident male’s horns get in the way, however, and the two males usually end up locking head to head. Sometimes brute strength and strategic maneuvers enable the intruder to force his way past the guard and into the tunnel, where the sparring resumes. At times, the previous resident is pushed all the way out of the tunnel and has to try to fight his way back in.

Fights between males may last only a few seconds or may entail half an hour of head butting and sparring. Although the sequence of events during a fight varies, the outcome is remarkably predictable. I staged contests between O. acuminatus males, for example, and found that the winner is generally the bigger individual and, in particular, the one with the longer horns. Duke University graduate student Armin Moczek and I have found an identical outcome for a second species, O. taum. Since success at guarding tunnels—thanks in part to horns—translates into success at passing genes on to future generations, this process of selection could easily have led to the evolution of bigger and bigger horns. Indeed, the males of many species have such large horns that often they cannot even turn around inside a tunnel but instead must push all the way down to the enlarged brood chamber below, or must back all the way up and out the entrance, before they can turn and face the other way.

There is, however, a twist to this story. Not all the males in each species are large, and not all the males grow horns. In fact, the males in the populations I study come in two basic classes: large, with horns, and small, with either very rudimentary horns or none at all. For a small male, fighting is not an effective option; the only way he can reach a female is on the sly. Sometimes he will wait until the guarding male leaves the tunnel briefly (returning to the dung pile to feed, for instance) and then dash inside to find the female. If he is small enough and smooth enough, he may even be able to sneak right past a guarding male without being detected.

The small O. acuminatus male has another ploy if these tactics fail. He may move a short distance away and excavate a tunnel of his own. After burrowing about half an inch below the surface, he cuts horizontally and sometimes succeeds in intercepting the guarded tunnel below the surface. Having evaded the guarding male, the “sneaker” male mates with the female and then returns to his side tunnel and waits. Hours later, he either tries to reenter the guarded tunnel or continues to dig horizontally. In a densely excavated area, one of these small males may gain access to several guarded tunnels via a single side tunnel of his own.

For her part, the female does not discriminate among suitors, mating readily with both sneaker
and guarding males. Unfortunately for the sneak, a single mating does not guarantee that he will sire offspring. The female has undoubtedly already mated with the guarding male and is likely to do so again after the smaller male leaves. And if the resident male detects the intruder, he will not only chase him out of the tunnel but will rush back to copulate again with the female. Still, a persistent small male may be able to get inside a tunnel several times, and one of those times might be just when the female is ready to lay an egg.

A second way that small males deal with the competition is by producing—and transferring—more sperm than their larger counterparts. Leigh Simmons, Joe Tomkins, and John Hunt, of the University of Western Australia, found that small *O. binodis* males had disproportionately large testes. These males also ejaculated more seminal fluid and produced longer sperm than did their guarding competitors. Hence, smaller males (which make up about 50 percent of the male population) may compensate for having fewer matings by transferring more sperm each time they copulate, thereby increasing the odds that they will fertilize an egg each time they do mate.

Onthophagine beetles are not the only invertebrates to have two classes of males, each with its own mating strategy. In the ground-nesting bee *Perdita portalis*, for example, Bryan Danforth, now at Cornell University, found that large males have exaggerated mandibles that they use in contests over subterranean burrows containing females. Because the smaller males lack these large mandibles, their only chance of mating is to intercept a female as she forages on a flower. *Panacercis sculpta* is a marine isopod studied for many years by Stephen Shuster, now at the University of Northern Arizona. In these creatures, males come not in two but in three morphs, each with its own specialized way of encountering females.

What determines which embryos or larvae will pursue a macho path and which will become little sneaks? In the isopods Shuster studied, both the morphology of a male and his mating tactics depend primarily on the genes inherited from the parents. In the beetles I study, it turns out, horn growth is more flexible and is affected by the course of larval development. Supplied with ample food for their entire larval stage, males become large and develop long horns. Larvae that run out of food prematurely do not grow as large, and if they fail to reach a critical minimum body size, they disperse with horn production altogether. The physiological “decision” whether or not to produce horns occurs toward the very end of the larval feeding period. H. Frederik Nijhout, of Duke University, and I discovered that painting minute amounts of what is called juvenile hormone onto small males at this time

**Horns may grow at the expense of other body parts.** Depending on the species, big horns may mean smaller eyes, wings, or antennae.

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causes them to produce horns despite their small size, suggesting that this hormone is the critical link between male body size and horn production. With insufficient juvenile hormone, horn growth never starts.

Growing horns takes time. In *O. taurus*, Hunt and Simmons found, the process adds several days to a larva’s development. This extra time is dangerous, they suggest, because it significantly increases the larva’s risk of falling prey to nematodes in the soil. And horns are likely to continue to exact a cost even after the beetles have emerged above ground: males must fly from dung source to dung source in order to locate females, and bulky horns may make flight slower, clumsier, or more energy draining, possibly increasing the risk that these males will be spotted and captured by predators.

Constituting up to 15 percent of a male’s total body weight, horns also require nutrients, energy, and other resources to grow. Dung beetle larvae develop in isolation, with nothing to feed on but the dung in which their mother packed the eggs. In this world of finite resources, devoting a portion of their share to horns means making less available for other body parts. *O. acuminatus* and *O. taurus* males, for example, cannot have both long horns and large eyes: horned individuals have fewer ommatidia, or eye facets (making their visual field like a computer screen with fewer pixels). When Nijhout and I experimentally manipulated the growth of male horns, we found that suppressing horn development resulted in larger eyes.

Various tradeoffs occur in other *Onthophagus* species. In some, horns extend from the thorax, and my preliminary data suggest that in this case, horns grow at the expense of wing size. In other species, horns extend from the front of the face, where they seem to squelch the antennae. Different types of horns thus incur different types of costs.

As we tease apart the factors shaping the horns, we are realizing just how intricate and numerous are the connections between ecology, evolution, and development. Discoveries in one arena open up exciting and often unanticipated research questions in the others. I suspect we will be spying on these little black beetles for a long time to come.  

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Onthophagine beetle horns begin when small sections of the larval skin, or epidermis, start growing rapidly. In *O. taurus*, there are two such regions of rapid growth, one on each side of the head. The horns are not visible in the larval stage because they are trapped under the cuticle and thus forced to grow inward, as dense clusters of folded tissue. When a male molts from a larva to a pupa, the horns evert, unfold, and stretch out to their full shape and length—not unlike extending a collapsed telescope. During the final molt, from pupa to adult, the epidermal cells secrete special enzymes that rigidify the horns as well as hardening all the other adult structures.
LIFE ON A LEAF
Even before they emerge from their buds, and long after they become part of the forest floor, leaves play host to ever-changing communities of minuscule fungi.

In a rain-drenched tropical forest canopy, where plants grow upon plants, even a single leaf serves as the staging ground for a multitude of species interactions, and competition for limited space and resources is intense. But even in the canopies of the world’s less crowded temperate forests, we find parallel situations. The fungal communities that grow on healthy new leaves are a shining example.

From the time a tender new leaf pushes through its protective bud scales and enters the world of intricately tangled food webs, it is colonized by fungi that have been lying in wait. Three or four species of yeast (which are unicellular fungi) often take refuge within the buds and shoots of deciduous trees. As each new leaf unfolds to greet the spring, wind- and water-borne fungal spores also arrive on the scene. For the most part, these organisms pose no greater threat to the emerging leaf than does the Spanish moss festooning the branches of live oaks in the Deep South. Except for the occasional pathogenic species, these early colonists use the leaf primarily as a platform from which to scavenge organic debris. But they may also, in fact, be beneficial to the new leaves and therefore to the tree itself.

One advantage of the plant’s keeping company with fungi is that some of the colonists have insecticidal properties. A few fungi have been found to excrete strong chemicals capable of interfering with insect development and even of killing the larvae outright. As a result, far fewer leaf-chomping caterpillars can feed their way into adulthood. When, for instance, a minute amount of Fusarium avenaceum (a fungus commonly found on the blades of various grasses and in the needles of fir trees suffering a budworm attack) is ground up in the laboratory and mixed into the diet of budworm larvae, it kills 80 to 100 percent of the population. There is nothing altruistic about the fungus’s services, of course; a fungus that sees insecticide is merely investing in its own survival. In the process, however, it also saves the leaf from getting devoured, although in the complex food web of the forest canopy, the coevolution of grazer and grazed inevitably results in some herbivores developing resistance and some fungi winding up as insect food regardless.

Several leaf fungi produce antibiotics that hinder the growth of other fungi. After all, when many species share the leaf surface, they are competing both for food and for precious space. Scientists intensively study these interfungal rivalries in laboratory cultures, because they may hold a key to controlling the fungal diseases that commonly afflict commercial wheat, rye, barley, and bean crops. (The nonselective fungicides currently used on some commercial crops also kill the beneficial epiphytes that may naturally inhibit the proliferation of their disease-causing cousins. In fact, the use of such chemicals may sometimes lead to an increase rather than a decrease in plant diseases.)

Leaves may indeed benefit from the presence of their fungal colonists, but the fungi also have a good thing going. The deceptively clean-looking surface of a fresh leaf contains a bounty of organic particles—pollen, spores, and other windblown debris—as well as nutritious materials that leak from the leaf’s epidermal cells. But in nature, plentiful sources of food energy seldom go uncontested for long.

About 1.5 million fungal species exist on our planet. Many of them flourish in a broad range of habitats, and nearly all of them are adapted for wide dispersal. With billions of fungal spores in the air, the pioneer populations on the leaf are quickly infiltrated by newcomers. The most suc-
cessful of the early invaders are certain kinds of Ascomycetes, a large class of fungi that includes truffles and morels as well as most molds and yeasts. *Cladosporium herbarum*, for example, is a species that grows in velvety green, branching chains and has a notorious tolerance of extremes (one strain of *C. herbarum* attacks meat in cold storage and can thrive at 20° F). These fungi are often quickly joined by other species, including those in the genera *Penicillium* and *Fusarium* (the latter is known for its parasitic strains that commonly attack vegetable crops). These “weedy” species are capable of fast growth under relatively impoverished conditions.

The surface of a fir needle, below, is laden with fungal hyphae and spores. Late in the life cycle of a leaf—or, more commonly, after the leaf has fallen from the tree—*Aspergillus*, right, fruits in treelike tufts (here magnified 305 times).

By the time most tree leaves have matured, several thousand fungal spores per square inch, representing many different species, may be found on their surfaces. Life on the surface of a leaf is not easy, though, and for many of the later arrivals, the stay is short. Viewed at the microscopic level, the epidermis of the leaf appears no more hospitable than the rugged canyon country of the arid Southwest, to which it bears a remarkable structural resemblance. What appears to the eye as a smooth, flat leaf surface is instead a complex landscape of erosional features that have been worn into the leaf cuticle from the gradual physical and microbiological breakdown of its waxy coating. The tiny canyons and crevices of the leaf are laden with the organic resources needed to sustain fungal growth, yet relative to the topographic features of the leaf, the newly arrived spore sits naked and exposed, like a giant boulder on a desert landscape.

By the time most tree leaves have matured, they may host thousands of fungal spores per square inch.

Of all the spores that settle on the leaf’s surface (many having gotten there by wind or a splash of rain), surprisingly few are able to survive for long under these conditions. Nutritional shortages—especially on the younger leaves, which leak fewer metabolites and have not yet accumulated substantial organic debris—often bring about competition and restricted growth. And although nutrients keep accumulating as spring rolls around to summer and as the leaf ages, equally challenging new circumstances are imposed on the leaf fungi. Midsummer weather, for instance, rapidly parches the surface of a leaf fluttering in the warm breeze, and with frequent thunderstorms come torrents of rain that easily wash spores out of the canopy. To mediate such extremes, the fungal colonists secrete sticky mucilaginous sheaths that help them hang on, but it’s a tenuous existence nevertheless. Some populations die; others encase themselves in thick-walled “resting structures” and weather the drought while the new arrivals try to settle in. It takes a hardy pioneering type to succeed under these circumstances.

By late summer, however, fungal spore production reaches its peak, the atmospheric fallout onto the canopy becomes increasingly heavy, and new recruits on the leaf surface begin to outnumber casualties. The same sticky secretion that holds
one fungus to the leaf also enables the spores of others to become attached to it. With the onset of fall, conditions become somewhat easier for the fungi. Moisture abounds as dew settles on the foliage in the chilly autumn mornings, and the cooler days mean less evaporation. These factors, along with the continuing accumulation of pollen, set the stage for yet another community shift on the leaf's surface. Many of the early colonists have by now relinquished the site to competitors better suited for these new conditions. Succession is again under way.

What began as a passive partnership between plant and fungi high in the forest canopy gradually shifts emphasis. While the leaf was young and healthy, many other fungal colonists—the true saprophytes (organisms living on dead or decaying matter)—remained quiescent. But with the onset of autumn and senescence, these decomposers emerge from dormancy and soon take over. High above the ground, the annual recycling of leaf material—the ultimate return of nutrients and organic matter to the soil—begins slowly but inexorably. In the end, it appears that the plant, through its remarkable lifelong partnership with fungi, has indeed married the undertaker.
Searching for the Wild

Remnants of the herds ancestral to all domesticated camels may still survive in the deserts of central Asia.

Story by John Hare ~ Illustration by Rodica Prato

It is late April 1999, and we are about to set out into the Gobi’s Chinese sector, a desert in whose heart the temperatures range from −10°F in December to 150°F in August and where less than an inch of precipitation may fall during the year. We go in search of wild Bactrian (two-humped) camels—remnants, we believe, of the ancestral herds that gave rise to all domesticated camels, both two-humped and one-humped. Perhaps no more than a thousand of these elusive animals survive, about a third in Mongolia and the rest in China, both here in this part of the Gobi and, to the west, in the Taklimakan Desert. Even in these marginal ranges, the animals are increasingly threatened—by iron-ore mining, gold extraction (which contaminates the land with potassium cyanide), oil prospecting, and illegal hunting.

The wild camels’ last best hope is in the Chinese Gobi, where the government has just authorized the establishment of the Lop Nur Nature Sanctuary. This 60,000-square-mile preserve includes the dry lake bed of Lop Nur (now cut off by irrigation channels from its former water supply) and the highly restricted zone where China conducted nuclear testing until 1996. The sanctuary project must be quickly translated into reality, and we hope to gather information on the number of animals and their condition, and whatever else we can glean about their lives.

Seven years ago, I had no idea that somewhere in the world there might be truly wild camels, as opposed to feral ones. But having had some experience with camels in Africa, I was invited in 1993 to accompany a joint Russian-Mongolian expedition to the animals’ remaining Mongolian homeland. On that venture, apart from seeing a dozen animals that had been captured for a controlled breeding experiment, I sighted only some footprints. Since
Bactrian Camel
then, I have been on three journeys into the camels' Chinese domains in Xinjiang Uygur autonomous region—by motor vehicle in 1995 and 1996 and by domesticated camel in 1997. The Chinese expeditions are led by Yuan Guoying, an ebullient professor of zoology from the Xinjiang Environmental Protection Institute (I call him the Professor). Joining the team again this time are Li Weidong from the same institute, a small-mammal researcher who doubles as an admirable cook; the Professor's twenty-nine-year-old son, Xiao Yuan, who acts as my interpreter; and the guide to whom we entrust our lives, Zhao Ziyun. A poacher-turned-gamekeeper who lays claim to having shot the last free-ranging Przewalski's wild horse, "Old Zhao" has been crisscrossing the Chinese Gobi, both legally and illegally, since the 1970s.

With two jeeps and a supply truck, we establish a base camp in Hongliugou Valley, where we have arrangements to hire twenty domesticated Bactrian camels. We plan to trek eastward, probing valleys in the foothills of the mountains (part of the great Altun Shan range) that border the south side of the desert. These foothills are a summer grazing ground for some of the wild camels, which take advantage of vegetation watered by melting ice and snow. Other camels of the Chinese Gobi remain in the heart of the desert year-round, surviving on plants that grow around saltwater springs. Two years ago, on our first camelback expedition, we discovered and followed the wild camels' well-worn migration route between these two ranges.

In Hongliugou a black sandstorm ("black" because of the very low visibility) scatters our hired camels in all directions. I am reminded that two years earlier we had a close call when, deep in the desert, all but two of our sixteen camels disappeared in a nighttime sandstorm. We were 175 miles from our base camp, and the last water source we had passed was a three days' walk away. On the basis of our water supply, we calculated that we had only six days to find our camels before we would be forced to head back on foot. It took nearly that long for our herdsmen to track down the animals, which had fled all the way to the foothills.

This time we are held hostage for a week until our herdsmen recapture sixteen of the twenty camels and we hire the necessary replacements. We are encouraged to quit camp by an onslaught of large mosquitoes, so Li Weidong, Xiao Yuan, Zhao Ziyun, and I, accompanied by four herdsmen, begin our desert journey, leaving the Professor and the jeep and truck drivers to conduct their own survey using the vehicles. Conditions are now perfect. The ominous mist of dust and sand left by the storm has lifted, and the crevices and gullies that gouge the sides of the mountains stand out in sharp relief.

We wind our way up and over a seemingly endless line of sandstone foothills. On the second day, one of our camels slips and breaks its shoulder, and we have to put the animal out of its misery. By midafternoon, it is clear that another of our camels is tiring. Three of the herdsmen drop behind to encourage her along. While waiting for them to catch up, Xiao Yuan and I rest atop a steep-sided escarpment abutting a valley that leads into the mountains. I lie back, hat over my face, and drift into sleep. Suddenly I hear Xiao Yuan calling me urgently. Six hundred yards away, marching toward us in formation, is the largest group of wild camels I have ever seen—so large a herd that at first I think they must be untended domesticated animals. I struggle to capture the sight with my video camera. Why is everything out of focus? The herd continues to advance. Then they spot us and immediately turn and scatter.

"Nineteen females, seventeen young, and one
Perhaps no more than a thousand of these elusive animals survive, about a third in Mongolia and the rest in China.

bull,” reports Usuman, one of the herdsmen. “Thirty-seven wild camels.” Thirty-seven! Like many other wild ungulates, Bactrian camels live in social groups dominated by a single male, but I had no idea that a bull could control such a large harem. And seventeen members of the herd are less than two years old, which shows a good rate of survival, since female Bactrian camels have a gestation period of thirteen to fourteen months and thus reproduce at most every two years. (In both the foothills and the desert, young are born between December and April.) We find this all very encouraging, especially since two years earlier we encountered no wild camels and counted seven dead...
young ones near Lop Nur. But I am beside myself with frustration: the picture of a lifetime has been scuppered because the focus switch was on manual instead of automatic. Xiao Yuan, even though he chases wildly after the retreating herd, doesn’t manage to take a satisfactory photograph either.

On our third day we sight a couple of solitary bull camels—probably defeated in the quest for a harem—and eventually arrive at Wutong Spring. Two years ago, this was a Garden of Eden: the wild poplar was in bloom, and the water that flowed from a crack in the rock seemed like nectar. Now our camels are just as thirsty, but Wutong Spring has a dry and dusty face. Tall brittle *Phragmites* reeds cover a hole in the gully where the camels might drink, but we can’t get near it. After some debate, we decide to set fire to the reeds. One match is enough: soon the narrow gully is alive with billowing flames. Less than an hour later, the camels are picking their way through charred, smoking tufts of vegetation toward the water.

The fire reveals that a pair of wolves have cunningly sited their den near the spring, where an unlimited supply of fresh meat—wild sheep, wild camels, and kiangs (Tibetan wild ass), among other animals—will parade by. Smoke drifting into the den flushes out three cubs that are no more than six weeks old (fortunately, the parents are away). The trio emerge blinking and gasping but unharmed, and the damage to the den is minimal. We feel certain that the adult wolves will return to their cubs as soon as we leave.

And we’d just as soon not stay long at Wutong; it is plagued with huge, aggressive ticks that, responding to vibrations caused by our motion, scurry up our legs to seek out warm, moist recesses. Queuing to drink the freshwater, the camels kick out in frustration as the ticks bury their heads in their flesh. “Are you wearing your Chinese long johns?” Xiao Yuan calls out to me. “If not, you’ll soon be kicking like a camel.” Usuman holds up a glowing cigarette end: “Tick medicine for you and the camels.”

On the fourth day we reach Many Rat Hole Valley, named for the pockmarks in the surrounding cliffs. These small holes are caused by wind erosion of the soft rock and don’t contain any rats. After a three-mile slog uphill through ice-cold snowmelt, we rendezvous with the Professor, who has man-
day while the Professor seeks a possible vehicular route to another valley along our itinerary, my swollen hands resemble those of a prizefighter and my left eye is almost closed. The Professor returns and tells us there probably won’t be another chance to rendezvous until we reach the end of our trek. “You had better fill up your camel hump tonight,” he says. “You won’t be seeing the supply vehicles for quite a long time.”

We now confront a daunting task—to cross dunes that are more than 500 feet high and are surfaced with treacherously soft sand. A wide tract of these sand mountains, known as the Kum Tagh, parallels the foothills for 400 miles. Generally they leave a corridor about 20 miles wide, but here they abut the mountains. As we leave the pockmarked cliffs behind, we are unsure how many days it will take to cross the sand and just where or when we’ll see the Professor again. The size of the dunes and the nature of the surface are unpredictable. Relying on maps, a Global Positioning System receiver, and our gut instincts, we plunge ahead toward what looks like the least formidable dune.

Smoke drifting into their den flushes out three wolf cubs that are no more than six weeks old (fortunately, the parents are away).

The kiang, or Tibetan wild ass, inhabits arid and semiarid habitats, preferring hilly terrain.
Soon we are struggling, the camels laboring painfully upward and soft sand filling the boots of those of us who choose to walk. I shed my boots for a while, and the hot sand burns the soles of my feet as I clamber over dune after endless dune. Whipped up by the wind into fragile knife-edged pinacles, the dune summits are particularly taxing; I manage to get across them only by scrambling on all fours. The pauses I make are to recover my strength, not to admire the view.

After nightfall, under a full moon and a brilliant mantle of stars, we camp in a hollow in one of the dunes, supremely thankful that a sandstorm has not blown up. I forget my burned feet and swollen hands when Li Weidong finds the energy to serve up handmade noodles with salt mutton. Zhao Ziyun burps with satisfaction as he scrapes the battered cooking pot with his chopsticks. “It’s better than eating camels,” he says. Happy and replete, knowing we are camped where no one else has set foot in recent history, I fall asleep watching countless satellites winking their way around the globe.

Another day under a baking sun tries both man and beast. Yet even here, in the midst of the sand mountains, we occasionally surprise wandering wild camels. They stare at us and, for a change, don’t run away. Then, toward evening, we give an involuntary cheer as we see, from the vantage point of the high dunes, a wide valley spread below. Three hours later, we finally shake the sand off our boots onto the broken, rocky surface of Ice Valley.

A thin stream of water percolates through the valley. Our poor camels have suffered during the dune crossing; they are run down and have lost weight. The seasonal molt of their woolly winter hair makes them look even more wretched. Once again they are in dire need of water. Unlike their wild cousins, which can survive on briny desert springs and slush, our camels need sweet water. The water here is fairly suitable, but they need a sizable pool, not merely this trickle, to fill themselves up. We camp on a sandy spit, and in the evening the herders lead the camels up the valley to seek out the source of the stream. After walking six miles, they find a spring, and the camels drink their fill. They don’t return until long after midnight.

**Even in the midst of the sand mountains, we surprise wandering wild camels. They stare at us and, for a change, don’t run away.**

As the sun rises, Xiao Yuan and I let the sleeping herdsmen rest, and we explore an interesting-looking gully that twists back into the dunes. It seems to be a well-used wild camel trail and probably leads to a spring. Halfway up the gully, we find large footprints that appear almost human. “It must be the wild man,” says Xiao Yuan, meaning the yeti. Then he notes the telltale faint imprints of claws. We did not know that Tibetan brown bears penetrated this far into the desert.

Emerging at the upper end of the gully, we sight two wild camels walking straight at us. We duck down behind a tiny bush, not daring to move, hardly daring to breathe. The camels continue to advance. To our intense delight, they walk slowly down into the gully, passing within thirty feet of us. They are leaner and smaller than their domesticated cousins, and we have a bird’s-eye view of their tightly formed, upright humps. The camels are in molt, but in prime condition. The lead camel suddenly stops (one camera click too many), turns, and sees us. Instantly the two race down the gully. Moments later, Xiao Yuan grips my arm. Another camel is coming toward us. This one pauses a long time before it turns and flees. I never dreamed I would get so close to one of these shy animals.
Pushing on, our caravan enters a huge dry plain. We see a kiang (distinguished by its large brown-and-white patches) and four surprisingly inquisitive wild sheep. Then the good-natured camel that is carrying my kit spots the bleached skull of a wild relative. He stretches out his neck and grasps the object with his teeth. Head held high, he crunches it up. I guess he must need a calcium supplement.

Twelve miles farther along, we pitch camp on a sandy incline facing the mountains. Here we establish radio contact with the Professor. He reports having reached a freshwater spring far to our east and is attempting to drive west to meet us. But no track exists, and the pitted ground is covered in rocks and boulders. “We dare not bring the jeeps and are only using the truck,” he tells us.

The following day, after finding an unmapped spring where we are able to water the camels, we cross a mountain pass into yet another seemingly endless plain, where we see more wild camels, wild sheep, and kiangs. We come across vultures, at least a dozen of them, feeding on the remains of a young wild camel. By carefully examining the carcass and the surrounding footprints, we can tell that the camel was killed and gutted a few hours earlier by four wolves. One attacked the throat, and the other three, the hindquarters.

I cut off some skin samples from the hind legs, hoping the material will be useful for genetic testing. We submitted similar samples to the Wildlife

A tract of high, shifting dunes creates a barrier between the foothills and the rest of the Chinese Gobi.
Conservation Society in New York and to other institutions after previous expeditions, and the results suggest that the wild camel has a DNA makeup distinct from that of domesticated stock. Evidence is mounting that these animals are indeed a vestige of the original wild herds that roamed central Asia until 4,000 years ago, when humans began domesticating the camel.

In the evening a sandstorm threatens but fortunately dies away. Then a sad accident occurs: the domesticated camel that has endured so much since the beginning of our journey loses her footing and crashes to her death at the edge of a steep-sided pass, even though she has been spared carrying a load and is walking untied. She has simply grown too weak. It is a reminder of the harshness of the land we are crossing.

The next day we see that more dunes stretch ahead. Our hearts sink; none of us, least of all our camels, want a repeat crossing. But Usuman spots, almost concealed within the dunes, a beautiful gorge with vegetation and water. Conditioned to scenes of endless rolling sand, my eyes take some moments to adjust to the extraordinary contrast.

As I arrive breathless at the bottom of the gorge,

The camel that is carrying my kit spots the skull of a wild relative. He stretches out his neck and grasps the object with his teeth.

Usuman, who is considerably ahead of me, begins to gesticulate frantically. In a grove of golden Phragmites reeds stands a wild camel that has guzzled so much water that it appears to be on the verge of giving birth. The camel raises its head from the muddy pool, takes one look at me, and flees. “That camel hadn’t drunk water for days,” observes Usu-
man when we meet up again. “It was determined to fill up its tank until it overflowed.”

This beautiful setting, which we call Kum Su (Sand Spring), is beguiling, but we must press on. We strike out over the dunes and find that their surfaces are firm, their contours benign. We camp in a cramped hollow that harbors ticks, and I soon discover I have set myself up as their evening meal. Xiao Yuan wisely perches his sleeping bag on top of a dune to avoid their onslaught.

The following day, in yet another valley, we finally meet up with the Professor. His fuel supply is dangerously low, and our water is finished. “One more day, and we would have been in real difficulty,” says the Professor as we embrace. “Yet again we have been very, very lucky.” We all enjoy a feast of fourteen dishes, including tinned pork, salt fish, and a mound of noodles the Professor has prepared. We have cause for celebration. On our trek, which has covered 132 miles in ten days, we have counted 141 wild Bactrian camels. The vehicle party has counted another 28. During the three previous expeditions, we saw no more than 70 in all, and most of them were specks on the horizon. The Professor, however, is reluctant to revise upward our estimate of about 660 wild camels in China. “We have seen too few on earlier expeditions for us to want to do that,” he declares.

A short, intense evening sandstorm scatters our banquet and forces us prematurely into flapping, sand-filled tents. The violent wind turns to rain, then to hail, and finally to snow. Overnight the desert turns white. Those of us who have crossed the sand dunes realize how truly lucky we have been. Had the weather behaved differently, we might have been stranded long enough to run out of water, and we might not have lived to keep our rendezvous with the Professor.
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A Classic Revisited

Darwin's great idea in the *Origin*—that life is a series of successful mistakes—is reinforced by a century and a half of evidence.

**REVIEW**

Screenwriters have a privilege denied to most of us. They can take the great classics of the past and fix them. You will remember that by the end of Charles Dickens's *Oliver Twist*, Oliver himself has pretty much dropped out of the story. When the murderer Bill Sikes is cornered by a pursuing mob, it is the minor character Charley Bates, one of Fagin's gang, whom he threatens with death. But in David Lean's marvelous 1948 screen adaptation, it is Oliver himself who is kidnapped and threatened by the villainous Sikes, bringing the movie to a hair-raising close. Why the dickens, we ask, didn't Dickens think of that?

In his updating of Darwin's *Origin of Species*, Steve Jones, too, has become a revisionist, tackling what is arguably the greatest scientific classic of all time and "the high point of the literature of fact." Darwin's prose cannot be copied, Jones is quick to point out, comparing it to a Victorian country house: "It radiates confidence from whatever direction it is viewed—as literature, as autobiography, or as brilliant science."

Jones does not fool with the plot, either, which would be very difficult to improve, and he remarks early on that the framework of the original book has remained remarkably robust. So powerful was Darwin's idea of natural selection (and so thorough was Darwin's understanding of its myriad implications) that many of the explanations have survived the intervening century and a half virtually unchanged. Indeed, Jones includes most of Darwin's end-of-chapter summaries, and he reprints chapter 14, "Recapitulation and Conclusion," in full.

Utilizing the chapter-by-chapter framework of Darwin's original, Jones illustrates the concepts with selections from the prodigious store of data that has accumulated since the publication of the *Origin* (the full title of which, by the way, is *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*), building on Darwin's thesis that "the present was the key to the past." In his introduction, Jones has picked "the biography of the AIDS virus, Nature's newest and tiniest product," as a telling example of the Darwinian idea of descent with modification. While Darwin, in his first chapter, looks at domestic pigeons as an example of variation within one species, Jones, in his exams, the astonishing array of dog breeds that have proliferated since 1859 (also, coincidentally, the year of England’s first dog show). Thus Jones wends his way through fourteen chapters, working into his own set of Grand Facts (a favorite phrase of Darwin's) and topics—from DNA and cloning to hydrothermal vents and the science of cladistics—and reinforcing Darwin's view of biology as a "system of knowledge rather than a set of random facts."

The idea is a clever one and in general succeeds quite well. Darwin barded the reader with so many facts that the cumulative weight of the evidence in support of his theory became overwhelming. Jones uses the same approach, enlivening his book with material drawn not only from science, literature, and history but from sources as diverse as Burke's Peerage, whiskey ads, and the gay press. He writes, however, as Darwin did not, with dry humor (although he also occasionally descends to domineering waggery).

In the last 140 years, scientists have done much more than simply add observations to Darwin's framework. The big thing we now know (that the *Origin*'s author did not) is how inheritance works. Darwin assumed, as did all his contemporaries, that traits acquired during an individual's lifetime can be passed on to the next generation (an idea attributed to French naturalist Lamarck but actually far older and more widespread). After he wrote the *Origin*, Darwin postulated that acquired characteristics were distributed throughout the body by "gemmules" and so was very upset when his cousin Francis Galton found that transfusing blood between different rabbit breeds had no effect on their offspring. There were, it seemed, no gemmules in the blood—or anywhere else, as it later turned out. Acquired characteristics were, after all, not inherited.

The discovery, by Austrian monk and botanist Gregor Mendel, that genes are passed on as discrete units from one generation to the next—and thus that genetic differences are not rapidly averaged out or blended away—rescued Darwin's theory from the difficulties presented by the heritability of acquired traits and opened the way for a synthesis of genetics and evolutionary biology. Jones discusses these developments, but there has been such an avalanche of knowledge since Darwin's time that he can do no more than skim the surface. Speciation, sexual selection, behavioral evolution, and the origin of life are among the major topics Jones zips
The Birds and the Bees

In the warm months, I enjoy watching the animals that are attracted to the flowers in my backyard. Hummingbirds are particularly welcome, with their precision aerial maneuvers, including steep dives to fend off interlopers. Since I want to see more of them and since every organism seems to have at least one Web site dedicated to it, I turned to the Internet to find out how to lure these tiny, swift birds.

It didn't take much effort to find www.hummingbirdsinet. It told me what I suspected about setting up a nectar feeder: "If you are not prepared to follow the rigorous maintenance routine outlined below, perhaps you should consider planting a hummingbird garden instead." So I clicked on "Attracting birds" to find out which plants hummingbirds prefer. I discovered that because hummingbirds, like most birds, have virtually no sense of smell, the fragrance of the flowers on my ordinary honeysuckle vine did nothing to attract them. Apparently color is what matters. I need to plant something like coral honeysuckle. Perhaps then I'd have a chance at drawing more of the twelve species that visit California.

This site has concise descriptions of the seventeen species of hummingbird that summer in the United States and lists them by state. There are also migration maps for the tiny birds, so that if I ever get good enough to tell one species from another, I can help with first sightings in the spring.

The other creatures that visit my honeysuckle flowers have no problem finding the nectar. For more information on them, I went to the BeeHive (www.xensei.com/users/alwine/beesite.htm), which I enjoyed more for its information than for its graphics. Click on an item such as "Bees at War," and you'll find out that the Romans used beehives as catapult projectiles. "This was so effective that they depleted central Italy of bee colonies for their ammunition." I also discovered a new term—apitherapy, which includes bee-sting therapy. When I clicked on "Apitherapy," I learned about a woman who regularly uses bee stings to relieve the symptoms of multiple sclerosis—an approach now being explored by mainstream scientists. And I wish I had read "City Beekeeping" before I moved out of Manhattan; perhaps I would have contemplated a rooftop hive.

Christopher Wills is a professor of biology at the University of California, San Diego. His books include Children of Prometheus: The Accelerating Pace of Human Evolution (1998) and (with Jeffrey Bada) the forthcoming Spark of Life: Darwin and the Primeval Soup, both published by Perseus Publishing.
BOOKSHELF

A Fish Caught in Time: The Search for the Coelacanth, by Samantha Weinberg (HarperCollins, 2000; $24)

Ever since the first living coelacanth (the deep-sea equivalent of a dinosaur) was found in 1938, researchers have been trying to establish this fish as the “missing link” between the marine and terrestrial worlds.

The Secret Knowledge of Water: Discovering the Essence of the American Desert, by Craig Childs (Sasquatch Books, 2000; $23.95)

Naturalist Childs describes his job mapping water in the arid Southwest and recounts finding a surprising variety of sources.

River of Lakes: A Journey on Florida’s St. Johns River, by Bill Belville (University of Georgia Press, 2000; $24.95)

Journalist Belville explores the myth, history, and ecology of Florida’s longest river (275 miles) and finds “enough wilderness left here to take the shrillness of civilization out of us.”

Hope Is the Thing With Feathers: A Personal Chronicle of Vanished Birds, by Christopher Cokinos (Penguin Putnam, 2000; $24.95)

A recent convert to birdwatching has collected information on such extinct birds as the Carolina parakeet, the ivory-billed woodpecker, and the heath hen in a poetic, passionate effort to “restory” the past.

Black Tides, by Miles O. Hayes (University of Texas Press, 2000; $21.95)

Starting with a 1990 airplane crash in Alaska (which he survived), geologist and marine scientist Hayes recounts his years cleaning up coastal oil spills from Chile to Saudi Arabia.


Lavished with breathtaking photographs, this report examines twenty-five shrinking geographical areas around the world that have phenomenal plant and animal diversity.

Prides: The Lions of Moremi, by Chris Harvey and Pieter Kat (Smithsonian Institution Press, 2000; $34.95)

Field researcher Kat and photographer Harvey document unique social strategies and hunting techniques of four lion prides inhabiting Botswana’s Oka-vango Delta.

Nabokov’s Butterflies: Unpublished and Uncollected Writings, edited and annotated by Brian Boyd and Robert Michael Pyle; translated by Dmitri Nabokov (Beacon Press, 2000; $45)

Nabokov’s Blues: The Scientific Odyssey of a Literary Genius, by Kurt Johnson and Steve Coates (Zoland Books, 1999; $27)

Two titles documenting the butterflies that flutter in and out of Vladimir Nabokov’s work illuminate his important contribution to the science of lepidopterology.

The books in “Natural Selections” are usually available in the Museum Shop, (212) 769-5150, or on the Museum’s Web site, www.amnh.org.
Charlie Merrels Lays Up Treasure for the Museum’s Future and for His Own Retirement

For most of his working life, Charlie Merrels was an importer of handcrafted products from developing countries. Seeking out traditional products that had sales potential, he worked with local crafts people and local governments to establish cottage industries that enabled their products to be marketed in the USA and Canada.

With his interest in helping people preserve their distinctive cultures in a way that is also economically successful, he became a regular Museum visitor and subsequently a member, especially enjoying such favorites as the Hall of Mexico and Central America. Then, last year, he learned about Charitable Gift Annuities. “I was so pleased to find a way to make a substantial gift to the Museum and also provide important benefits for me.”

A Gift Annuity is a way to support the Museum and provide lifetime income to one or two people. When low-yield, appreciated securities are used to fund the plan, capital gains tax is avoided. According to Charlie, “I significantly reduced the capital gains taxes I would have owed if I had sold the shares myself. Best of all, I have the satisfaction of knowing that, in the future, my gift will go directly to the Museum for its work.”

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What's New in Prehistory
An exhaustive guide to stones and bones brings human evolution studies up to date. By Richard Milner

One evening about twenty years ago, some members of the American Museum of Natural History's scientific staff gathered for a few beers. Anthropology curator Ian Tattersall had just returned from one of his frequent trips abroad to study early hominid fossils and was lamenting the fact that the institution's vast collections held only a few Old World stone tools and not a single early hominid bone. Without such fossils, he asked, how could the Museum hope to be a leader in the study of human origins?

John Van Couvering, editor in chief of the Museum's Micropaleontology Press and a former field geologist for Louis Leakey in Africa, answered Tattersall with his own question: "Why don't we just bring all the world's human evolution fossils to us?"

In this offhand manner was born the 1984 exhibition "Ancestors: Four Million Years of Humanity." Hand-carrying precious fossils in foam-lined cases, paleoanthropologists converged on the Museum to pool information and to display such treasures as *Homo erectus* from Asia, Neanderthals from Europe, and the famous Taung Child (the first known *Australopithecus africanus*) from South Africa. For the first time, experts were able to gather in a single room containing the world's most precious relics of human evolution. By hosting this historic event, the Museum did indeed emerge as a world leader in promoting scholarship about human origins.

In the process, three of the exhibition's key organizers—Tattersall, Van Couvering, and paleoanthropologist Eric Delson—became a clearinghouse for new discoveries. Delson completed his own compendium on primate fossils (*Ancestors: The Hard Evidence*), while Tattersall took on the task of designing the new Hall of Human Biology and Evolution for the Museum (it was completed in 1993). In 1985 a publisher asked whether they would be willing to compile a comprehensive encyclopedia on the subject—a project as unparalleled as the "Ancestors" exhibition itself. Enlisting the aid of about forty colleagues, the trio produced the first edition in 1988.

This month, a second edition of the *Encyclopedia of Human Evolution and Prehistory* appears, with a fourth editor (archaeologist Alison S. Brooks, of George Washington University and the Smithsonian Institution), 800 entries (200 of them covering the latest finds and interpretations), and 450 illustrations.

So what have we learned about human evolution that we didn't know a decade ago?

Species from outside the Rift Valley, such as an australopithecine from Chad and the monkeylike *Otavipithecus* from Namibia (codiscovered by Van Couvering in 1994), enrich and complicate the fossil record. Outlines of the human family tree are showing many more branches and twigs, and recent finds indicate that this "bushiness" existed in Africa from the very beginning. It is now thought that in Indonesia, *Homo erectus* lived alongside *Homo sapiens* as recently as 40,000 years ago, when Neanderthals still inhabited Europe and the Middle East.

Dating methods continue to improve; for example, cyclostratigraphy now provides a way of calibrating peri-
MAY 2
At 7:00 p.m., historian Olivier Bernier, author of The World in 1800, talks about cultures that flourished at the dawn of the nineteenth century.

MAY 4
At 7:00 p.m., George Plimpton and Dmitri Nabokov give a dramatic reading of correspondence between Edmund Wilson and Vladimir Nabokov, from the play entitled Dear Bunny, Dear Yolodja, by Terry Quinn.

MAY 9, 16, AND 23
The last three talks in the series “Revolutionizing Medicine in the 21st Century,” about the state of genetic research, will be given by oncologist Karen Antman (“Cancer: New Weapons, New Directions”), geneticist Ronald Crystal (“Gene Therapy Enters Adolescence: Progress and Issues”), and cell biologist Samuel Waksal (“Generating New Cells, New Organs: Stem Cell Research and Application”). The talks start at 7:00 p.m. For information, call (212) 769-5176.

MAY 11
In the fourth of a series of five 7:00 p.m. lectures cosponsored with Earthwatch Institute, biologist and ornithologist Constance D. Becker discusses her work enlisting local people to protect the fifty-five endemic bird species in the cloud forests of coastal Ecuador.

At 7:00 p.m., Peter M. Rutkoff, coauthor with William B. Scott of New York Modern: The Arts and the City, talks about painters and writers of the past five decades, among them Georgia O’Keeffe, Jackson Pollock, and Allen Ginsberg.

The push to discover medicinal properties in plants and animals is the subject of ethnobotanist Mark J. Plotkin’s 7:00 p.m. talk and of his new book, Medicine Quest: In Search of Nature’s Healing Secrets.

MAY 15
As part of the “Frontiers in Astrophysics” series, astronomer Jay Pasachoff gives a talk at 7:30 p.m. entitled “Sun and Solar Eclipses.”

MAY 17, 24, AND 31
In a series of three 7:30 p.m. talks in the series “The River Indians: First People of the Hudson Valley,” National Park Service ethnologist and archaeologist Robert S. Grumet explores the diverse cultures and histories of Native Americans living along the Hudson River beginning 12,000 years ago.

MAY 18
At 7:00 p.m., astronaut Buzz Aldrin, the second man to walk on the Moon, discusses the future of the space program.

MAY 19
The exhibition “Fighting Dinosaurs: New Discoveries From Mongolia,” opening in Gallery 3, presents the 80-million-year-old dinosaur fossil finds of the Gobi that have shed new light on the rise of modern bird and mammal groups.

MAY 22
As part of the “Distinguished Authors in Astronomy” series, astronomer Lucy McFadden gives a talk at 7:30 p.m. entitled “NASA Unveils Asteroid 433 Eros.”

MAY 22–28
The Department of Education is hosting public programs to celebrate tradi-
Naadam, Mongolia's annual festival of archery, wrestling, horse racing, music, and dance, will take place in Central Park May 19–20. In conjunction with these events, the Museum is offering a number of Mongolia-related exhibitions and programs. The exhibition "Mongolia Observed: Photographs Present and Past" opens in the Akeley Gallery in May. (See also May 19 and May 22–28 listings, pp. 91–92.) For information, visit www.undp.org/missions/mongolia/festival-form.htm.

**DURING MAY**

Leonhardt People Center programs continue at the Museum in connection with Asian Pacific American Heritage Month. For a complete schedule, call (212) 769-5315.

For information on field trips and workshops for adults and children, call (212) 769-5304.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100. Visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are now available online.
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Scorch and Soda

Late in the dry season of central Africa, blooms of red algae grow in expansive mats over a white crust of sodium carbonate on Tanzania’s Lake Natron. Few multicelled organisms can endure the high temperatures and extreme alkalinity of the lake’s shallow waters, which can sometimes reach 120°F and a pH of 11 at this time of year. Supported by the bounty of algae and tiny crustaceans, both greater and lesser flamingos nest by the thousands on this lake each season.

Natron is one of many soda, or alkaline, lakes that lie in disjointed chains along the great, expanding tear in Earth’s crust known as the East African Rift Zone. Deep geophysical forces have been at work there for more than 40 million years, slowly twisting and wrenching the eastern portion of the African continent into mountains and valleys, forming a bumpy, volcano-pocked seam that runs from Ethiopia to Mozambique. Large bodies of freshwater, such as Lakes Tanganyika, Victoria, and Malawi, conspicuously mark the large valleys along the rift, while smaller lakes, such as Natron, alternately flood and evaporate on the arid eastern steppes of the continent. Lake Natron has no river outlet, and sodium carbonate accumulates in it, leached out from the surrounding volcanic rocks. A highly effective desiccator, this mineral—in the form of a paste called natron—was one of the ingredients used by ancient Egyptians to mummify their queens and kings.—Barbie Bischof

Photograph by Gerry Ellis
Old age is not the problem for plants that it is for animals. Being modular, plants can grow new limbs when old ones die off. More crucial to the longevity of a tree is its size. A tree reaches a stage when it cannot get taller, owing mainly to the difficulties of bringing water up from the roots, and when its side branches cannot grow longer, because they are too expensive to support. So the number of leaves a tree holds becomes more or less fixed, and this means that the tree’s ability to produce food—the sugar made in leaves by photosynthesis—also levels off.

Yet each year the tree adds a new layer of wood under the bark, and the amount of wood needed to coat the whole tree increases, just as, in a set of Russian dolls, each new doll on the outside has to be bigger. As the tree grows, the amount of food needed for running it rises. The tree resembles a bank account whose income (sugary food) is fixed but whose outgo (respiration and new wood) keeps mounting. The tree compensates for a time by producing narrower and narrower rings, but there comes a point when a ring cannot get any narrower. Something has to give, usually the water-deprived topmost branches. The result is a stag-headed tree, so named for the antlerlike dead branches sticking out of the top. A downward spiral begins: the loss of branches means fewer leaves, and fewer leaves means less new wood.

But many trees can slow the process. Some have buds in the trunk that sprout new branches. These may hold enough leaves to make up for those lost higher up, so the tree can keep the leaf area constant while cutting out the expensive-to-maintain upper trunk and its big branches.

Although these new trunk branches are fairly short-lived (a hundred years in oak, sixty years in hornbeam and beech, and less in birch and willow), an oak with plentiful trunk buds can stave off death for centuries. As the old saying goes: “Oak takes 300 years to grow, 300 years it stays, 300 years it takes to decline.” Perhaps we should think of a stag-headed oak as merely entering middle age and, like many humans, just going a little bald on top.

A tree has no fixed life span. To live long, it must stay small. One way to do this is to grow slowly. Bristlecone pines are the supreme example: they live on poor soil in a dry, cold environment with a short growing season. One bristlecone in the American Southwest has been documented at three feet tall, less than three inches in diameter, and 700 years old! The other way to stay small and live long is, paradoxically, to be cut down repeatedly. (This strategy, of course, will work only for trees capable of regrowing when cut.) The ash Fraxinus excelsior normally lives for 250 years, yet Suffolk, England, hosts a coppiced ash with a stump almost seventeen feet in diameter. It is at least a thousand years old.

A tree’s bank balance is also influenced by savings in the form of food reserves. As a tree gets bigger, however, it has less food left over. At the same time, the larder—the sapwood—gets smaller. Eventually, infections penetrate inner structures, and storage capacity is lost behind a barrier zone, a layer of new cells produced in the inner bark to seal off infected wood.

The living part of the tree is walled into a thinner and thinner space under the bark. Part of the tree dies. New branches on the trunk can still save its life, but a large old tree is not good at producing new shoots, perhaps because it is running out of stored buds or because they are trapped behind thick bark. New sprouts on weak trees often die just when people think the tree is going to live. This may be because the barrier zone is missing or because there are too few reserves left for the tree to grow a strip of tissue from the new branch down to the roots. Either way, disease easily overtakes the tree, and the branch withers away. At this point, the tired old tree bows out gracefully.

Peter Thomas is a lecturer in environmental science at Keele University, United Kingdom.
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THE GREATEST RISK IS NOT TAKING ONE.

They do not write the stories of those who played it safe. Yet that is what most of us do. It is inherent in our nature to avoid risk. From the earliest age there is something that tells us to sidestep danger. Perhaps because of that, there is also something in us that admires the risk taker, the adventurer, the person with the courage to step up to the edge of the precipice and believe that he can make it to the other side.

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INNER BEAUTY

Remarkable photographs reveal the structure of fossil organisms whose tissues, over eons, have been replaced by minerals.

PHOTOGRAPHS BY GIRAUD FOSTER AND NORMAN BARKER

THE CROWN OF MONTECRISTI

Surprise! Summer’s quintessential straw hat was never made in Panama.

STORY BY TOM MILLER

Cover A flattened ammonite fossil from the Jurassic period. Its mineralized layers act as a prism, intensifying color and iridescence.

STORY BEGINS ON PAGE 48
PHOTOGRAPH BY GIRAUD FOSTER AND NORMAN BARKER

A STAR IS BORN

How a small, blind, mud-dwelling mammal evolved a high-resolution scanning device on its nose.

STORY AND IMAGES BY KENNETH CATANIA

RHYTHM AND BLOOMS

Getting a plant to flower earlier (or later) than normal is a matter of tinkering with its DNA. Genetic engineers are on the case.

STORY BY ROSIE MESTEL
ILLUSTRATIONS BY RODICA PRATO
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In a footnote to his 1996 book *The Island of the Colorblind*, Oliver Sacks points out that some people have a great deal of “biological” intelligence. This inborn affinity for other living things is most obvious in the great naturalists, such as Darwin and Wallace, but it is present in varying degrees in the rest of us, too. Sacks cites novelist and poet D.H. Lawrence as an artist with the gift of knowing “by a sort of connaturality, what it is like to be a snake or mountain lion; to be able to enter the souls of other animals.”

For many people, however, empathy with other organisms has very definite limits. What fellow feeling they do have decreases with taxonomic distance. We bond first and foremost with other vertebrates, especially mammals and birds. There are those who are drawn to snakes and lizards, but even a photograph of these animals activates a deep-seated phobia in a fair number of people. As for invertebrates—the immense majority of animal species—some humans are, at best, ambivalent about them.

Still, a good piece of nature writing can allow you to walk (a short way, perhaps) in another creature’s shoes.

This month, Carl Zimmer’s “Biomechanics” column invites the reader to think like a crustacean. While a crab’s sidelong skittering across the sand has always seemed to me quite alien and even rather sinister, Zimmer—by explicating the work of Marlene Martinez—made me appreciate how seamlessly these creatures move from land to sea and back again. Reading on, I began to imagine how it would feel to walk like a crab. Would I attempt to enter the water head-on? Clearly not. With the wider part of my body facing forward, I might be knocked off my eight feet by the first wave. Martinez was right; turning sideways and hunkering down a little would make the transition into the ocean much easier. Once in, I might enjoy punting my way along—floating mostly—and pushing off the bottom now and again with one of my pointy legs.—Ellen Goldensohn
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TO THE EDITOR

A Domestic Planetarium
I very much enjoyed the special February 2000 issue (“To Know the Universe”)—especially James B. Swetzter’s “Theater of the Stars,” detailing the chain of planetarium history from simple orreries to the grand, reborn Hayden Planetarium. I draw your attention to one tiny missing link: a mini-planetarium that has been operating for over two centuries in Franeker, a small town in the northern Netherlands.

Its builder, Eise Eisinga (1744–1828), was a knitting-wool processor who devoted his spare time to astronomy and mathematics. When the announcement of a May 1774 conjunction of the Moon, Mercury, Venus, and Jupiter in the same constellation spread panic among Europe’s unenlightened (who thought it was a fearsome omen of Armageddon), Eisinga was shocked to see how much was squeezing the wheel mechanisms between the ceiling of the room and the beams supporting the attic floor. A particular annoyance to Eisinga’s wife was the combination pendulum-bedstead, which had to do its work partly in the conjugal sleeping accommodation (behind curtains in above photo).

Eisinga completed the project in 1781. Thirty years after his death, the house was handed over to the town of Franeker on condition that it would be opened to visitors, kept up, and the workings of the planetarium explained. In all respects, the town has been faithful to its obligations, as I saw for myself on a 1998 visit.

A monument to human endeavor and practical idealism, Eisinga’s creation deserves a small memorial stone on the road to Hayden.

Eleonore F. Wysman
Baarn, Netherlands

Passion and Precedent
Stephen Jay Gould’s thoughtful essay on the links between oratorios and a humanist scientist’s concerns (“The First Day of the Rest of Our Life,” 4/00) includes one very troubling passage. Referring to the portentous line from J. S. Bach’s Saint Matthew Passion in which the Jews accept responsibility as a people for the murder of an innovative rabbi destined to be embraced by much of the Western world, Gould states that as much as he deplores this blood libel, he would never “consider changing the text for any modern performance, lest an understandable deed for a particular purpose establish a precedent and open a floodgate for wholesale revision of any great work to suit the whims of fashion.”

For lawyers, precedents are the means by which the law ensures its continuity. But the value of precedent can be overstated. As Justice Oliver Wendell Holmes put it, the fact that something has always been done in a certain way is a damned poor reason for continuing to do it that way.

Gould’s profoundly conservative approach to the question of altering Bach’s text contrasts with the spirit of the Enlightenment that Gould celebrates elsewhere in the essay. That spirit is confident of humanity’s ability—most of the time—to draw the line on change at or near the point where the harmful consequences of an innovation outweigh its benefits. This is the spirit we need if we want the first day of the rest of our life to be any better than the previous days.

Stanley N. Futterman
New York, New York

The Pros and Cons of Kinship
Meredith Small (“Kinship Envy,” 3/00) finds herself “a bit envious” as she traces the strong kinship connections in a model African village. But her treatment of the subject is incomplete. Although kinship provides support and meaning, it also imposes obligations and restricts freedom. In America today, families and individuals can make a trade-off between the two. Most do not, but those who wish to are free to do so. If the author were to consider the full consequences of kinship, she might not be so envious.

Alan Balfour
Tampa, Florida
The Desert That Glistened With Water.

Southeastern New Mexico is home to mesquite and chaparral, mesas and horizons that shimmer with heat. For animals of this parched land, survival comes with water. So people who work nearby helped design and build a system of dozens of unique watering units that gather, store and distribute water to bobcats, antelopes, hawks and more. Quenching nature’s thirst and giving it a chance to survive.

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Giraud Foster and Norman Barker (“Inner Beauty”) have worked together for twelve years, using light-scanning macrographic equipment of their own design to capture the rich patterns and colors of fossilized organisms. Foster (at left) lives in Baltimore and is a physician, biochemist, archaeologist, and gourmet chef. Barker, a six-time winner of Nikon’s Small World Competition, is an assistant professor of pathology and arts as applied to medicine at the Johns Hopkins University, where he also runs the photography laboratory. The two men—who use a Hasselblad camera mounted on a heavy monorail base, macro lenses, and Ektachrome EPP film for their fossil photographs—share a passion for the “shouts of vivid color, twists and convolutions, and geometric patterns” of fossils. Eighty of their images will appear in Ancient Microworlds, scheduled for publication this fall.

Tom Miller (“The Crown of Montecristi”) first encountered the people behind Ecuador’s legendary hats more than fifteen years ago, when he researched his book The Panama Hat Trail (William Morrow, 1986). He welcomed the opportunity for a follow-up visit to see how the industry and its workers were faring. A writer and lecturer based in Tucson, Arizona, Miller is the author of Trading With the Enemy: A Yankee Travels Through Castro’s Cuba (Basic Books, 1996). He has previously contributed two articles about Cuba to Natural History: “The Season of Las Parrandas” (12/97-1/98) and “Cuba’s All-Stars” (4/99).

Every spring, Kenneth Catania (“A Star Is Born”) travels from the Tennessee campus of Vanderbilt University, where he is a research assistant professor in the psychology department, to the wetlands of Maryland and Pennsylvania. There, in addition to star-nosed moles, he inevitably encounters shrews, voles, weasels, field mice, and the occasional snapping turtle. Catania’s interest in star-nosed moles began more than a decade ago, when he was working with small mammals at the National Zoo in Washington, D.C. His current research focuses on brain organization and behavior in mammals—including hedgehogs and opossums as well as moles—with an emphasis on cerebral cortex function. Recipient of the 1998 Capranica Foundation Award and the International Society of Neuroethologists’ 1998 Young Investigator Award, Catania is also interested in how complex brains have evolved.

After earning a Ph.D. in genetics from the University of California, Davis, Rosie Mestel (“Rhythm and Blooms”) repaired to the laboratory to study, among other things, fruit flies. A couple of years later—and without a backward glance at the flies—she segued from hands-on science to science journalism. Mestel, left (with her daughter, Renée), has been a reporter for Discover, the U.S. correspondent for New Scientist, and a contributing editor for Health and Earth magazines; she is currently on the staff of the Los Angeles Times, where, as well as writing about health and medicine, she contributes a weekly column. Her last Natural History article was “The Genetic Battle of the Sexes” (2/98). Rodica Prato, born in Bucharest, Romania, studied architecture before becoming a freelance illustrator. Her work has appeared in dozens of books and magazines. She illustrated “Searching for the Wild Bactrian Camel” in last month’s Natural History.

Mark W. Moffett (“The Natural Moment”) is a research scientist with the Museum of Vertebrate Zoology at the University of California, Berkeley. He describes himself as an “ecologist who climbs trees for a living.” Moffett, who is fascinated by tropical ants (he studied for his doctorate under E.O. Wilson at Harvard), has spent much of the past twenty years studying and photographing life in tropical rainforests. Author of The High Frontier: Exploring the Tropical Rainforest Canopy (Harvard University Press, 1994), he is now working on two more books: one on the problem of living on vegetation (as weaver ants do) and the other on the nature of adventure and exploration. Wired magazine recently cited Moffett in an article about “people who travel too much” (he was ranked just above U.S. Attorney General Janet Reno), but he says he has lately been trying to learn how to stay in one place.
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Stone Ground Flowers

Born of molten rock, isolated mountains offer fragile niches to plants.

Rising above the flattened Piedmont terrain east and southeast of Atlanta are several large rock masses known as monadnocks. Based on the name of a mountain in New Hampshire, this term refers to an isolated rocky hill or mountain that stands out in a region otherwise worn down to a plain. (New Hampshire’s Mount Monadnock derives its name from the Abenaki for “island mountain.”) Ten miles east of Atlanta is the best known of these Georgia landmarks, Stone Mountain, but the vegetation there is far from pristine, having been decimated by the hiking traffic. From a naturalist’s point of view, better sites to visit are Panola Mountain and Arabia Mountain, which are located about twelve miles south and southeast of Stone Mountain.

Arabia Mountain, which geologists date to about 375 million years ago, consists of granitic gneiss, while Stone Mountain and Panola Mountain, formed between 350 million and 275 million years ago, are made of a type of granite. All three mountains had a similar origin. Magma, or molten rock, surged upward through existing rock, cracking it, spreading it apart, heating it, and incorporating much of it. The pressure was not great enough to cause a volcanic eruption, however,
so instead the magma slowly cooled into a hard mass. Eventually the surrounding layers of older rock eroded away, leaving this mass exposed as a monadnock. Continued weathering has carved pits and cracks in the surface, where particles of soil accumulate, providing suitable niches for the growth of plants.

Panola Mountain was the first place in Georgia to be designated a State Conservation Park; it also ranks as a National Natural Landmark. Two excellent trails are available, one that goes through a moist woodland near the base of the mountain and another, higher up, that winds through dry woodland. Above the dry forest the granite is relatively bare and flat; some plant communities here are quite fragile, and visitors may reach them only under the guidance of a park ranger. At Arabia Mountain, however, visitors can wander across the exposed rock that begins just a few feet above the small parking area. The trail is marked by stone cairns.
Although they seem barren, the flat rock outcrops, known as pavement rock, support some lichens and mosses. In addition, a limited assortment of flowering plants survive in cracks and small depressions, called solution pits, where the rock has been dissolved away. Some of the solution pits contain soil a foot deep and have a rocky rim that holds in water following a rain. Usually the water slowly evaporates and the soil dries out as the summer progresses, but in a few of the deeper ones, a shallow pool persists for most of the year. At the other extreme are pits that have lost part of their rocky rims through erosion, so water drains away rapidly after it rains; these often dry up by late spring.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

For visitor information, write:
Park Superintendent
Panola Mountain
State Conservation Park
2600 Highway 155 S.W.
Stockbridge, Georgia 30281
(770) 389-7801
www.mindspring.com/~panolamt

HABITATS

Moist woodland on the lower mountain slopes and extending down to streams that meander in the valleys contains tulip poplar, sweet gum, and umbrella tree (a magnolia). Smaller trees and shrubs include red maple, Carolina allspice, and the fragrant spicebush. Among the wildflowers, most of which bloom in April and May, are jack-in-the-pulpit, several kinds of violets, and Asiatic dayflower. Near the streams is an abundance of lady fern, netted chain fern, royal fern, cinnamon fern, and New York fern, often growing beneath a layer of mountain laurel.

Dry woodland has a diversity of species but is dominated by loblolly pine, rock chestnut oak, and a shrubby layer of azaleas and New Jersey tea. Beginning in late spring and continuing through the summer and into autumn comes a steady procession of wildflowers, including bird’s-foot violet, fire pink, Indian pink, cinquefoil, blue-eyed grass, southern beardtongue, Carolina phlox, spotted wintergreen, and blazing star.

Pavement rock depressions that retain shallow water for all or most of the year contain two aquatic or semiaquatic plants, both confined to these granitic habitats in Georgia and surrounding areas. One is Ampelopsis pusillus, a dwarf member of the snapdragon family whose pinkish white flowers appear in mid-March. The other is a quillwort, or Isoetes, which reproduces through male and female spores and thus is considered more closely related to ferns than to flowering plants. These spores are formed by the thousands in the swollen pouch at the base of each of the leaves, which resemble blades of grass.

In depressions that do not sustain water year-round, the depth of the soil determines which flowering plants appear. If it is less than four inches, usually the only one is Diamorpha smallii, a tiny member of the same family as sedum (and named for the botanist John Kunkel Small, not for its size). Its fleshy leaves enable it to survive arid conditions. Where the soil is four to six inches deep, providing more nutrients and more room for roots, a few additional species appear: a delicate bent grass and a delicate sedge, both with threadlike leaves; sandwort, a tiny plant related to chickweed; rushfoil, whose leaves are covered with silvery scales; and a type of Saint John’s-wort called orange-grass, whose minute leaves give off an orange scent when crushed.

Depressions that contain six to ten inches of soil—in part because they dry out more slowly—support a still greater variety of flowering plants. Common examples are sunnybells, a yellow-flowered lily with grasslike leaves; Georgia rush, a dwarf species known only from granite depressions in Georgia; Confederate daisy, a yellow-headed daisy also found only on granite; and fame flower, a portulaca-like succulent with bright pink flowers that open during the afternoon for only about an hour.
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Location, Location, Location

Female bats in a maternity roost seek the ideal temperature zone.

Guided by the dim light of my headlamp, I wade out to the nearly invisible net stretched over the water. I have just caught the first bat of the night, and I carefully slip its silky wings free of the thin black filaments that snagged it in midflight. As I work, the tiny western pipistrelle, its body not much more than an inch and a half in length and its wingspan barely eight inches, clutches my finger tightly in its miniature rasplike teeth, more for support, it seems, than in defense. The thirsty young bat undoubtedly sensed the net, but the pool of water was too strong a magnet. The bat was caught in the act of drinking on the wing.

June is a busy time for bats, and in some regions, their abundance and diversity can be impressive. In just three evenings at the American Museum of Natural History’s Southwestern Research Station in Portal, Arizona, a small group (myself included) under the expert tutelage of Merlin Tuttle, Janet Tyburec, and Bob Benson, of Bat Conservation International, has intercepted, examined, and released more than 400 bats representing eighteen species. Two species—the lesser long-nosed bat and the Mexican long-tongued bat—are unique to the Southwest; as the columnar cacti and agaves come into bloom, the bats migrate northward along “nectar corridors.” Most of the others have moved a short distance from winter roosts to summer colonies. The shift from winter to summer quarters is typical all over the country, although it isn’t always from south to north (many bats fly southward from caves in Vermont and Tennessee in spring). But the move, at least for the females, serves a common purpose.

The birthing and successful nurturing of young pose some special challenges for bats. In seasonal climates, mammalian offspring must mature quickly enough to be able to endure their first winter, but for many bat species, this may involve accumulating enough food to support migration and to survive the winter entirely on fat reserves. So in species that live where summers are short, being born early is essential. Many bats also must overcome another problem: males and females do not rove from winter torpor and migrate to summer quarters at the same time. Their solution is to mate in the fall, before entering the winter roosting site, with fertilization delayed until spring.

Even with this head start, however, problems may arise. Bats choose relatively cool wintering sites, probably because lower temperatures favor slower, more efficient utilization of fat during dormancy. But both the gestation and the growth of juveniles can be significantly slowed by cold surroundings, since it is difficult for young bats and for females in late stages of pregnancy to effectively regulate their body temperatures. So in spring, females must either seek out warm roosts or elevate roost temperatures themselves. They accomplish the latter by using to advantage a behavioral trait—their willingness to congregate, sometimes in huge numbers, in places where their massed bodies can significantly increase the surrounding temperature.
Three thousand bats clustered in a roof chamber within a cave can easily raise the roost temperature 15°F. (See "Batmom's Daily Nightmare," *Natural History,* October 1987, for an account of millions of Mexican free-tailed bats roosting together.) This warming may shorten gestation by several days, and it can accelerate growth rate during the steady. In forests, red bats cling to leaf clusters in broad-leaved trees, and Seminole bats to pines. Seminoles also roost in clumps of Spanish moss, as do eastern yellow bats. Other species utilize tree cavities or loose bark, where individuals in even small huddles profit from one another's warmth and the bark's absorption of sunlight. (Like bats in rock crevices, those roosting behind slabs of bark often move around as the day progresses, seeking the ideal temperature zone.) All these temperature-adjusting behaviors are crucial: studies of Indiana bats have shown that during cool summers, young bats reach the flying stage about two weeks behind schedule and may depart maternity colonies as much as three weeks late, leaving little time to accumulate fat before freezing temperatures drive them into torpor.

Successful rearing of young requires the balancing of many needs. In the insecure world of tree-roosting bats, roosting sites are frequently changed. Among these species, even lactating females have been reported to switch locations as often as every two weeks, although usually within a small range. This behavior may reduce infestation by parasites, lessen the risk of being found by a predator, or minimize the commuting distance to richer foraging areas. In many cases, though, the move may be dictated by the ephemeral nature of the roosts themselves, particularly those located under the loose bark of dead trees.

As I ease another bat from the net strings (this one a Mexican free-tailed), I press gently on her abdomen. I can feel the bones of a developing fetus, nearly full term and soon to enter the domain of its progenitors. I hold her a little longer than the others, then open my hand gently. She sits for a moment, then lifts silently off, spiraling sharply upward as if drawn, by some unknown force, into the night. The stakes are high, it seems to me, as these secretive mammals negotiate with the summer night for the success of, in most cases, a single offspring.

*Peter J. Marchand,* author of several books on natural history, is working hard watching clams for his next *Natural History* column.
That Sneaky Solstice

As the days start getting shorter, why isn’t the Sun setting earlier?

On what day does summer officially begin? The solstice. What day has the longest period of sunlight? The solstice. On what day does the earliest sunrise (or the latest sunset) occur? Not the solstice.

I remember wondering as a child why, just as summer finally—finally!—arrived, the days started getting shorter. Now I know: because life’s not fair. Yet however philosophically sound that answer seems, it turns out to be incomplete, at least from an astronomical point of view.

Like the seasons themselves, the solstice is a function of the tilt of Earth’s axis. Earth “rests” at 23°26’28” away from an upright position relative to its path around the Sun. Because of this orientation, the Northern Hemisphere tilts toward the Sun during half of Earth’s annual orbit, and the Southern Hemisphere tilts toward it during the other half. Twice each year, then, one hemisphere or the other is at maximum tilt away from the Sun. To an observer on Earth, the noonday Sun reaches its northernmost or southernmost position in the sky on those days and appears to pause briefly—hence the word “solstice,” from the Latin sol (sun) and sistere (standing still)—before beginning its next six-month cycle.

To be precise, the solstice takes place at the moment the Sun reaches a point on the celestial sphere (an imaginary sphere around Earth on which celestial bodies can be positioned in terms of latitude and longitude) that corresponds—not coincidentally—to the latitude 23°26’28” north or south of the equator, marked by the tropics of Cancer and Capricorn, respectively. This month the solstice occurs on June 21 at 1:48 Universal Time, which is June 20 at 9:48 p.m. Eastern Daylight Time. At latitude 40° north (near Philadelphia and Denver, for example, in the United States), daylight during this “longest day” will last fifteen hours and one minute.

Contrary to popular belief, however, for several days after the solstice (through June 27 at latitude...
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40° north), the Sun will continue setting later instead of earlier each evening. But the period of daylight will actually be getting shorter, because after June 14, the Sun will be rising later, too.

The reason these three events—earliest sunrise, latest sunset, and longest day—don’t coincide comes down to one simple fact: the twenty-four-hour day is a contrivance. What our “day” measures is merely the average of how long Earth takes to complete 1/365.24 of its annual 365.24-day orbit around the Sun. We commonly accept that a day equals the time between consecutive appearances of the midday Sun. But if you tracked the actual time between those appearances, you’d find that the day can run as much as fourteen minutes shorter or sixteen minutes longer than exactly twenty-four hours.

This fluctuation in time is due in part, again, to the tilt of Earth’s axis. If Earth’s position were upright relative to its path around the Sun, to an observer on Earth the Sun’s position wouldn’t budge from one noon to the next. But in fact, from day to day the earthbound observer does see the midday Sun at a different point along the same celestial longitude—up or down relative to the horizon. This slight change in orientation and configuration between the two bodies translates into a slight difference in the exact length of each day.

Further complicating the situation is the question of where you happen to be in relation to that ever-shifting point on a particular longitude—that is, your terrestrial latitude. In general, the farther north you are, the more closely the dates of the earliest sunrise and latest sunsets will converge around the time of the solstice, at the rate of about one day for every five degrees of latitude.

And finally, there’s the elliptical shape of Earth’s orbit, which means that the planet is closer to the Sun, and moving faster, along some of its stretches than along others. So at some times of the year, Earth’s “clock” is running either ahead of or behind the average twenty-four-hour day.

Put all this together, and you have what astronomers call the equation of time, which produces a similar effect around the winter solstice. (For a more technical explanation of the equation of time and some useful diagrams, go to www.bc.cc.ca.us/programs/sea/astronomy/nakedeye/nakedeyb.htm.)

The equation of time, alas, does nothing to make life fairer. But as is often the case with astronomy, it does somehow make life slightly more understandable, and that’s a start.

Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens (Penguin, 1999).

THE SKY IN JUNE

Mercury is in the evening sky during the first half of the month and should be evident soon after sunset, low in the west-northwest. Its greatest eastern elongation comes on June 9, when it lies 24° from the Sun. Look for it around June 4, when it appears as a zero magnitude “star” setting at about 10:15 P.M. local Daylight Time. Try to catch a glimpse of the sliver of Moon hovering about 5° below Mercury on the evening of June 3. By the next evening, the Moon moves well above and to the left of Mercury. After midmonth, this swift-moving planet fades rapidly as it swings back toward the Sun, and it is soon lost in the bright evening twilight.

Venus is too near the Sun to be visible this month. Superior conjunction occurs on June 11, when (from our viewpoint) the planet seems to pass behind the Sun.

Mars, like Venus, is too close to the Sun to be visible in June as it heads toward solar conjunction on July 1.

Jupiter and Saturn appear momentarily amid the stars of Taurus and slowly emerge from the bright morning twilight. The two giant planets had their long-awaited “Great Conjunction”—the first of its kind since 1981—on May 31. They spend the rest of 2000 slowly moving away from each other. On June 1 they are separated by 1.2°, by June 13 they are 2° apart, and by the 24th, 3° apart. If you have a clear and unobstructed east-northeast horizon, you should catch sight of these two morning planets at the start of the month, both rising at about 4:30 A.M. With each successive morning, the pair rises a little earlier and a little higher. By the last week of June, they are easily visible as they ascend in a dark sky by 3:30 A.M. Jupiter is the brighter of the two, and Saturn shines with a slightly yellowish hue. The waning crescent Moon slides past these two planets on the mornings of June 28 and 29.

The summer solstice occurs on June 21 at 9:48 P.M. The Sun reaches the point where it appears farthest north of the equator, so in the Northern Hemisphere the days are the longest of the year and the nights are the shortest (it’s the other way around for the Southern Hemisphere).

The Moon is at new phase on June 2 at 8:14 A.M. and at first quarter on June 8 at 11:29 P.M. Full Moon occurs on June 16 at 6:27 P.M., and last quarter on June 24 at 9:00 P.M.

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Eight If by Land, None

Leg deployment is crucial to a crab’s success as it moves in and out of the water.

People who build robots envy the performance of animals—the flawless landing of a bird on a branch, the agility of a mountain goat stepping lightly along a cliff ledge. Some engineers are particularly interested in building robots that can walk both underwater and on dry land. The robot they envision will be able to jump out of a marine transport ship, for example, and defuse mines hidden in the surf. The crab is the creature these engineers hold dear.

To get a feeling for the crab’s accomplishments, try walking across a beach and into the ocean. At first, you stride along smoothly. It’s so easy you could do it for hours. But when you enter the ocean, you slow down. Water pushes against your ankles and then, as you move into deeper water, against your shins and thighs and, finally, your whole body. Soon the slowest shuffle becomes exhausting. Running in water is no easier. When you push off from the bottom, you mostly bob up and down, barely moving forward. Next time you go swimming at the shore, after you haul your exhausted body back onto the beach and lie back to catch your breath, watch the crabs as they skitter across the sand and slide into the water without slowing down one whit.

Marlene Martinez, a zoologist at Pacific University in Oregon, has been trying to figure out how the crabs do it. Part of her work involves filming Hawaiian intertidal rock crabs (Grapsus tenuicrustatus) as they walk on land and in water. She also places crab models (actually epoxy-filled crab shells) in different positions in a water flume and measures the hydrodynamic forces acting on them.

On land, crabs walk much the way humans do—or cockroaches or salamanders or any other animal with legs. Walking makes the body act somewhat like an upside-down pendulum. You push off with one foot, and your body swings forward and up. Once you hit the peak of the arc, gravity starts to pull you back down again. That downward fall provides kinetic energy, which is used in the next step to move the body forward. Crabs follow the same pattern, although their gait, involving eight legs instead of two, is considerably more complicated.

Walking this way works well on land because air is too thin to exert much force against the oncoming body. But water is 800 times denser than air and thus more resistant to a body trying to move through or push down into it. The upward push of
buoyancy reduces the effect of gravity and, with it, the amount of kinetic energy available for the next step forward. In addition, flowing water can lift a body up in the same way air lifts a plane’s wings, making it harder to keep contact with the ground.

Martinez has found that the shape of Hawaiian rock crabs goes a long way toward making it easier for them to move in water. Their slender, horizontal bodies mean that less breadth is exposed to the oncoming water. Walking sideways further reduces this exposure and also cuts down on drag. The crab’s shape poses problems of its own, however: as a crab scuttles along, water pushes up under the leading edge of its shell, threatening to flip the animal over. In response, the crab spreads its legs and hunkers down, which helps to keep it from overturning. This position widens its stance by about 20 percent and is more stable, enabling the crab to walk 50 percent faster than it could if it tried to use a terrestrial stance underwater.

But crabs do more than just hunker down as they make their way through the water. On land they walk in a fixed pattern, alternating four legs in the air and four legs on the ground. In the ocean, that pattern breaks down. As Martinez saw in her movies, multiple legs might push off simultaneously, while at other times only one of the legs ever touched bottom. And sometimes none of the legs touched down at all while she was observing the animal. This behavior reminded Martinez of a punt, a flat-bottomed boat propelled by a pole that a boatman pushes against the riverbed; between pushes, he lets the boat glide. Thanks to buoyancy, the crab is unlikely to be immediately pulled back down by gravity after every step and thus doesn’t need to be so careful about always having a few legs in position to break the fall. Consequently, it doesn’t much matter which legs the crab pushes with, and, like the punt, the animal can glide between pushes.

Engineers who work on amphibious robots have tended to look at the ocean as an enemy their creations would have to fight against. But Martinez’s research shows that the water may be their ally. Rather than trying to hug the seafloor, crablike robots could punt along, relaxing and saving the precious energy in their batteries.

Science writer Carl Zimmer lives in New York. His first book, At the Water’s Edge, is now available in paperback.
The Jew and the Jew Stone

Ruminations on earlier views of fossils, medicines, and minorities

By Stephen Jay Gould

The human mind may love to contemplate exemplary universes of abstract grandeur and idealized perfection, but we can extract equal pleasure from a tiny embodiment of some great thought, or some defining event of a lifetime, in a humble but concrete object that we can hold in our hands and rotate before our eyes. We cherish such explicit reminders and call them mementos, souvenirs, or mementos—for their salience as markers of distinctive moments in our unique trajectory through the general adventure of human life.

For this reason, I have never been able to understand the outright purchase, from catalogs or store shelves, of distinctive items that (I would think) can only have meaning as mementos of our own experiences. I do, for example, cherish a few baseballs signed by personal heroes, but only because they intersected my life in a meaningful way—the pop foul off DiMaggio’s bat that my father caught in 1950, as I sat next to him, and that the great man signed and returned after I mailed him the relic along with a gushing fan letter; the ball signed by Hank Aaron and presented to me after a talk I gave at Atlanta’s Spelman College, as I, nearly speechless for once, stammered thanks to my hosts for the equivalent of an item inscribed by God himself. But what could a ball signed by a Ted Williams or a Pete Rose mean when ordered from a catalog by anyone willing to fork over a specified sum?

I take special delight in the particular category of things long known and admired in large abstraction but then seen for the first time in the form of a humble but concrete memento. I don’t refer to first views of the grand things themselves—the obvious and anticipated thrill of initial contact with the Taj Mahal or the Parthenon—but rather to the sublime surprise of finding my father’s card of honorable discharge from the navy after hearing his war stories for so many years, or seeing my grandfather’s name entered on a ship’s manifest for his arrival at Ellis Island in 1901.

As a scholar, most of my thrills in this category arise as unexpected encounters in actual print—in an old book read by real people—of the founding version of stories or concepts once learned in a classroom or textbook and stored as an important memory implanted by others but never validated by original sources. I get a special jolt when I first see (as my grandmother would have said) in schwartz—that is, “in black” ink or printed type—something that had long tickled my mind but had never stood right before my eyes in its overt and original form.

The tale of this essay begins with such an experience of transfer from vague abstraction to factual immediacy. I do not remember where I first heard the story—perhaps in a guest lecture by a distinguished visiting luminary or as a casual comment from a professor in an undergraduate class at Antioch College. I do not even know whether the tale represents a standard example, well known to all historians of early science, or an original insight from one teacher’s personal research. But I do remember the story itself and the striking epitome thus provided for the revolutionary character (at its codification in the seventeenth century) of the explanatory system now called science.

The story featured a memorable example to demonstrate how respected styles of former explanation became risible and “mystical” in the light of
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new views about causality and the nature of the material world. The essence of the difference between prescientific and scientific explanations, my unremembered source stated, could be epitomized in a popular prescientific remedy for the healing of wounds inflicted by swords or other weapons.

The formula called for boiling boar fat in red wine and adding crushed worms, the boar’s brain, sandalwood, dust from a corpse, and skull scrapings from a man who had been killed.

The prescribed salve must be applied to the wound itself, where, by modern understanding, the potion might well work as advertised, since early pharmacists and herbalists had, by experience, discovered many useful remedies, even if we now dismiss their theories about modes of action. But, the recipe for the remedy continued, the salve must also be applied to the weapon that inflicted the wound, for healing required a sympathetic treatment, a re-balancing, a putting right of both the injurer and the injured.

The nub of the revolutionary difference between prescientific and scientific explanation, my anonymous source continued, lies beautifully exposed in this microcosm, for the Western world’s transition to modernity may virtually be defined by the realization that although some material property of the salve may heal the wound by direct contact, the formerly sensible practice of treating the weapon in a similar way must now be scorned as utter nonsense and absurd mysticism.

This tale about treating the weapon as well as the wound has rattled around in my head for twenty years or more, with no documentation beyond a dimly remembered lecture. Then, a few months ago, I bought a copy of Johann Schröder’s Pharmacopoeia medico-chymica (the 1677 edition of a work first printed in Ulm in 1641), perhaps the most widely used handbook of remedies from the seventeenth century. And in this copy, published right in the midst of the ferment that generated modern science in the late seventeenth century, I found the formula for the salve that must be applied to weapons as well as wounds—in schwartz on page 303 and named Unguentum Sympatheticon Crollii, or Croll’s Sympathetic Ointment (we shall learn more about Mr. Croll a bit later).

The formula for this concoction may raise modern hairs and hackles. We must begin, Schröder tells us, with adip. vetri aprign. (the fat of an old boar) mixed with bear fat as well. Boil them both in red wine, pour the resulting mixture into cold water, and collect the fat that accumulates at the top. Then add a motley assortment of pulverized worms; the brain of a boar (presumably from the same creature that supplied the initial fat); some sandalwood; haematite (a rock containing iron); mumia, or the dust from a corpse; and to top it all off, usueae e crano hominis interempti (or scrapings from the skull of a man who has been killed).

Schröder then appends a series of notes about permitted variations, including a most welcome statement (to modern sensibilities): sunt qui omittunt usueae et mumiam (some people omit the cranial scrapings and corpse dust). But another note then warns us that the cranial scrapings, if included, must be gathered while the Moon waxes (that is, during its increase from a thin crescent to a full circle) and under a good astrological sign, preferably with Venus in conjunction (that is, within the reigning zodiacal constellation) but certainly not Mars or Saturn.

Under the next heading, Usus (use), Schröder first tells us that this ointment will cure all wounds, unless the nerves or arteries have been severed. The next line—ungatur telum, quo vulnus infictum (the weapon that inflicted the wound must be anointed)—then advances the argument that so impressed me as a succinct example of the dramatically different account of nature and causality that modern science would soon drive to intellectual extinction.

Schröder’s description ends with a set of instructions for treating the afflicted object with the ointment. We learn that “it” must be wrapped in linen and kept out of the wind, in a place neither too hot nor too cold, ne damnnum infenatur Patienti (so that no damage shall be inflicted upon the pa-

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to the anointed weapon: if the wound was inflicted by the point of a sword, then the ointment must be applied from the hilt downward toward the tip; if the weapon cannot be found, a stick of wood dipped in the victim's blood may suffice.

In a final paragraph, Schröder offers his only statement about why such a procedure might enjoy success. The cure occurs because the same balsamic (healing) spirit inheres in both the patient and the blood of his wound, and both must be fortified by the ointment. The weapon, I presume, must be treated because some of the patient's blood still remains (or perhaps merely because the weapon drew the patient's blood and must therefore be cleansed along with the patient himself in order to bring both parts of this drama back into harmony).

Oswald Croll (ca. 1560–1609), the inventor of this ointment, followed the theories of Paracelsus (1493–1541) in proposing external sources of disease, in opposition to the old Galenic theory of humors (see illustration on page 34). In this major debate of premodern medicine, externalists believed that outside forces or agents entered the human body to cause illness and that healing substances from the three worldly kingdoms (animal, vegetable, and mineral, but primarily vegetable, as plants provided most drugs and potions) could rid the body of these invaders. The humoral theory, on the other hand, viewed disease as an imbalance among the body's four basic principles: blood (the sanguine, or wet-hot, humor), phlegm (sluggish, or wet-cold), cholera (dry-hot), and melancholy (dry-cold). Treatment must therefore be directed not toward the expulsion of foreign elements but to the restoration of internal balance among the humors (blood-letting, for example, when the sanguine humor rose too high; sweating, purging, and vomiting as other devices for setting the humors back in order).

In Paracelsian medicine, treatment must be directed against the external agent of disease, rather than toward the restoration of internal harmony by raising or lowering the concentration of improperly balanced humors. How, then, could the proper agents of potential cure be recognized among plants, rocks, or animal parts that might neutralize or destroy the body's invaders? In his article on Paracelsus for the Dictionary of Scientific Biography, Walter Pagel summarizes this argument from an age before the rise of modern science:

Paracelsus . . . reversed this concept of disease as an upset of humoral balance, emphasizing [instead] the external cause of disease . . . He sought and found the causes of disease chiefly in the mineral world (notably in salts) and in the atmosphere, carrier of star-born "poisons." He considered each of these agents as a real ens, a substance in its own right (as opposed to humors, or temperaments, which he regarded as fictitious). He thus interpreted disease.
This doctrine of signatures summarizes the key difference between modern science and an older view of nature, shared by both the humor theorists and the Paracelsians despite their major disagreement about the nature of disease. Most scholars of the Renaissance and of earlier, medieval times viewed Earth and the cosmos as a young, static, and harmonious system created by God, essentially in its current form, just a few thousand years ago, and purposely imbued with pervasive signs of order and harmony among its apparently separate realms—all done to illustrate the glory and subtlety of God's omnipotence and to emphasize his special focus upon the human species, purposely created in his own image.

This essential balance and harmony achieved its most important expression in deep linkages (we would dismiss them today as, at best, loose analogies) between apparently disparate realms. At one level—thus setting the central principle of medicine under the doctrine of signatures—the microcosm of the human body must be linked to the macrocosm of the entire Earth. Each part of the human body must therefore be allied to a corresponding manifesta-

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tion of the same essential form in each of the macrocosmic realms: mineral, vegetable, and animal. Under this conception of nature, so strikingly different from our current views, the idea that a weakened human part might be treated or fortified by its signature from a macrocosmic realm cannot be dismissed as absurd (the orchid that looks like the male genitalia, and receives its name from this likeness, as a potential cure for impotence, for example). Oswald Croll, in particular, based his medical views on these linkages of the human microcosm to the earthly macrocosm, and Schröder’s Pharmacopoeia represents a last gasp for this expiring belief, published just as Newton’s generation began to establish our present, and clearly more accurate, view of nature.

At a second level, the central Earth (of this pre-Copernican cosmos) must also remain in harmony with the heavens above. Thus, each remedy on Earth must correspond to its proper configuration of planets as they move through the constellations of the zodiac. These astronomical considerations specified when healing plants and animals (and even rocks) should be collected and how they should be treated—hence, in Croll’s ointment for wounds and swords, the requirement that cranial scrapings be collected under a good constellation, with the loving Venus, but not the warlike Mars or Saturn, in conjunction.

As a memorable example of this approach to healing under the doctrine of signatures and stable harmony among the realms of nature, consider an illustration (see page 28) from the last major work of scholarship in this tradition, so soon to be extinguished by modern science: the Mundus subterraneus, published in 1664 by perhaps the most learned scholar of his generation, the Jesuit polymath Athanasius Kircher (who wrote an important ethnography of China, came closer than anyone else to deciphering the hieroglyphs of ancient Egypt, wrote major treatises on music and magnetism, and built, in Rome, one of the finest natural history collections ever assembled). In this figure, entitled (in Crollian fashion) “Sympathetic Types of the Microcosm With the Macrocosm,” lines radiate from each part of the human body to the names of plants (in the outer rim) that will cure the afflicted organs. To complete the analogies and harmonizations, the inner circle (resting on the man’s head and supporting his feet) presents astronomical signs for the zodiacal constellations, while the symmetrical triangles, radiating like wings from the man’s sides just below his arms, include similar signs for the planets.

We rightly reject this system today as a false theory based on an incorrect view about the nature of the material world. And we rightly embrace modern science as both a more accurate account and a more effective approach to such practical issues as healing the human body of weakening and disease. Viagra does work better than crushed orchids as a therapy for male impotence (though we should not doubt the power of the placebo effect in granting some, albeit indirect, oomph to the old remedy in some cases). And if I get badly cut when slicing a bagel with my kitchen knife, and the wound becomes infected, I much prefer an antibiotic to a salve made of boar fat and skull scrapings that must then be carefully applied both to the knife and to my injury.

Nonetheless, I question our usual dismissal of this older approach as absurd, mystical, or even prescientific (in any more than a purely chronological sense). Yes, anointing the wound as well as the weapon can only be labeled ridiculous mumbo-jumbo in light of later scientific knowledge. But how can we blame our forebears for not knowing what later generations would discover? We might as well despise ourselves because our grandchildren will, no doubt, understand the world in a different way.

We may surely brand Croll’s Sympathetic Ointment, and its application to the weapon as well as the wound, as ineffective, but Croll’s remedy cannot be called either mystical or stupid under the theory of nature that inspired its development—the doctrine of signatures and of harmony among the realms of nature. To unravel the archaeology of human knowledge, we must treat former systems of belief as valuable intellectual “fossils,” offering insight about the human past and providing precious access to a wider range of human theorizing only partly realized by modern views. If we dismiss such former systems as absurd because later discoveries superseded them, or as mystical in the light of causal systems revealed by these later discoveries, then we will never understand the antecedents of modern views with the same sympathy that Croll sought between weapon and wound and that Kircher proposed between human organs and healing plants.

In this light, for example, the conventional image of Paracelsus himself as the ultimate mystic who sought to transmute base metals into gold and to create homunculi from chemical potions must be reevaluated. I do not challenge the usual description of Paracelsus as, in the modern vernacular, “one weird dude”—a restless and driven man, subject to fits of rage and howling, to outrageous acts of defiance, and to drinking any local peasant
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under the table in late-night tavern sessions. But as a physician, Paracelsus won fame (and substantial success) for his cautious procedures, based on minimal treatment and tiny doses of potentially effective remedies (in happy contrast to the massive purging and bloodletting of Galenic doctors), and for a general approach to disease—as achieved by science, in our understanding of nature through time. We must also acknowledge that these ancient and superseded systems, however revealing and fascinating, did impede better resolutions (and practical cures of illness) by channeling thought and interpretation in unfruitful and incorrect directions.

To unravel the archaeology of human knowledge, we must treat former systems of belief as valuable intellectual “fossils” of human theorizing.

I therefore searched through Schröder's *Pharmacopoeia* to learn how he treated the objects of my own expertise—fossils of ancient organisms. The search for signatures to heal afflicted human parts yielded more potential remedies from the plant and animal kingdoms, but fossils, from the mineral realm, also played a significant role in the full list of medicines. Mineral remedies discussed by Schröder, and made of rocks in shapes and forms that suggested curative powers over human ailments, included, in terminology that prevailed
among students of fossils until the late eighteenth century, the following items in alphabetical order:

1. Actites, or pregnant stones, found in eagles' nests and useful in a suggestive manner: partum promovet (it aids [a woman in giving] birth).

2. Ceratites, or thunderstones, useful in stimulating the flow of milk or blood when rubbed on breasts or knees.

3. Glasspeta, or tongue stones, an antidote to the poisons of animal bites.

4. Haematites, or bloodstones, for staunching the flow of blood: refrigerat, exicat, adstringit, glutinat (it cools, it dries out, it contracts, and it coagulates).

5. Lapis lychnus, the lynx stone, or belemnite, helpful in breaking kidney stones and perhaps against nightmares and bewitchings. Many scholars viewed these smooth, cylindrical fossils as coagulated lynx urine, but Schröder dismisses this interpretation as an old fable, while supplying no clear alternative.

6. Ostiocola, or bone stones, shaped like human bones and useful in helping fractures to mend.

But among all stones that advertise their power of healing by resembling a human organ or the form of an affliction, Schröder seems most confident about the curative powers of the lapis judaicus, or jewel stone (named for its abundance near Palestine, not, in this case, for its shape or form). The figure on page 30, included in the most beautiful set of fossil engravings from the early years of palaeontology (commissioned by Michele Mercati, curator of the Vatican collections in the mid-sixteenth century, but not published until 1717), mixes true jewel stones (bottom two rows and center figure in top row) with conoid stem plates (top row, each separately labeled entroclus, or wheel stone—for these stem plates, of flat and circular form, even bear a central hole for the passage of an imaginary axle).

In Schröder's world, jewel stones provide the mineralogical remedy par excellence for one of the most feared and painful of human ailments: kidney

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stones and other hard growths in body organs and vessels. Schröder tells us that jew stones may be male or female, for sexual distinctions must pervade all kingdoms to validate the full analogy of human microcosm to earthly macrocosm. The smaller, female jew stones should be used *ad vesicas lapidem* (for bladder stones), while the large, male versions can be employed *ad renum lapidem expellendum* (for the expulsion of stones from the kidneys). The doctrine of signatures suggested at least two reasons for ingesting powdered jew stones to fight kidney stones: first, their overall form resembled the human affliction, and powdering one might help to disaggregate the other; second, the precise system of parallel grooves covering the surface of jew stones might encourage a directed and outward flow (from the body) for the disaggregated particles of kidney stones.

With proper respect for the internal coherence of such strikingly different theories about the natural world, we can gain valuable insight into modes and ranges of human thought. But our fascination for the peculiarity of such differences should not lead us into the fashionable relativism of “I’m OK, you’re (or, in this case, you were) OK,” so what’s the difference, as long as our disparate views each express an interesting concept of reality and also do no harm? A real world, regulated by genuine causes, exists “out there” in nature, independent of our perceptions (even though we can only access this external reality through our senses and mental operations). And the system of modern science that replaced the doctrine of signatures—despite its frequent and continuing errors and arrogances (which all institutions operated by human beings must experience in spades)—has provided an increasingly more accurate account of this surrounding complexity. Factual truth and causal understanding also correlate, in general, with effectiveness—and incorrect theories do promote harm by their impotence. Snake venom cannot be neutralized by powdering and ingesting stones that look like serpent’s tongues (the *glossopetra* of the preceding list), for the doctrine of signatures holds no validity and these fossils are shark’s teeth, in any case. But so long as we favor an impotent remedy dictated by a false theory, we will not find truly effective cures.

Schröder’s quaintly incorrect seventeenth-century accounts of fossils do not only reflect a simple ignorance of facts learned later. Better understanding may also be impeded by false theo-
tinction, to the larger category of "things in rocks that look like objects of other realms." Some of these "things" are organisms—glossopetra as shark's teeth; lapis lycis as internal shells of an extinct group of cephalopods, the belemnites; ostiocolla as true vertebrate bones; and jew stones as the spines of sea urchins. But other "things" placed by Schröder in the same general category are not organisms—actites as geodes (spherical stones composed of concentric layers and formed morganically); ceraria as axes and arrowheads fabricated by ancient humans (whose former existence could not be conceived on Schröder's Earth, created just a few thousand years ago); and haematites as red-hued rocks made of iron compounds.

Second, how could the status of fossils as remains of ancient organisms even be imagined under a theory that attributed their existence to a necessarily created correspondence with similar shapes in the microcosm of the human body? If actites aid human births because they look like eggs within eggs; if ceraria promote the flow of milk because they fell from the sky; if glossopetra cure snake bites because they resemble the tongues of serpents; if haematites, as red rocks, stanch the flow of blood; if ostiocolla mend fractures because they look like bones; and if jew stones expel kidney stones because they resemble the human affliction but also contain channels to sweep such objects out of our bodies—then how can we ever distinguish the true fossils among these putative remedies when we conceptualize the entire motley set only as a coherent category of mineral analogues to human parts?

I thus feel caught in the ambivalence of appreciating both the fascinating weirdness and the conceptual coherence of such ancient systems of human thought, while also recognizing that these fundamentally incorrect views stymied a truer and more humanly effective understanding of the

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natural world. So I ruminated on this ambivalence as I read Schröder's opening dedicatory pages addressed to the citizens of Frankfurt am Main—and the eyes of this virtually unshockable street kid from New York unexpectedly fell upon something in *shvartz* that, while known perfectly well to me as an abstraction, stunned me as an explicit printed statement and helped me focus (if not completely resolve) my ambivalence.

The improvement of knowledge cannot guarantee a corresponding growth of moral understanding and compassion.

Schröder's preface begins as a charming and benign, if self-serving, defense of medicine and doctors, firmly rooted within his controlling doctrine of signatures and the correspondence between the human microcosm and the surrounding macrocosm. God of the Trinity, Schröder asserts, embodies the three principles of creation, stability, and restitution. The human analogues of this Trinity must be understood as generation (to replenish our populations), good government (to ensure stability), and restoration (when these systems become weak, diseased, or invaded). The world, and the City of Frankfurt am Main, needs good doctors to assure the last two functions, for medicine keeps us going and cures us when we falter.

So far, so good. I am a realist, and I can certainly smile at the old human foible of justifying personal existence (and profit) by carving out a place within the higher and general order of things. But Schröder then launches a diatribe against the "diabolical forces" that undermine stability and induce degeneration—the two general ills that good physicians fight. Still OK by me, until I read, in *shvartz*, Schröder's description of the most potent earthly devil of all: *Choraeam in hiis ducent jubaei* ("the Jews lead this dance [of devils"]). Two particularly ugly lines then follow. We first learn of the dastardly deeds done by Jews to the Gojim—for Schröder even knows the Hebrew word for gentiles, goyim (the plural of goy, "nation"—the Latin alphabet contains no y and uses f instead).

Schröder writes: *His enim regulis suis occultis permittus novit Gojim, id est, Christianos, impune et cita homicidii notam, adeoque cita conscientiam interminem—"for by his secret rules, he is granted permission to kill the goyim, that is, the Christians, with impunity, without censure, and without pangs of conscience." But luckily for the good guys, Schröder tells us in his second statement, these evil Jews can be recognized by their innately depraved appearance—that is, by *notam malitiae a Natura ipse impressa* (marks of evil impressed by Nature herself). These identifying signs include an ugly appearance, garrulous speech, and a lying tongue.

Now I know both the depth and long pedigree of anti-Semitism in Europe. I also understand that such political and moral evil has been rationalized at each stage within the full panoply of changing views about the nature of reality, with each successive theory pushed, shoved, and distorted to validate this deep and preexisting prejudice. I also know—for who could fail to state this obvious point—that the most tragically effective slaughter ever propagated in the name of anti-Semitism, the Holocaust of recent memory, sought its cruel and phony "natural" rationale, not in an ancient doctrine of harmony between microcosm and macrocosm, but in a perverted misreading of modern theories about the evolution of human variation.
Nonetheless, my benign appreciation for the fascinating but false doctrine of signatures surely received a jolt when I read, unexpectedly and in shruntz, an ugly defense of anti-Semitism rooted (however absurdly) within this very conception of nature. More accurate theories can make us free, but the ironic flip side of this important claim has often allowed evil people to impose a greater weight of suffering upon the world by misusing the technological power that flows from scientific advances.

The improvement of knowledge cannot guarantee a corresponding growth of moral understanding and compassion, but we can never achieve a maximal spread of potential benevolence (either in curing disease or in teaching the factual reality of human brotherhood in biological equality) without nurturing such knowledge. Thus, the reinterpretation of jew stones as sea urchin spines (with no effect against human kidney stones) can be correlated with a growing understanding that Jews, and all human groups, share an overwhelmingly common human nature beneath any superficiality of different skin colors or cultural traditions. And yet this advancing human knowledge cannot be directed toward its great capacity for benevolent use—and may actually (and perversely) promote increasing harm in misapplication—if we do not straighten our moral compasses and beat all those swords (once anointed with Croll’s Sympathetic Ointment to assuage their destructive capacity) into plowshares, or whatever corresponding item of the new technology might best speed the gospel of peace and prosperity through better knowledge allied with wise application rooted in basic moral decency.

Stephen Jay Gould teaches biology, geology, and the history of science at Harvard University. He is also Frederick P. Rose Honorary Curator in Invertebrates at the American Museum of Natural History.
A Worm That Turned  Exemplars of biological control, *Cactoblastis* larvae have long lived up to their name by devouring unwanted prickly pear cacti. Lately the caterpillars are revealing a taste for rarer succulents.

By Peter Stiling

When the first ships carrying British convicts landed on the site that is now Sydney, Australia, in 1788, the human passengers were not the only newcomers on board. A type of prickly pear, *Opuntia monacantha*, also made the voyage. Collected in Rio de Janeiro, the cactus—or, more precisely, the cochineal insects that feed on it and yield a red-purple stain when crushed—were to be the basis of a dye industry. The dye enterprise never took off, but the prickly pear did.

In addition to *O. monacantha*, other imported cactus species (in particular, *O. stricta* and *O. inermis*) spread relentlessly on open land that ranchers were eager to use for raising other introduced species: cattle and sheep. In 1925, at the height of the problem, 94,000 square miles in Queensland and New South Wales were covered with *Opuntia*. Several years earlier, Australians had reacted to the situation by establishing the Commonwealth Prickly Pear Board. When the cacti were originally imported, care had been taken to ensure that no insects except cochineals accompanied the plants. The board’s first step was to send entomologists to the United States, Mexico, and Argentina to find other insects that naturally fed on *Opuntia* and that could be shipped to Australia and released in the hope that they could destroy the pest cacti. The Prickly Pear Board, in reuniting insects with their host plants, was using biological control. Biologists were already beginning to see the practice as a worthy form of pest control. In the late 1880s, for example, predaceous ladybird beetles imported from Australia had decimated the cottony-cushion scale insect that was consuming citrus crops in California.

About fifty insect species were sent to Australia, and some had limited success in reducing the thick stands of *Opuntia*. But the effect of all these insects put together was negligible compared with that of the South American moth *Cactoblastis cactorum*, imported in 1925. Shipped from Argentina, a cargo
of 2,750 eggs landed in Brisbane as half-grown larvae. These were the only Cactoblastis ever brought to Australia, but they were enough. The arrivals were used as breeding stock, and by March 1927 more than 10 million eggs had been placed on cactus plants in the field.

The female Cactoblastis moth lays eggs in a chain, or egg stick, that usually dangles from the tip of a cactus spine. Egg sticks contain fifty to eighty eggs, and each female lays three or four of them in its adult life span of about nine days. The gregarious larvae bore into a cactus pad, feed on the inner flesh, and then move on to a new pad after the destruction of the old. The larvae from an average egg stick need about four pads of Opuntia stricta to sustain them. Under favorable conditions, as many as three generations of Cactoblastis may mature each year. By 1930, thanks to the voracious larvae, vast tracts of eastern Australia had been cleared of dense prickly pear.

Australia’s experience with Cactoblastis is probably the world’s most famous case of one introduced species being controlled by another. Biological control has continued to gain in popularity. Since the 1980s, it has been promoted as environmentally sound and a healthy alternative to chemical control, because unlike pesticides, the agents do not pollute soil or water. So, compared with the use of pesticides, does the technique present any serious problems? What prevents a biological agent brought into an environment for a specific purpose from going out of bounds? Most of these agents are carefully screened before introduction to ensure that they will feed only on the targeted pest species. Yet just as medicines can have side effects, biological controls have occasionally produced what are called nontarget effects. Recognition of this potential for unintended results is leading to a contentious debate between advocates of biological control and some conservationists.

My own interest in the debate stems from my experience with the very species that were paired so successfully in Australia. This story begins in 1957, when Cactoblastis was brought to the Caribbean island of Nevis, in the Lesser Antilles, to control Opuntia there. Whether biological-control users overstepped their mark in the Caribbean case is difficult to judge. This genus of cactus is native to the Caribbean and the United States, although Cactoblastis is not. But the plant covered land that was seen as potentially profitable. As in Australia, Cactoblastis did clear out the cactus, and the land was freed up for grazing. In the wake of that success, the moth was also introduced to other islands, such as Montserrat and Antigua.

The problem was that the moths began to disperse on their own. In 1989 William Starmer, a Syracuse University professor of biology studying cactus yeasts in Cuba, found Cactoblastis there by chance. Starmer alerted botanists at the Fairchild Tropical Garden in Florida to the possibility that the species would soon arrive in the Florida Keys, just ninety miles from Cuba. Sure enough, that same year, researchers on the lookout for the insect came upon larvae feeding on Opuntia in the lower Keys. The moth could have taken two possible routes to Florida. Records indicate that in the mid-1980s, infected pads of ornamental cacti from the Dominican Republic had been intercepted in the port of Miami. But the fact that Cactoblastis appeared first in the Keys, without apparent help, suggests natural dispersal. Most likely, the moths simply island-hopped from Cuba.

Once in Florida, the larvae began to devour the prickly pear, which is not considered a problem there, and then went on to attack other Opuntia species. Of greatest concern was the semaphore cactus, O. spinosissima. Only twelve individual plants of this species were known. Fortunately, these few

ABSTRACTS

BAT SIGNALS What is the sound of a flower or a riverbank? Don’t ask a Zen monk—ask a bat. Some of these “wing-fingered” mammals habitually use riverbanks as acoustic landmarks, while others find their favorite flowers by sensing the blossoms’ acoustic properties. Zoologist Ben Verboom, of the Institute for Forestry and Nature Research in the Netherlands, measured the duration of pond bats’ sound pulses as they flew along the midlines of canals. Bats emitted longer pulses where the water courses widened and shorter ones where they narrowed. The sounds lasted just long enough not to overlap with echoes returning from the edges of the canal, enabling the bats to map the banks. Dagmar and Otto von Helversen, of the Zoological Institute at Germany’s University of Erlangen, discovered that the blossoms of the tropical vine Macuna rotundifolia have evolved a small, concave acoustical “mirror” that reflects the bats’ high-pitched squeaks directly back to them. (Apparently the bats can distinguish their own reflected sounds from other echoes.) During the bats’ nocturnal searches for nectar, this feature provides an acoustic beacon to home in on. And in their quest for pollen, the bats inadvertently pollinate the plants. (“Acoustic Perception of Landscape Elements by the Pond Bat [Myotis dasycrurus],” Journal of the Zoological Society of London 248, 1999; “Acoustic Guide in Bat-Pollinated Flower,” Nature 398, 1999)

FEELING THOSE VIBES While most kinds of creatures hiss, warble, growl, or vocalize, a few (including a species of rodent and a frog) communicate by vibrating their bodies. At least fifteen species of social wasps shake their bodies rapidly when arriving at or while inside their nests, setting up vibrations that can be perceived by other wasps inside. Adult females of the paper wasp species Polistes fuscatus and P. metricus may drum their antennae, wag their ab-
domens, or oscillate the enlarged portion of their abdomens against the nest, producing short bursts of repeated, low-pitched sounds. These vibrations may signal wasp larvae to stop secreting their nutritious saliva, which is used by adults as food. In colonies guarded by a single “foundress,” or queen, for example, females often vibrate just before departing the nest, which they are leaving unattended. Almost immediately, the larvae cease producing saliva. The researchers believe that these larval secretions attract other insects and that the foundress’s signaling causes the larvae to stop the flow. The highly nutritious larval saliva might well also attract parasites and predatory ants to the unattended nest.

Another recent study reports “an apparent example of the use of plantborne vibratory signaling in a chameleon”—the first reported case of vibratory communication in any reptile (if one discounts the nervous tail-twitching of some snakes). Kenneth E. Barnett, of the New York State Department of Environmental Conservation, and two colleagues recorded signals from three adult, hand-reared veiled chameleons (Chamaeleo calyptratus). A researcher first noticed the signal while holding the animal in his hands; a buzzing sensation seemed to emanate from its body just in front of its forelimbs. “When the animal was held close to the ear, a faint, lower-frequency sound could be detected,” he said. Male chameleons buzzed when handled, or when a female was placed on the same branch. Other chameleon species have been reported to vibrate when handled or when exposed to a member of the opposite sex, and researchers believe the animals may communicate through vegetation-transmitted vibrations. (“Lateral Vi-

殖植物生长在由自然保育机构管理的地上。一位研究者，Derek Johnson, 证明了仙人掌的信号作用。他展示了仙人掌的信号作用是被选择的Cactoblastis寄生虫的宿主。因此，生物学家们不得不迅速建立起围栏保护仙人掌免受昆虫的侵害。但是，这种方法只是短期的解决方案。由于这些昆虫经常在仙人掌中繁殖，因此，当暴风雨即将来临时，仙人掌必须被移开，然后重新种回原地。这是因为暴风雨会破坏仙人掌，使其不能再次开花。

为了保护仙人掌，研究人员从仙人掌母株和后代中采摘仙人掌叶。1996年5月至1998年9月，我与学生们和自然保育机构的工作人员一起种植了276株仙人掌叶。我们发现，当这些仙人掌叶被放置在年轻仙人掌周围时，它们可以提供额外的保护；游荡的动物，可能是鹿，会撞倒并踩踏仙人掌。

我们的努力已经恢复了仙人掌的传播，但这种传播受到了无控制的蔓延的影响。我们发现，这种仙人掌的传播，特别是在尼维斯和由仙人掌的幼虫携带的新可见的口味方面，影响着Opuntia。许多人可能会对这种相对不明显的仙人掌的传播感到担忧，因为这种仙人掌带来的商业利益被Cactoblastis染色。在澳大利亚、尼维斯和其他全世界的仙人掌广泛蔓延。

仙人掌的来源是多刺的梨果。对其他人来说，仙人掌的不利影响在佛罗里达只是冰山一角。

自1989年抵达佛罗里达以来，这种仙人掌已经传播。1992年，它到达了坦帕湾地区的多米尼加共和国，并在1999年，Spread到格鲁吉亚。如果这种仙人掌可以生存，它将向北扩展，其传播范围将扩展到Opuntia丰富的沙漠，影响到西南部的美国州，仙人掌是必须的且非常受欢迎的特征。有什么是关于Opuntia在墨西哥的？有多少种Opuntia支持 cochineal的染料工业？
control and are in favor of looking for and then importing a South American parasitic wasp that preys on Cactoblastis larvae. Parasitic wasps inject their eggs into the bodies of caterpillars. After hatching, the wasp young devour the larvae from the inside out. But after being released in Florida, such a wasp could take off on its own nontarget trajectory, parasitizing not only Cactoblastis but also native species of Opuntia-feeding caterpillars.

Given the popularity of biological control as an alternative to pesticides and given the care taken to match natural enemies, just how common are nontarget effects? The discovery of Cactoblastis in Cuba was serendipitous, and only when botanists were put on alert was its presence in the Keys confirmed. Lately some university researchers have been looking for and uncovering other examples of nontarget effects. Svata Louda, of the University of Nebraska, discovered that a weevil introduced to control nonnative thistles on midwestern range land is also attacking native thistles. In South Dakota, an exotic ladybird beetle brought in to prey on aphids has had the unfortunate effect of lowering the abundance of native ladybird species. A crayfish and a mosquito fish imported into coastal regions near Los Angeles to cut down on mosquitoes also feed on a rare newt and may be responsible for local extinctions of this amphibian. In the Northeast, a single species of parasitic fly has caused declines in the populations of two native silk moth species. Researchers at the University of California, Irvine, claim that at least 50 of the 313 parasites released against pests in the United States attack other species as well. And these are just direct effects.

On San Salvador Island in the Bahamas, prickly pear cactus is a major food of rock iguanas. But because the plants are also under heavy attack by Cactoblastis, fears are growing that the iguana population will be severely, although indirectly, hurt by the activities of Cactoblastis larvae. In Montana, gall flies released to limit knotweed turn out to provide a food bonanza for white-footed mice. While the mice benefit from the nontarget effect, their proliferation has the potential to change the structure of the small-mammal community and can also produce a ripple effect if, for example, more mice lead to an increase in hantavirus and its transmission to humans.

Can biological controls themselves be better controlled? Diligent testing of possible nontarget effects prior to an organism’s release can help, as can more widespread recognition of the problem. In the United States, the Invasive Species Council, established in February 1999 and composed of representatives from federal agencies, has taken on the task of developing a management plan for invasive species—those that have entered new areas on their own, often driving down numbers of native plants and animals. Think of zebra mussels in the Great Lakes and Asian long-horned beetles in New York City. Perhaps some of the federal money allocated to the council could be used to study deliberately released exotic species, which do not fall under the invasive category.

At an October 1999 meeting in Montpellier, France, biological-control practitioners presented—and, for the first time in twenty years, openly discussed—the problem of nontarget effects. I am not advocating that we simply stop biological control. But we do need to weigh all forms of pest control against one another and against the cost of doing nothing, and we need to consider the value of rare species as well as the damage done by pests. "Water and words," says a Chinese proverb, "easy to pour, impossible to recover." Similarly, once these tiny organisms are slipped into the environment, we can never take them back.

Ecologist Peter Stiling is an associate professor of biology at the University of South Florida in Tampa.
William D. Hamilton Remembered

A revolutionary thinker, Hamilton gave biologists the tools for understanding sociality in all organisms.

By Richard D. Alexander

William D. Hamilton died of malaria in England on March 7 at the age of 63. Although he had pondered the evolutionary impact of diseases for much of his professional life, he died because he had traveled to damp equatorial Africa unfortified by malaria-fighting drugs. Some may see this as indicating a paucity of common sense. Bill's forte was, indeed, not common sense but an astonishing fund of uncommon sense. Perhaps if he'd had much more common sense, he might not have provided the rest of us with the insights that have caused him to be described as the greatest evolutionary biologist of his generation.

Bill's extensive field meanderings, especially in the New World and Old World tropics, and his breadth of curiosity about natural history appear to have been—for him as for Darwin—a source of ideas richer than most of us can imagine. He ranged similarly across the literature of biology, seeing it, too, as a flood of significant anecdotes. Except for his own amazing internal logic and the "maths" with which he backed it up, he relied on others to test his theories and was delighted when any such effort succeeded.

Bill's originality of mind often turned the barely articulated ideas of distinguished predecessors—ideas overlooked or neglected by all the rest of us—into magnificent theoretical edifices affecting our view of all life. He expanded Charles Darwin's explanation of the existence of sterile castes in insects and combined it with Ronald Fisher's hint about quantifying altruism in caterpillars toward siblings, creating a comprehensive theory accounting for underlying patterns of sociality in all organisms. Similarly, Hamilton converted a maddeningly cryptic question about territory and sex ratios (the proportions of males and females in populations), posed by Fisher in 1930, into a broadly enlightening explanation of why the females of thousands of insect species have so many daughters and so few sons. Such females mate with a brother (who provides no parental care) and determine the sex of each egg as it is laid (a determination made possible because males derive from unfertilized eggs). Bill argued that for such females to make more or harder males than are sufficient merely to fertilize the eggs would be an unnecessary
Bill also contributed extensively to the development of many other theories, such as George Williams’s now widely accepted pleiotropic theory of senescence (the idea that because selection is less powerful later in life, incidental deleterious effects late in life can persist if they are accidental consequences of reproductively beneficial effects of the same genes early in life); the so-called Red Queen hypothesis, including the idea that the costly process of sexual (as opposed to asexual) reproduction pays for itself by enabling organisms to outtrace rapidly multiplying pathogens and parasites; and Robert Trivers’s theory of reciprocal altruism among even unrelated individuals. One of my favorite Hamilton essays is “Geometry for the Selfish Herd,” in which he explains how even the seemingly random strollings and mergings of individuals, as in a foraging bird flock or mammal herd, are almost certainly strategies that involve continual trade-offs between such alternatives as obtaining the best food and placing other individuals between the strategist and possible predators.

I once heard Bill assert that he avoided applying his theories to humans because he thought such extrapolation was too difficult and too subject to misinterpretation (a reluctance he later overcame). Yet only his theory of nepotism accounts for the universal human ability to respond to differing degrees of relatedness among relatives and for the varied patterning of human kinship systems in hundreds of societies in different situations worldwide. Extensive differential nepotism (meaning assistance to a wide variety of relatives, meted out so as to take into account the degree of genetic relatedness to oneself) is the crowning glory of Hamilton’s theory, yet it is still known only in humans.

It is curious that Bill, who received an unprecedented array of international honors, was never made a foreign associate of the U.S. National Academy of Sciences and that one still hears even some prominent biologists dismissing his work. I see this starting attitude—which all evolutionary biologists are now and then required to endure—as a reflection of the difficulty that even thoughtful and educated people often have in fairly evaluating findings in the field of evolutionary history that purport to account for day-to-day human behavior. Bill Hamilton, as much as or more
than any other twentieth-century biologist, provided the basic tools for understanding and modifying such resistance. It is now up to the rest of us to use and develop all such glimpses into the human condition to generate a self-understanding adequate to the task of significantly reducing human misery and strife across the globe.

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In His Own Words

Frans Roes, a journalist based in the Netherlands, had the following conversation with W. D. Hamilton in 1996.

FR: Some of your ideas about how natural selection might favor a form of altruism were foreshadowed in the 1930s by Ronald Fisher's writings on the distastefulness of some insects. In what way?

WDH: Fisher realized that if the insect is actually eaten by the predator in the course of the predator learning to avoid it, then whatever made that insect conspicuous to the predator is obviously disadvantageous to the individual being preyed on. So Fisher reasoned that the only way you could see that kind of selection getting started would be if the insects were gregarious, the group were siblings, and the predator, having tasted one and found it awful, were then to leave the rest of the group alone. The genes of the one eaten would then be indirectly promoted. Fisher also realized that this was not such a strong form of selection—not as strong as if it were the individual itself that had a form of protection. He made some remark about the selection going ahead at half the speed [since siblings share 50 percent of their genes], and that was one key early statement of the selection principle concerning the closeness of relatedness that I later came to develop.

FR: In part two of your 1964 article "The Genetical Evolution of Social Behaviour," you describe postreproductive behavior in two kinds of moths. What was the general phenomenon being illustrated?

WDH: I noticed that someone had written about the postreproductive life spans of two kinds of moths. The author had noticed that the cryptic [well-camouflaged] insect tends to die very soon after it has laid its eggs, whereas the warningly colored ones [such as the distasteful monarch butterfly] often have a long life after they have laid their eggs. Again, this could be interpreted in terms of the kinship principle in a rather neat way. In the case of the cryptic one, if there are any relatives around in the neighborhood at all, it is advantageous for the moth to give up its life as soon as it has finished its own main business, laying its eggs. Because if it is around and the predator detects the moth and eats it, then that is a step in the predator's learning to detect other moths, perhaps including those that have not yet laid their eggs. So by causing itself to die soon after it has laid its eggs, it is actually doing a service to its cousins in the neighborhood. Quite the contrary holds for the warningly colored one. Once it has laid its eggs, it is in a position freely to use its warning colors to warn everyone it can. So it should continue to live and wait, and actually expose itself to being tasted by the predator, because that would be a step in teaching the predator to avoid its relatives.

FR: In moths, both sexes have wings, but in some other insects either the males or the females are wingless. Why?

WDH: Gene dispersal is a very crucial evolutionary phenomenon. For a female to sacrifice wings without having some other way of dispersal for her offspring would be a deadly mistake sooner or later. Where females have become wingless, there is some other way in which they or their offspring are dispersed to other localities. Most commonly they have a young stage, a larva, which is very mobile. Either it may climb onto other insects or onto a twig and from there be dispersed by wind. Often such larvae have long hairs that enable them to balloon on the wind very satisfactorily. In some species the wingless female is carried by the winged male—in his arms, almost literally. During this flight time he is mating with her, and finally he drops her off in a place suitable for egg laying. As for the males becoming wingless, if the male can inseminate a mobile female, then he doesn't have to worry about wings too much, because his genes can be carried off by the female. This often happens in cases where wingless males mate with their close relatives. So I think we can find some sort of rationale for many particular cases, but as far as I know, there is no very sweeping theory that explains why in some groups there is male winglessness and in others, female winglessness.

FR: You went to Brazil in 1975 to study the fig wasp. What did you discover?

WDH: Actually, I went to study life in rotting wood, but I ended up studying fig wasps instead. Each fig is a little world in itself. Some species of male fig wasps have no mouth and thus cannot eat; these are entirely fighting and mating machines—a very strange kind of animal with a very short life. In this incredible symbiotic pollination system, the males hatch out as adults from the fig's gallflowers, and the easiest—
Indeed the only—females to mate with are those hatching inside the same fig. Theory says that if the males mate with their sisters, and their sisters are capable of storing sperm, then you must expect the proportion of males to be cut down drastically. A mother should do much better if she produces a lot of females and just enough males to fertilize them. In that way she would get more descendants.

**FR:** Why do the male insects of some species engage in fights to the death, while in other species the males tend to bluff?

**WDH:** For fig wasps, there is not much point in bluffing inside the fig, because there is no time to “live and fight another day.” Everything is over in a few hours, and if you don’t fight now and try to win, then you won’t be given another chance.

I saw bluffing with the giant Chilean stag beetle. In all the tournaments I held between males, it turned out to be the second-largest one that was the overall victor. This suggests that those with the biggest “tongs” were not actually as strong as they seemed to be. And they live in a situation where I can imagine that bluffing would pay off. Stag beetles are quite long-lived, and there are many flowers on the trees they could visit where females are arriving, and so it might be worthwhile to pretend that you are stronger than you are, in the hope that a rival male will go away. Then the bluff would have paid off.

**FR:** You use a lot of mathematics in your work, and you write, “I had realized from experience that university people sometimes don’t react well to common sense, and in any case, most of them listen to it harder if you first intimidate them with equations.”

**WDH:** Equations seem to frighten a lot of people; if you come at them with a display of mathematical strength, then they often back off. With me, you might call it a kind of bluff. If you have a simple idea, state it simply and forget about the mathematics. But often I use mathematics because I need to straighten out my own ideas. I have a somewhat illogical brain, and unless I put it through the mill of mathematics, I cannot try to understand how genes work in evolutionary processes.

**FR:** A general question: Do living organisms behave as if they want to pass on their own genes, or do they behave as if each of their genes is trying to replicate itself, possibly at the expense of other genes of the same genome?

**WDH:** This is a very deep and difficult question. One’s impression is that there is a conflict between selfish genes, but largely it is being overridden by a kind of democracy that has arisen in the genome. [This will] suppress this intergene conflict, and the outcome is that the organism acts largely as a whole.

**FR:** You write that evolutionary ideas “turn out to have, or are perceived to have, the unfortunate property of being solvents of a vital societal glue.”

**WDH:** The glue that I am thinking of is various myths that tend to hold societies together. Religious people think that if people “believe” in evolution instead of, say, the gospels, they will no longer be able to celebrate simple honesty—or kindly and warm feelings toward others—as unequivocally “good.” I think they exaggerate the danger, but they don’t exaggerate a nothing. There is a danger of that kind.

**FR:** How are evolutionists trying to deal with this problem?

**WDH:** If you believe that we evolved out of animals—are animals—and have the same kinds of drives, it does not mean that we have to be selfish and inhumane. When you fully work out the consequences of the rules of kinship and of reciprocation, you will see that the outcome is in fact quite a moderate kind of behavior. That it avoids evil and is as good in holding the society together as are the religious myths. Indeed, under a rational theory, we should be able to do better for human happiness by avoiding various naive errors.
Petrified wood/Triassic/Chinle formation/Arizona

This fossil was part of a tree more than 200 million years ago. A solution of silica (the oxide of silicon) seeped into the fallen log and permeated its cells, crystallizing into quartz and eventually producing petrified wood. In this specimen, limonite (an iron oxide) contributes to the bright central arc, while fine spherules of hematite (another iron oxide) suffuse the quartz with a purplish hue. Hematite also yields the red bordering the yellow.
When minerals seep into fossils, nature is transformed into art.

INNER BEAUTY

Tree-fern stem/Jurassic/Lune River, Tasmania, Australia
In a partial cross section of a tree fern that lived about 200 million years ago, blue chalcedony (a type of quartz) and orange iron oxides and hydroxides have replaced the original structures. The area at the top was once bundles of wood cells, the circles at the bottom were leaf bases, and the tiny rounded shapes were roots.

Stromatolite/Precambrian/Bristol, England
Cyanobacteria formed mats in shallow seas billions of years ago. Their blue-green pigmentation made photosynthesis possible, thereby adding significant quantities of oxygen to Earth’s early atmosphere. In this 2.5-billion-year-old specimen, sand was entrapped in the folds of the mats when they were buried by carbonate sediments.

Photographs by Giraud Foster and Norman Barker
ChanceUoria, a small invertebrate that lived on the seafloor 500 million years ago, captured prey by using its supple body as a net. Brown, many-armed iron oxide stars embedded in an azure matrix of slate were once the creature’s cells.

Pentoxylon, Jurassic, Miles, Australia
A tree with long leaves on short stalks, Pentoxylon was unlike any tree known today. Its fossilized pollen resembles that of ginkgoes and cycads. Columns of vascular tissue are visible here in a cross section of trunk. The colors of the chert (the variety of quartz that has replaced the wood) are imparted primarily by iron oxides.
Ammonites—mobile marine predators with spiral shells resembling those of the modern nautilus—thrived for millions of years before disappearing, along with the large dinosaurs, 65 million years ago. The evenly spaced layers of shell at the molecular level diffract light to produce this fossil's iridescence.
Gomphotheriid tooth/Oligocene/Montana
Early relatives of modern elephants, with shorter trunks and elongated jaws bearing shovel-like incisors, gomphotheriids thrived about 30 million years ago, although some members of the group persisted until much later. This polished section of a tooth crown reveals figure-eight patterns of the blue mineral vivianite, a phosphate of iron.

Coral/Lower Pleistocene/Caloosahatchee formation/Florida
This piece of a coral colony's calcium carbonate skeleton, from a long-vanished lagoon near what is now Florida's Gulf Coast, has been preserved for about 1.5 million years. Corals like these have altered little since their origin in the Triassic, about 230 million years ago.
In the spongy interior of a dinosaur bone, the surfaces of the chambers between the bone spikules incorporated iron oxides after undergoing structural change. Later these chambers filled with blue-gray agate. Concentric circles mark the growth periods of the agate crystals.
The Crown of MONTECRISTI

Genuine Panama hats are crafted—as they always have been—in Ecuador. By Tom Miller

When I was growing up in Washington, D.C., in the 1950s, my dad wore a Panama hat—but just between Memorial Day and Labor Day and, even then, only with a seersucker suit. I always assumed the hat came from Panama and the suit from Sears. I was wrong on both counts. A store downtown supplied the suit. And the stylish straw hat? It was from Ecuador, a South American country that once shipped its exportable wares to the Isthmus of Panama. In the mid-1800s, the hats were picked up by gold seekers crossing the isthmus overland as they rushed to and from California. During the Spanish-American War, in 1898, the U.S. government bought some 50,000 of these hats for the troops from merchants in Panama. Add to that the hat’s popularity with the crews that constructed the Panama Canal in the early twentieth century—well, it’s a wonder that anyone at all knows them as Ecuador hats.

To understand how a Panama hat zigzags from an outpost just south of the equator to the gleaming window of a New York haberdashery is to understand how the world works. The trail begins in Cadeate, a coastal village in Ecuador’s Guayas province. Two enterprises sustain the 1,500 local residents. Most of the time the men wade into the water to collect shrimp larvae, which they sell to shrimp farms. But for five days in every lunar cycle, they harvest toquilla (Carchidovia palmata), the ten-foot-tall, palmlike wild plant from which the Panama hat is woven.

Arriving in Cadeate, I ask people at random if they know any of the straw cutters whose names I have been given. One of the men I ask, Jorge Vicuña, is on my list; he acts nonchalant, almost as if he’s been expecting me. He has been harvesting toquilla straw for most of his fifty years, traveling ten miles inland with other straw cutters to areas where the plant grows, including hillsides where each family has been assigned a lot.

The straw cutters schedule their monthly harvest for the five days after the moon reaches its waning quarter, when, Vicuña explains, the straw holds less moisture and thus is lighter, easier to cut, and more pliable to weave. Wielding machetes, they harvest the slender new four-foot-high stalks, each containing the tightly wrapped fingers of one growing frond. The village council imposes a daily quota of 1,200 stalks per family; the harvest is brought back by mule and truck. Vicuña shows me how he strips away the worthless outer sheath of each stalk and then splits and separates the inner fingers, leaving dozens of yard-long, ribbonlike strands attached to the leaf stem. He tosses the prepared stalk into a vat of boiling water for about an hour and hangs it on a clothesline to dry.

After expenses, each family nets the equivalent of about $13 for the six huge sacks of stalks it fills monthly. In the 1940s the women of Cadeate wove hats from the harvested straw, but not any more. Instead the straw gets trucked east to Guayaquil, Ecuador’s largest and most industrialized city, and then to Cuenca, a town in the Andes that is at the center of hat production. Trucking the sacks this distance (some 230 miles by road) is no minor matter, especially now. Pounded by El Niño’s torrential rains for weeks at a time, the region has re-
recently suffered wasted highways, homes, and crops.

In Cuenca I meet Victoria Moreno, a no-nonsense businesswoman whose father and grandfather were both in the Panama hat industry. Every few weeks, a truck delivers sacks of straw to the courtyard of her home. She sells them to women from the town and from the surrounding countryside; they in turn sell to straw weavers or, more commonly, to straw vendors. It costs Moreno about $150 for a sack, and she sells it for $170. “The straw is expensive, mainly because of the transportation,” she says. “I extend credit to the reliable straw sellers. Everything here is by credit. They buy one sack every two weeks. The debt, it never ends.”

Sunday is market day for the straw sellers, weavers, and hat buyers in Biblían, a small town about thirty miles from Cuenca. One of the straw sellers, Victoria Gutiérrez, stands beneath a makeshift plastic cover that protects her from the persistent drizzle. She sells straw for about 8¢ a stalk, realizing a profit of 1¢ for each one. Weavers stop to buy enough for one or several hats, each of which requires about six stalks.

On another morning I locate the home of Isaura Calderón, a hat weaver who makes four small hats a week, along with baskets, place mats, caps, and other items that take less time to weave and that bring in a few additional pennies. Each hat requires roughly 40¢ worth of straw and is sold to a middleman for about 90¢. Like other weavers, Calderón uses a wooden mold shaped like the crown of a Panama to get the basic size and shape, but she leaves the product unfinished, with a somewhat unshaped body and with the straw ends protruding around the brim. The task of edging the hat by working the ends back into the woven brim is usually farmed out to specialists at a hat factory.
Many weavers in Biblián sell their unfinished Panamas to Adriano González, who comes from Cuenca every week. Soon after he takes up his position behind a worktable in his local residence one Sunday morning, the women begin to arrive. They watch and nod as he looks over their newly woven hat bodies, but they say nothing. It takes González just a moment to assess each hat’s size, quality of weave, uniformity of straw, and consistency of pattern. He has promised to pay up to $1.70 for each hat that meets his exacting demands. The first woman offers four hat bodies. Two of them are rejects, he tells her, worth only 60¢ each. One of the others, he says, is the right size but not the style he seeks. In all, the woman walks out with the equivalent of $4.20 for her week’s weavings.

“The hat industry has been seriously affected by El Niño and by the shantung,” González observes. Although usually marketed as a “Panama hat,” the shantung is a lower-priced imitation woven in China from twisted rice paper.

“I got 10,000 hats a weekend back in the 1980s. Now I’m often down to 1,500. In the old days we had forty weavers in Biblián turning out finos,” he continues, referring to the top-of-the-line category.

“Now we’re down to ten, and there’s no one to replace them. I still have a few weavers in Guapan who make finos. It takes them weeks, and I pay them $16 for each one.” By the end of the day, he has paid out just under $2,400 to the weavers of Biblián. He will sell their hats to the Cuenca factories at a 5 percent markup, giving him a week’s profit of about $120.

Just a couple of decades ago, Cuenca boasted dozens of hat exporters. Today the yellow pages list just eight, among them Kurt Dorfzaun, a Jew who as a teenager fled Nazi Germany for South Amer-
ica. He joined an uncle in the hat trade in Ecuador and has since maintained not only his Panama hat factory but a reputation for community service and integrity. “The people who used to sell us hats came on horseback and donkey,” he recalls, with only a trace of a German accent. “We had a place for their horses. Now they come in little Toyota pickups. We need a garage.”

Dorfzaun’s factory consists of a series of well-lighted, open rooms in which the hat bodies are inspected, disinfected, scrubbed, and washed. Some are rejected for blemishes or discoloration. The hats are beaten into shape, their protruding strands are trimmed off in stages, and they are bleached in dipping tanks. Employees in aprons bustle about with stacks of hats in their arms, sorting them by size and quality, giving them their final shape on steam presses, and preparing them for export.

Cuenca, in Azuay province, has dominated the Panama hat industry since the mid-nineteenth century, but the very best hats come from Montecristi, in the province of Manabi. Set against the side of a mountain and dominated by a large wood church, the town is the market center for master weavers who live in various remote villages. Few know the terrain better than Rosendo Delgado, who is in his late sixties and whose family has been in the business for generations. He scours the countryside for the types of hats that take months to weave and are sold in pricey shops in the States and Europe. These hats all fall into the fino category, which itself is broken down into quality grades such as the silky superfino and the rare extrafino. (In New York these items may fetch $400 to $2,000.)

El Niño has devastated Manabi more than any other province, preventing Delgado from reaching some of the more isolated pueblos. He takes the opportunity offered by my rented four-wheel-drive vehicle to show me Pile, a town seventy miles away that he hasn’t been able to visit in six months. After a bone-jarring four-hour drive along highways with bathtub-sized potholes, we limp into Pile. Parking is no problem, since we seem to have the only car in town. Delgado ambles over to a group of men and starts chatting as if he has just returned from a lunch break.

A couple of the men walk me a few minutes uphill and around a bend so that I can meet Arquimedes Delgado (no relation to Rosendo), who lives in a sturdy wood house with a cement floor. “Here we plant corn, yuca, and bananas and tend cattle,” Arquimedes tells me. “And weave hats. Always we weave hats. It takes three to four months to weave a fino. Rosendo will pay up to $80 for each one. He does this in stages, so we always make sure to have two hats going at once.”

Arquimedes holds out one stalk of toquilla. “It takes forty of these to make one fino,” he says, “Each stalk has about 200 strands after we split them.” He stops to make sure I understand. “Look.” Using his fingernail, he splits one ribbon of straw into five separate yard-long strands. Only selected strands are used for the finos.

As we talk, Arquimedes’s wife, Mari López, enters and quietly resumes her work on a partially completed hat that is sandwiched near the top of a waist-high stack of wooden hat molds. She bends over the stack to keep the hat in place. Monica, the couple’s energetic teenager, follows her in and steps up to her own tower of blocks and hat-in-progress. Monica began weaving when she was eight, boasts her father. “It takes the young ones fifteen years to learn how to weave a real fino,” he declares. “Our

As we walk, Arquimedes's wife, Mari López, enters and quietly resumes her work on a partially completed hat that is sandwiched near the top of a waist-high stack of wooden hat molds. She bends over the stack to keep the hat in place. Monica, the couple’s energetic teenager, follows her in and steps up to her own tower of blocks and hat-in-progress. Monica began weaving when she was eight, boasts her father. “It takes the young ones fifteen years to learn how to weave a real fino,” he declares. “Our
twelve-year-old son, Gabriel, also weaves. He can already turn out a respectable hat.”

I also visit sixty-four-year-old José Raúl Alarcón, a weaver recommended to me before I left the United States. “If you see Alarcón, look deep into his eyes,” advised Milton Johnson, owner of the Montecristi Custom Hat Works in Santa Fe, New

A hat finisher in Montecristi, right, pounds several Panamas with a wooden mallet, both to soften the straw and to work in powdered sulfur, a bleaching agent. Below: Ironing helps give a hat its final shape.
Mexico. "He's just about the last of his generation of master weavers," I ask the humble, clear-eyed man if he is aware of his international reputation. He nods, then shyly names the countries to which his hats have traveled and from which his determined fans have come to visit him. "I weave between seven in the morning and noon," he tells me. "The sweat builds up on the fingertips too much in the afternoon to weave. Sometimes I go out to the banana and coffee fields then."

Periodically one of the men in Pile takes a bus to Montecristi to deliver hats from the local weavers to Rosendo Delgado. In his hands, their finos and those from other Andean communities have their long hair clipped between rounds of soaking, washing, bleaching, pounding, and ironing. When they are ready for sale, Delgado's luxury Panamas are often bought directly by exclusive retailers abroad.

A number of importers furnish Panamas to stores in the United States and elsewhere. One U.S. importer is the World Hat Company, a Florida firm run by Roberto Dorfzaun, son of Cuenca exporter Kurt Dorfzaun. "Hat sales don't go by fashion as much as by what the public sees on television or films," the younger Dorfzaun says one morning in his showroom. "When people see Tiger Woods and almost everyone else wearing visors and caps at the U.S. Open, that affects the business," he observes. "We'll see a jump in orders when a sports or entertainment personality wears a Panama in public or in the movies."

Resistol, a well-known Texas hat company, was formerly one of the world's biggest importers of Panamas. "The quality of the Ecuadorian straws we'd see went down, and the prices went up," reports Bob Posey, Resistol's manager for product development. "They'd dry out to a brittle yellow. If you bleached them for uniform color or squeezed them, they sometimes cracked." Once, he tells me, the U.S. Customs Service put a hollow metal rod through a stack of Panamas as if taking the core from a tree. They were looking for cocaine-soaked imports and got a plug of straw instead. "That isn't the sort of treatment that encourages you to continue importing straw hats from South America." Resistol now buys less than 5 percent of its straws from Ecuador.

A proud industry is going through a painful metamorphosis. Between 1997 and 1998 alone, Ecuador's hat exports fell by more than 30 percent overall and by almost 40 percent to the United States. No one has yet figured out how to reverse
this trend. Still, a few advocates are trying to preserve this time-honored business. An analysis by the Guayaquil branch office of the Ecuadorean Foundation for Nature Conservation concludes that because the villagers keep going deeper into the deforested countryside to find mature, cuttable wild straw, the plant itself may eventually become endangered. The group hopes to plant new toquilla acreage and bring about a managed straw harvest. Others would like to legally restrict usage of the very name "Panama hat" so that it would apply only to genuine toquilla straw hats woven in Ecuador. This, they hope, would reduce competition from the makers of similar hats, such as the shantung.

Mark Baum and Orlando Palacios, who used to work at a high-end hat shop in New York City, have helped the people of Pile by building a medical clinic to replace one damaged by El Niño. "We thought we really should be giving something back to these people," explains Baum. Inspired by the new clinic in Pile, Brent Black, an importer in Hawaii, has underwritten a study of the town's medical needs, with an eye to providing monthly visits by a health-care team. And he is planning to give weavers new cam wood molds that are sized for the overseas market.

The story of this legendary hat has, I believe, a number of generations to go. Every month, on the waning quarter-moon, I think of the path this product travels from straw to sale, and if I'm wearing my Panama, I tip it toward the equator. □
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The fleshy pink "fingers" on the snout of the star-nosed mole point to this animal's unique evolutionary history.

One of the most intriguing stars in the universe is right here on Earth: the eleven pairs of pink fleshy appendages ringing the snout of the star-nosed mole. From its appearance and location, one would think this star might be a supersensitive olfactory organ, helping the nearly blind mole negotiate its subterranean environment, or an extra hand for grasping prey or manipulating objects. Some researchers have hypothesized that the star detects electric fields, thus acting as a kind of antenna. But in reality, the star is an extraordinary touch organ with more than 25,000 minute sensory receptors, called Eimer's organs, with which this hamster-sized mole feels its way around.

Under a microscope, the Eimer's organs appear in a honeycombed pattern of tiny epidermal "domes," each sensitive to the slightest touch. Although the star is less than half an inch across, its surface is supplied with more than 100,000 large nerve fibers. By comparison, the touch receptors in the human hand are equipped with only about 17,000 of these fibers. Imagine having six times the sensitivity of your entire hand concentrated in a single fingertip.

Together with Jon Kaas, also of Vanderbilt University, I have been investigating how the star-nosed mole (Condylura cristata) uses this exquisitely sensitive organ to explore its dark, damp world. (This North American species is unique in its preference for wetlands, where it digs tunnels and forages mostly in mud and water.) First the mole samples an area by touching the ground with all twenty-two appendages. Its brain processes this information in less than a twentieth of a second. If one of the appendages detects anything of potential interest (often an unfortunate earthworm or other invertebrate), the mole moves its nose slightly to bring the lowermost central pair into contact with the object. The Eimer's organs on this pair are particularly well supplied with nerves and can provide the animal with a higher-resolution "image," enabling the mole to know whether it has encountered something good to eat or should keep searching. For small prey, the entire process—from first touch by peripheral appendage to swift ingestion—takes just about a fifth of a second.

The star-nosed mole continuously scans its environment with its nose, much as we constantly
from the central appendages of the star than from each of the less important peripheral appendages. Handling information this way conserves neural tissue, because it concentrates most of the brain’s computing power on only a small part of the sensory world at any given moment. Some scanning time might be saved if large areas of the brain received high-resolution data from the entire star (or from your entire visual field), but to do this, the brain would have to be gigantic.

In addition to learning how this mole’s remarkable star works, we have been trying to determine how it evolved. For clues to the history of bony structures, one can turn to the fossil record, but there are no bones in the star and no fossilized mole noses. So we have turned to another, less direct place to look for evolutionary clues: embryonic development.

Most animal appendages (including antennae, wings, legs, fins, and arms) start out as simple extensions of the body wall—essentially as direct outgrowths of the embryonic tissue. Moreover, similar genes are expressed during the early development of appendages in animals as different as humans, fish, birds, and insects. This suggests that a basic “program” for appendage outgrowth evolved hundreds of millions of years ago and has been redeployed many times in the course of evolution.

But what about the star-nosed mole’s novel snout appendages? While we do not yet know the genes
The raised patches of Eimer's organs on the nose of an adult coast mole, left, resemble the swellings on the snout of a star-nosed mole embryo, right. This suggests that the star-nosed mole evolved from an ancestor whose snout looked like that of the coast mole.

involved, we have been able to document the mechanics of the star's development. As it turns out, the star's appendages develop unlike those in any other animal, suggesting that it had unique precursors and an entirely independent evolutionary history.

Working in collaboration with Kaas and Glenn Northcutt, of the University of California, San Diego, I examined star-nosed mole embryos at various stages of development. We quickly found that all but the very earliest embryos have a protostar (as well as huge embryonic forelimbs destined to become the digging arms of the adult mole), but that instead of forming as outgrowths of the embryonic nose, the star's twenty-two appendages first appear as slight, elongated swellings on the embryonic face. In later stages, when the swellings are more pronounced, it almost looks as if the star has been folded back against the side of the face. This impression is not quite accurate but does foreshadow events to come.

During most of the mole's embryonic development, nothing separates the swellings from the side of its face. But just before birth, a new layer of epidermis grows underneath the swellings. At this point, the appendages become separate cylinders, though they are still attached to the face by this new skin. Shortly after birth, the back end of each cylinder detaches from the face and swings forward, remaining attached only at its front end (a bit like peeling a banana). What was once the hindmost part of each cylinder thus becomes the forward-facing tip.

The developmental sequence of the star differs from the way other animal appendages are known to form. In his book *The Blind Watchmaker*, biologist Richard Dawkins gives examples of unusual developmental sequences in other animals, such as the sole, a bony flatfish that spends most of its life...
lying on one side and has both its eyes on the upward-facing side of its head. As a young sole develops, it essentially “pulls” one eye across its face, grotesquely distorting its skull and facial musculature. This awkward process makes sense only when we appreciate that flatfish were not designed carefully and then created, but rather evolved from upright fish that had symmetrical bodies. As Dawkins points out, the ancestors of flatfish must have begun their evolutionary journey by lying on their side on the ocean floor—a position that would have resulted in one eye facing the bottom. In each subsequent generation, the most successful offspring would have been those in which the eye shifted slightly closer to the other side of the face. Today we can read the course of this evolution in the development of a flatfish.

What clues does the unusual development of C. cristatus’s star provide about the evolution of this animal? Perhaps the ancestors of the star-nosed mole had strips of Eimer’s organs along the side of the face, and perhaps, in the course of evolutionary time, these strips slowly elevated and eventually “peeled” forward to form separate appendages. If so, the stages of this evolutionary sequence may have been conserved in the present sequence of embryonic development. While this explanation of the scenario seems reasonable, we can’t be certain of it without further evidence. Hoping that an analysis of living species could provide insights into the star-nosed mole’s past, we began to examine other moles from around the world.

Our studies showed that nearly all of the roughly thirty species of mole have some Eimer’s organs on the tip of the snout (usually 1,000 to 2,000, distributed evenly around the nostrils) but no indication of starlike appendages. Three species in the genus Scapanus from western North America, however, seemed to provide what we were searching for. The coast mole (S. orarius), for example, has—in addition to Eimer’s organs around its nostrils—small, raised modules of these sensory receptors surrounding the center of the nose. Moreover, the adult snout of the coast mole bears a strong resemblance to the early embryonic snout of the star-nosed mole, with “proto-appendages” pointing backward and adhering to the sides. This arrangement is just what we would predict for an ancestor of the star-nosed mole.

The coast mole, of course, is not ancestral to the star-nosed mole; in fact, the two are not even especially closely related. But the existence of the coast mole’s proto-appendages supports the proposition that the ancestors of the star-nosed mole had similar structures. Embryonic development in the coast mole stops at the proto-appendage stage but continues in the star-nosed mole, leading to the unfolding of separate appendages that form the marvel of sensitivity we see today.

The mole uses the 25,000 minute touch receptors on its exquisitely sensitive star to find its way around its subterranean world.

Left to right: At birth, all appendages are still attached to the nose. After a few days, the first of the upper appendages detach and swing forward. By the time the young mole is a week or two old, all the appendages have broken free and the star is ready to go to work.
RHYTHM AND BLOOMS

By Rosie Mestel ~ Illustrations by Rodica Prato

Cancer, heart disease, smoky bars, and hotel rooms stale with the stench of old ashtrays—there's nothing very good to be said about tobacco. But delve into the plant's murky past and you will find something precious: the miraculous Maryland Mammoth, a plant that amazed turn-of-the-century farmers because it kept growing and growing and growing, long after other types of tobacco had stopped churning out leaves and had begun producing pretty, trumpet-shaped flowers instead.

Maryland Mammoth was good for growers. Every ten-foot-high giant produced twice as many dryable, sellable, smokable leaves as the average plant could yield. It was to prove even better, though, for scientists who wanted to know how plants make flowers—more specifically, how they decide when to make them.

It's important for a plant, this flowering decision, since popping up one's delicate buds in the midst of a bleak, dark winter could be seriously detrimental to reproductive success. It's important for people, too, since every grain, fruit, vegetable, and ornamental plant has its own prerequisites for flowering, and only by understanding these prerequisites can farmers and breeders work with them, maybe alter them, so that humankind can grow crops when and where it wants. As for those of us who garden at home—well, flowering science lies behind everything from knowing why lettuce bolts after a cold snap to why, if you planted the right flowers in an ideally situated garden, you could count off the weeks like a clock simply by noting what is blooming when.

A cursory survey of the plant kingdom might discourage one from seeking clear, generalizable principles governing the whys and whens of flowering. All over the world, plants are doing different things for their own special reasons: flowering in springtime before their leaves unfurl so that their blossoms are showy for pollinating insects or are exposed to the wind that carries the pollen; flowering just in time to beat the frost; flowering when it's wet enough or dry enough or when other plants aren't hogging the birds or insects needed for pollination. Some of the strategies are extreme. The Brazilian jaboticaba tree waits for a drenching monsoon and then blooms like there's no tomorrow. The North American pink lady's slipper orchid flowers during the springtime flight of the queen bumblebee. Then there's bamboo, which grows without flowering for years (120 years in one remarkable species), and then suddenly whole acres decide it's time to flower. They then die en masse, leaving vast swaths of land bare and brown, and the giant panda wondering where its next meal is coming from. Clearly, if there is a grand unifying theory behind flowering, it can be summed up in one short phrase: find a strategy that works.

Despite all this variability, broad patterns behind flowering do exist—patterns that scientists can study in their own favorite, easy-to-breed-and-grow plant, with confidence that what they find out will be relevant to many other species. Maryland Mammoth, a mutant variety that appeared unexpectedly in a field of standard Narrowleaf tobacco back in 1906, was a perfect case in point.

The difference between Maryland Mammoth and other varieties of tobacco was that the former flowered so late in the year that frost often cut it down before seed had even set. This frustrated farmers, since it meant that the only way to get seed was to grow the plant in greenhouses. But it fascinated Harry Ardell Allard and Wightman Wells Garner, two scientists working in 1918 at a U.S. Department of Agriculture research farm in Arlington, Virginia (right where the Pentagon sits today). The duo set out to tackle the mystery.

They learned that while most commercial varieties of tobacco grow until they reach a certain size and age, Maryland Mammoth stops growing only...
if the days shorten to a certain critical length. Picture Garner and Allard hefting pots of Maryland Mammoth into light-tight little houses every afternoon at four, then hefting them back outdoors again at nine the following morning, to artificially give the plants long nights of seventeen hours and short days of just seven hours. The result was flowers. And seeds. In July. Meanwhile, out in the field, Maryland Mammoth was basking in fourteen-hour summer days and was a long way from flowering. Garner and Allard concluded that the plants were measuring day length and that sensing either light or dark was the way they were doing it.

With this knowledge, it was now easy enough to get Maryland Mammoth seed by growing the plant in winter in southern Florida, where the weather was mild and the days short. More important, it soon became clear that many, many plants, both wild and commercially bred, exhibit a similar photoperiod response—that is, they have day-length requirements for flowering, although the length varies with latitude and lifestyle. Take plants like chrysanthemums or asters or summer wheat. All flower when the days start getting shorter. Giving them time to enjoy the long sunny summer but still get their blooms out before the frost. Or think of the lilies that bloom in time for Easter, when the days are getting longer and winter has finally passed.

Decades of research are beginning to reveal how plants perform this trick. To sense the light, plants use molecules called photoreceptors. Some, known as phytochromes, were discovered four decades ago; they are most sensitive to wavelengths in the red portion of the electromagnetic spectrum. Other, very recently discovered photoreceptors called cryptochromes sense blue light. Yet other molecules, which sense ultraviolet light, are still lurking out there, waiting to be found.

Having sensed the light, plants need to be able to "count" and to leap into flower-making action when day (or night) length is just right. Here's where the science of circadian rhythms enters the picture. Circadian rhythms are regular rhythms of growth and activity, occurring roughly every twenty-four hours. They control everything from when animals sleep, wake, and are most alert, to when an insect emerges from its pupal case or a flower produces nectar.

All these organisms have biochemical clocks that enable them to perform a host of activities and cellular processes in a neat, timely fashion. With its clock, a plant can crank up production of its light-harvesting enzymes before dawn and make the most of every iota of daylight. It can time the opening and shutting of the pores in its leaves so that gases enter when they're needed and precious water is retained when they're not. Some plants shut their flowers at night to protect them from the cold and the pollen-damaging dew and open them up in the day so that insects and birds can visit and pollinate them. Others open theirs at night to greet bats and moths. So precise is this flower-opening stunt that a gardener could conceivably tell not only what week it is by when different species bloom but also what hour it is by noting when certain blooms open up.

Researchers have pinpointed many of the genes involved in circadian rhythms and have come up with an elegant model for just how proteins tick and tock and thus orchestrate an organism's daily functions. Circadian clocks, which have proved remarkably similar in nearly all the organisms studied (the one exception so far appears to be blue-green algae), are complicated and not yet fully understood. In fruit flies, the focus of most of the research, the story goes something like this: Two proteins, called period and timeless, build up slowly in a cell. When these become plentiful enough, they prevent the production of two other proteins—clock and cycle—without which, however, they themselves can no longer be made. So now period and timeless disappear from the cell. This allows clock and cycle to be produced again, which eventually brings period and timeless back into the picture. And on and on, in an approximately twenty-four-hour rhythm.

A circadian clock is essential for responding to daylight: destroy it and you're left with a befuddled plant that doesn't know when to flower. But even with a clock in good working order, a "Time to Flower!" signal must travel up from the leaves to the apex of the plant, which will continue churning out leaf after leaf until it gets instructions to do otherwise. Scientists know the signal must come from the leaves, because if you provide plant A with the appropriate flower-triggering day length, then cut off a leaf and graft it onto plant B—which has never experienced that day length—plant B

Plants need to be able to "count" and to leap into flower-making action when day (or night) length is just right.
will dutifully flower. Something in the foreign, transplanted leaf travels up the plant and trips some developmental switch.

The identity of that something is still a mystery, sixty years after it was given the name florigen. Which isn’t to say that scientists haven’t sleuthed away like crazy trying to find out. Yeast extract, acids, vitamins—you name it—they’ve all been spritzed onto plants at one time or another in the hope that a blossom would ensue. Frustratingly, no clear and simple picture has emerged from all these efforts. But some scientists today are leaning toward an idea known as the theory of multifactorial control. This means that a medley of substances—perhaps sundry plant hormones such as gibberellins and cytokinins, along with a burst of sucrose and calcium ions—travel up to the bud, triggering flowering only when all the substances are present and accounted for in just the right ratios.

The complexity of flower induction is also reflected in the number of genes involved in the process. In Arabidopsis thaliana (most of the genetic work on flowering has been done on this little mustard weed), there are now in excess of forty known flowering-time genes. When inactivated, some of these genes, such as those named hasty and speedy, result in mutants that flower too soon; others, such as gigantea, sca, and constant, produce mutants that flower too late. Many of these genes are involved in controlling the plant’s response to day length. But many others aren’t. When it comes to flowering, photoperiodism is by no means the only game in town.

Most plants, for instance, go through a juvenile phase, just as humans do. Reproduction during that phase is strictly verboten, and genes like hasty appear to be part of the brake. And many plants, such as sunflowers and most tobacco varieties, pay no attention to the length of day or night; they grow until they reach a certain size, and then boom! they bloom. The timing of that decision depends on the balance of a whole slew of genes, some of them pushing the plant toward reproduction, others cold-showering the inclination. Different balances of these pluses and minuses translate into different flowering times.

Then there’s temperature. With some plants, such as lettuce, a quick cold snap tells them winter is coming, and they’ll flower posthaste. But many others need a more protracted period of cold before they deign to put out blooms, which is why inhabitants of warm climes have to shave their tulips and daffodil bulbs into the fridge if they’re ever to get more than one springtime’s worth of color from them. It’s also why farmers who plant wheat and barley in the fall choose varieties that require this same chilly treatment, known as vernalization. This way they’ll be sure their crops will grow vegetatively through the winter and yield an abundant harvest in the spring.

The more scientists know about flowering, the more they can play with the process in the plant of their choice—and this makes for great agricultural potential. Treating lily bulbs with cytokinin hormones can mean early flowers and more of them. As for vernalization, growers would like to save money by chilling bulbs for the shortest time possible, yet they have to be sure they’ve successfully flipped the molecular flowering switch, or their bulbs will be no good. Diagnostic tests for successful vernalization, based on genes that turn on when this switch gets flipped, are under development.

Genetic engineering, too, can do remarkable things to flowering. Not everyone agrees it’s desirable to fool Mother Nature this way, but there’s no denying the potential significance of the results. Getting a plant to flower even slightly earlier or later than normal can extend the geographical range of a particularly favored variety, and fast flowering also means faster breeding. Experimenting with Arabidopsis, for example, molecular biologists have created early bloomers by inserting extra copies of various flowering genes into the plant. They’ve even engineered plants that will flower on command, in response to a gene that turns on when exposed to the right chemical trigger. Efforts are afoot to do similar things with economically valuable plants such as sunflowers, lettuce, and cereals.

One flowering gene, called leafy, has already been inserted into aspen trees, with spectacular results. Normally aspens wait ten to twenty years before they flower, which makes them less than popular for breeding. In the leafy aspen, flowers spring forth from inch-high seedlings after a mere three months. Tree breeding at last becomes a viable, do-it-in-your-own-lifetime proposition.

With all this going on, who knows what the plants of the future will be like?
Myth and Bone

What influence did spectacular fossil finds have on the legends of the early Greeks and Romans?

By Kate A. Robson Brown

Giants, monsters, gods, goddesses, and heroes populate the literature and visual imagery of the ancient world, and classical folklorist Adrienne Mayor, in *The First Fossil Hunters*, believes they represent Greco-Roman interpretations of the giant bones that have long abounded in the Mediterranean region. Huge, strange mammals of the Miocene and Pliocene epochs had migrated through the terrestrial corridor created there about 15 million years ago as the vast Sea of Tethys receded, and rich deposits of their remains were exposed through the ages as a result of colliding continental plates and violent seismic and volcanic activity.

Mayor's book presents and examines classical interpretations of these fossils. Among the ancients whose imaginations were fired by perplexing bones of great size was Plutarch, who relates that the remarkable finds from the Greek island of Samos were displayed as the remains of the war elephants that Dionysus employed in his mythological battle with the Amazons. Aристaeus, a seventh-century B.C. traveler to central Asia, spoke of gold-seeking nomads who fought creatures resembling "lions but with the beak and wings of an eagle." Apollonius of Tyana roamed the southern foothills of the Himalaya in the first century A.D., bringing back fantastic tales of gem-encrusted dragons dug out of the earth; Saint Augustine cited Virgil and Pliny in his defense of the reality of gigantic creatures from the remote past.

It is refreshing, in a book that relies heavily on literature, to see art and archaeology also being given a central role. We learn about an assemblage of massive bones and teeth on Capri that may explain why the emperor Augustus established the world's first palaeontological museum there. We also learn about a sixth-century B.C. vase decorated with a painted monster, quite clearly depicted as a massive white animal skull protruding from a rocky outcrop. Equally intriguing is the case of the Egyptian sites of Qau and Matmar, where, between 1300 and 1200 B.C., worshipers collected nearly three tons of black, river-polished fossil bones. In 1923 Sir Flinders Petrie found another cache of fossils at Qau, wrapped in linen and carefully stored in rock tombs. From the time Petrie shipped them back to England until last year, when archaeologist David Reese tracked these fossils down, they had languished in the textile division of Lancashire's Bolton Museum—still wrapped in linen and bearing Petrie's original labels.

Mayor poses the question whether the ancients developed a science of palaeontology. She challenges the widely accepted assertion, made by historian of science Martin J.S. Rudwick in *The Meaning of Fossils: Episodes in the History of Palaeontology* (1992), that natural historians in classical times did not have the knowledge to interpret fossils as organic remains of the past. She also takes issue with historian Colin Ronan's view that the ancients were hampered by a "static belief in fixity of species and the mistaken notion that they were all created at once.” Crediting French naturalist Georges Cuvier with a more realistic appraisal of classical explanations for the existence of these fossils, Mayor argues that the early Greeks and Romans were attuned to the unique paleogeology of their lands. Not only did they
recognize the organic nature of large fossil bones, they also tried to visualize the appearance and behavior of the original living creatures. Moreover, they collected, measured, compared, and displayed the giant bones—and even attempted to reconstruct whole skeletons from the remains.

In a brief final section, the author discusses "paleontological fictions" such as tritons, centaurs, and satyrs. She compares these ancient attempts to understand the fossil record with our own continuing quest for knowledge of the natural world, and she touches particularly on the social role of fabricated fossil evidence and on the vague boundary between "science" and "fiction" within modern popular culture.

Not afraid to court controversy, Mayor presents her case with an engaging zeal, describing her sleuthing efforts at length. The best of her examples are supported by evidence from a wide range of sources—literary, archaeological, and paleontological. In a chapter about the origins of the griffin in classical thought, she describes a large collection of bronze griffin statuettes excavated from a sanctuary on Samos. These muscled and beaked creatures, with their "empty eye sockets, leathery necks, and bumpy skulls," appeared so prehistoric that at first she leaped at the idea that they were fantastic versions of the mammalian fossils known from the island. But this route soon proved to be a blind alley. The fossils turn out to be large, giraffelike grazers very unlike the griffin; unexpectedly, the reader is directed afar, to the deserts of central Asia, for their possible origin.

Using a combination of writings by nineteenth-century classicists and information from twentieth-century paleontological excavations, Mayor makes a convincing case that ancient Greco-Roman writers had picked up on the tales of Saka-Scythian nomads from the gold-rich deserts of the western Gobi. The nomads' myths of gold-guarding griffins, it turns out, were based on Protoceratops skeletons exposed by shifting desert sands.

Other examples presented by Mayor are less convincing, however. Myths about giants and oversize human ancestors need not be linked to the finding of Pleistocene mammoth bones. Many cultures around the globe have colorful giant lore—Norse fables and Australian creation stories come to mind—without the benefit of rich fossil deposits. Similarly, the tale of Geryon, a monster-giant renowned for his herd of massive oxen and killed by Heracles in his tenth Labor, is explained with reference to the discovery in classical times of massive bovine fossils near what is now Uşak, Turkey. But the bones could also be those of the huge wild ox Bos primigenius. Although extinct today, it survived in central Europe well into the second millennium A.D. and would certainly have been known to some classical writers.

Nonetheless, Mayor has succeeded in opening a new window on the worldview of classical writers. "Just as a fossil is 'petrified time,' " she writes, "so is an ancient artifact or text. The tasks of paleontologists and classical historians and archaeologists are remarkably similar—to excavate, decipher, and bring to life the tantalizing remnants of a time we will never see." By the end of the book, you will find yourself filled with enthusiasm for following Mayor's lead in breaking down interdisciplinary boundaries and thus enriching your understanding of the human experience.

Kate A. Robson Broun is a professor of biological anthropology at the University of Bristol in England and a researcher in the development of hominid locomotion.

**The Sixth Extinction**

Recently I was talking to an acquaintance who brought up the subject of the "supposed" mass extinction now unfolding. I was disturbed when he brushed off the problem by saying that in any event, new plants and animals would evolve to replace the ones we might eliminate. Thinking about his response, I realized that I, too, had developed a somewhat fatalistic attitude toward the loss of species.

On the Internet, I found a site that has plenty of information on the extent of the crisis (www.well.com/user/davidu/extinction.html). David Ulansky, a professor at the California Institute of Integral Studies in San Francisco, has gathered together a number of reports, articles, and Web sites dealing with what many now call the sixth extinction.

Clicking on "Humans' Closest Relative in Danger of Extinction," I discovered that even the bonobo chimpanzee—the animal most like ourselves—is in greater peril than I had imagined. Browsing through this site is not a pleasant experience, but avoiding the issues raised by its contents is a worse choice. According to a Harris poll commissioned by the American Museum of Natural History in 1998, that is exactly what most people are doing. In another selected article ("Why Are We Not Astonished?") Ed Ayres, of the Worldwatch Institute, gives a number of reasons for our inability to confront the mounting losses. The foremost, he says, is the landslide of information (some prepackaged for public relations and some generated for its entertainment value) that buries real news.

Robert Anderson is a freelance writer living in Los Angeles.
A Gathering of Wonders: Behind the Scenes at the American Museum of Natural History, by Joseph Wallace (St. Martin's Press/The American Museum of Natural History, 2000; $23.95)
As the author remembers it, the Museum was “my oxygen, a doorway to green worlds that I otherwise could not have imagined.” Wallace presents a “nearly endless procession of brilliant, witty, often eccentric, and always interesting scientists and collectors,” including current curators and their research.

Travels With the Fossil Hunters, edited by Peter Whybrow (Cambridge University Press, 2000; $39.95)
Firsthand accounts by eleven paleontologists of expeditions as far afield as the Sahara and Antarctica describe not only their fossil-finding triumphs but the dangers and disasters that go hand in hand with the bone chase.

Journalist Shabecoff advocates bold new environmental initiatives to repair biosphere damage, and he concludes by quoting Henry David Thoreau: “If you have built castles in the air, your work need not be lost; that is where they should be. Now put the foundations under them.”

The Eighth Continent: Life, Death, and Discovery in the Lost World of Madagascar, by Peter Tyson (William Morrow/HarperCollins, 2000; $27.50)
Science writer Tyson gives us a feel for the breadth and complexity of the world’s fourth-largest island and tells us just why it is worth saving. Accompanying scientists in the field, he tracks lizards and lemurs, collects artifacts and fossils, and seeks clues to the origins of the Malagasy people.

The Variety of Life: The Meaning of Biodiversity, by Colin Tudge (Oxford University Press, 2000; $45)
In this illustrated inventory of creatures from protists to pangolins, zoologist Tudge provides an enjoyable swing through the thickets of systematic classification and its application to evolutionary theory, molecular genetics, and the history of biological thought.

The Apache Diaries: A Father-Son Journey, by Grenville Goodwin and Neil Goodwin (University of Nebraska Press, 2000; $29.95)
In this double diary, Neil Goodwin alternates excerpts from his father’s 1927–31 journal, kept while Grenville was conducting ethnographic studies on a relict band of “wild” Apaches, with his own intensely personal account as he retraces his father’s journey.

The Spark of Life: Darwin and the Primeval Soup, by Christopher Wills and Jeffrey Bada (Perseus Publishing, 2000; $27)
How did life arise on Earth? The authors look at various hotly debated ideas—from Martian meteors to hydrothermal vents—and conclude that the first genetic material was spawned on the surface of a sea, perhaps in the form of a protovirus.

A Fly for the Prosecution: How Insect Evidence Helps Solve Crimes, by M. Lee Goff (Harvard University Press, 2000; $22.95)
A forensic entomologist casts his dispassionate, analytic eye on scenes from which most people would recoil—human corpses in various stages of decay.

Wilderness and Razor Wire: A Naturalist’s Observations From Prison, by Ken Lamberton (Mercury House, 2000; $14.95)
Lamberton observes nature from within the “wilderness” of an Arizona prison. This, his first book, has been described by one reviewer as both “moving and troubling.”

The books in “Natural Selections” can usually be purchased at the Museum Shop, (212) 769-5150, or via the Museum’s Web site, www.amnh.org.
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Events

JUNE 1
Narrated by Robert Redford, *The Mystery of Chaco Canyon* presents new research on these prehistoric ruins in New Mexico, suggesting that the site was a ceremonial center laid out according to complex astronomical alignments. Producer Anna Sofaer introduces the film at 7:00 P.M.

Michael Shara, of the Department of Astrophysics, moderates a panel of scientists discussing new information on stellar collisions. A computer-generated demonstration of the evolution of galactic star clusters accompanies the 7:00 P.M. event. The program is part of the colloquium “Cosmic Catastrophes: Stellar Collisions, Mergers, and Their Consequences” (May 30–June 2). For more information, visit www.amnh.org/rose/stellar.

JUNE 3 AND 4
In conjunction with two Mongolia-related exhibitions at the Museum, the Department of Education presents feature and documentary films and videos celebrating Mongolian culture, beginning at 1:00 P.M. For a complete schedule, call (212) 769-5305.

JUNE 7
At 7:00 P.M., documentary filmmaker Jim Hubbard presents *The Turtle Hunter*, a portrait of a Southern woodsman whose livelihood depends in part on hunting 100-pound snapping turtles.

Drawing on his new book, *The Muse of History and the Science of Culture*, Robert Carneiro, curator in the Department of Anthropology, discusses the question whether there is a science of history. The event starts at 7:00 P.M.

JUNE 8
Biologist and ornithologist Michael Kreger gives the final talk, "Stand Vigilant: Whooping Cranes Return to Florida," in a series co-sponsored by Earthwatch Institute at 7:00 P.M.

JUNE 13
Mother-and-son team Pamela Windo and Simon Russell give a slide-illustrated talk at 7:00 P.M. about their decade of travel experiences while researching the guidebook *Fodor’s Escape to Morocco*.

JUNE 14
Madagascar is the subject of a 7:00 P.M. talk by Peter Tyson, science writer and online producer for the PBS series *NOVA*. Drawing on his new book, *The Eighth Continent: Life, Death, and Discovery in the Lost World of Madagascar*, he describes the endangered environment of the world’s fourth-largest island.

JUNE 15
At 7:00 P.M., geologist Jill S. Schneiderman, of Vassar College, discusses global warming, water pollution, and coastal erosion—issues addressed in a newly published collection of essays edited by her and entitled *The Earth Around Us: Maintaining a Livable Planet*.

JUNE 16
Author Bara Caseley Swain returns to the Museum with another performance, at 7:00 P.M., of “Amazing Graces: A Sticks and Stones Presentation,” an evening of colorful vignettes celebrating women today.

JUNE 20
As part of a national series of lectures to commemorate the centennial of the American Astronomical Society, Annela Sargent gives a talk at 7:30 P.M. entitled “From Dust to Us.” This special presentation, given on the summer solstice, is hosted by astrophysicist Neil de Grasse Tyson, the Frederick P. Rose Director of the Hayden Planetarium.

JUNE 22
At 7:00 P.M., neurologist and writer Oliver Sacks presents the U.S. premiere of the 1974 documentary *Awakenings*, a film about the first patients to use the drug L-DOPA.

DURING JUNE
The Arthur Ross Terrace, a plaza linking the Theodore Roosevelt Park to the new Frederick Phineas and Sandra Priest Rose Center for Earth and Space, opens this month.


For information about workshops for children and adults, as well as field trips ranging from walking tours of Times Square and Gramercy Park to boat cruises exploring the geology of Manhattan, call Central Reservations at (212) 769-5200 and ask for a program brochure.

In addition to *Epic Journey: Migrations* (a film that follows gray whales, zebras, Christmas Island red crabs, and monarch butterflies on their remarkable journeys), the Museum’s IMAX theater is also presenting *Dolphins*. Featuring a soundtrack by Sting, the movie follows mammalogist Kathleen Dudzinski and two colleagues as they research dolphins in the wild.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100. Visit the Museum’s Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are now also available online.
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Truncating a Trespasser

In Bako National Park on the island of Borneo, a little red leaf beetle of the subfamily Chrysomelinae has made the mistake of alighting on a tree where a colony of weaver ants has fashioned a nest. Any creature, even a small mammal, that intrudes on the colony's territory becomes a target for these aggressive predators.

To make the nest, individual ants grasp one another's bodies, forming a chain that pulls together the edges of stiff leaves, which other ants then bind with silk from larvae they are carrying with them. Weaver ants dominate canopies of tropical lowland forests from sub-Saharan Africa to Asia and Australia.

When an individual locates a potential meal, such as this beetle, it returns to the nest and notifies the others by releasing a chemical scent. Streaming out of the nest, the ants spread-eagle their prey and immobilize it. Each worker grabs a leg in its mandibles and pulls. Within minutes, the beetle will be dismembered and its remains transported back to the nest.—Richard Milner

Photograph by Mark W. Moffett
One essential event or presence can save a child, can flower in her and claim her for its own. The French novelist and humanist Albert Camus said, “A man’s work is nothing but this slow trek to rediscover, through the detours of art, those two or three great and simple images in whose presence his heart first opened.”

I was raised on a junkyard on the outskirts of a town called Baxley, the county seat of Appling, in rural south Georgia. For me, growing up among piles of scrap iron and glittering land mines of broken glass that scattered ivory scars across my body, among hordes of rubber tires that streaked my legs black, among pokeweed and locust, I attribute the opening of my heart to one clump of pitcher plants that still survives on the backside of my father’s junkyard. I know it now to be the hooded species, Sarracenia minor, that sends the red bonnets of its traps knee-high out of soggy ground. In spring it blooms loose, yellow, exotic tongues.

In fifth grade my 4-H project was carnivorous plants. The only information I could find was a short entry in the outdated set of Encyclopedia Americana we owned. On a poster I sketched the inards of a pitcher plant, showing how its upright, trumpet-shaped leaves are lined with downward-pointing hairs, how it lures insects through its lips with a sweet-smelling nectar. The insects can descend but never climb out again. I sliced open one of the Sarracenia stems to show the judges at the regional competition in Jesup that it was full of a ripe stew of insect parts—ant bodies, fly legs, beetle wings—but they weren’t impressed.

The pitcher plant taught me to love rain, welcoming days of drizzle and sudden thundering downpours, drops trailing down its hoods and leaves, soaking the ground. In my fascination with the pitcher plant, I learned to detest artificial bouquets of plastic and silk. Its carnivory taught me the sinlessness of predation and its columns of dead insects the glory of purpose no matter how small. In that plant I was looking for a mane de ser, a way of being—no, not for a way of being but of being able to be. I was looking for a patch of ground that supported the survival of rare, precious, and endangered biota within my own heart.

My brothers and sister and I worked hard, cleaning bricks and hauling junk, tearing down old buildings and pulling nails and stacking lumber, handing Daddy tools and feeding the sheep and cutting grass, nailing shingles and ferrying Sheetrock and measuring and sawing boards, and Daddy had neither the time nor the inclination to take us hiking or camping or fishing. Not a hard-hearted man, he could have paved the county with his empathy toward the downtrodden and his compassion for hurt animals, although he wouldn’t waste his breath offering congratulations to anyone enjoying health, happiness, and success. Nature wasn’t ill regarded, it was superfluous. Nature got in the way.

One morning, out scrambling to get a tractor running, he stepped on a toad. The loam of the junkyard was rich and fertile, streaming with healthy earthworms, mole crickets, and wary toads camouflaged against the ground. They could be found in cool, moist places—under boards and cement blocks—where they burrowed to keep from desiccating. When you picked a toad up, it peeled instantly.

This one squished under his work boot, belly exploding. I knew he hated that, for when there was work to do, Daddy didn’t stop for much, except maybe pause to pass a jug of ice water around or break for dinner.

He stepped to the door of the house and began to yell. “I need a knitting needle,” he hollered. “Lee Ada, get me a sewing needle and thread.” He was short-tempered as a hornet when he was rattled.

On the gray-painted porch floor my father sewed up the fat toad. I watched the operation from behind the living-room curtains because of my father’s thunderous mood and because if I were any closer I’d vomit. Daddy stood in my little flower bed, where I planted whatever flowers I could afford with my twenty-five-cents-a-week, Saturday-go-to-town allowance, knee-deep in daylilies, poking the toad’s guts back inside the crepe of its stomach like you’d do the popped seam of an upholstered chair.

Before the next day dawned, the toad was dead, stiff and dry. The tractor ran, thumping in time with my father’s heart.

How the Heart Opens
By Janisse Ray

Janisse Ray is a writer, naturalist, environmental activist, and radio commentator. Ecology of a Cracker Childhood is her first book.
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A Dissenting Opinion

As recently as the first quarter of the twentieth century, evidence for an ancient human presence in the New World was scant. Then came the unearthing in Folsom, New Mexico, of distinctive spear points in association with the bones of extinct bison and deer. Analyses of this find in 1926 definitively pushed the date of human arrival in the Americas back into the Pleistocene, or Ice Age. The following year, J. D. Figgins, director of the Colorado Museum of Natural History, told the story of the Folsom site in these pages (“The Antiquity of Man in America,” May–June 1927).

Discoveries of so-called Clovis spear points followed apace at widespread sites. These additional finds were given somewhat earlier dates than Folsom’s. A consensus began to form: Humans, crossing the Bering Strait from Asia, came to this hemisphere about 11,500 years ago.

This view held firm for several decades, but it did not lack challengers. From midcentury on, a minority of archaeologists believed there was strong evidence for a much earlier human presence in both North and South America.

Now the consensus seems to have shifted. Discoveries at the Chilean site of Monte Verde (excavated between 1977 and 1985 by Tom Dillehay, of the University of Kentucky) have convinced an interdisciplinary team of scholars who visited there that humans had penetrated deep into South America by 12,500 years ago. (Dillehay wrote about Monte Verde in Natural History in April 1987, as part of our series “The First Americans.”)

In this issue’s book review, archaeologist Anna Roosevelt registers a dissent (“Who’s on First?” page 76). Based on her assessment of a wide range of New World sites, she questions the new, earlier dates for a human presence in South America and disagrees as well with the older, established hypothesis that big-game hunters using Clovis points were the first arrivals in North America. Roosevelt argues that if consistently stringent standards were applied to all the relevant sites, a new and more complex view of ancient American history would emerge.

Seventy-five years after Folsom, the debate goes on.—Ellen Goldensohn
The Desert That Glistened With Water.

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Waiting to Inhale
My first reaction when reading “Calling a Bluff” by Carl Zimmer (3/00) was astonishment at the “French horn” tracheas of trumpeter swans. My second was wonderment at how these birds can get enough oxygen down into their lungs. Whenever we exhale, a certain quantity of air remains in the lungs, the bronchial tree, and the trachea—since those structures cannot completely collapse, as a balloon can.

Trumpeter and trachea

This carbon-dioxide-laden, oxygen-depleted air mixes with the next batch of incoming fresh air, slightly reducing its total oxygen concentration. I would think that with an elongated

trachea, the volume of used, low-quality air would increase and that this might diminish flight capacity. Does it?

Jan Blakkam via e-mail

W. Tecumseh Fitch replies: Tracheal elongation would indeed pose big problems for most air-breathing animals. However, bird respiration works somewhat differently from that of mammals or reptiles.

The system of air sacs in the avian respiratory tract allows one-way flow through an essentially rigid lung that is much more efficient than the balloonlike mechanism seen in all other air-breathing vertebrates. The air sacs leading into and out of the lungs hold a large volume of fresh air, so in general, the respiratory costs of tracheal elongation are probably not high. In fact, most birds with long tracheas are good fliers, and some (most notably, cranes and swans) perform amazing long-distance migrations.

Nonetheless, birds with a really extreme elongation, such as the trumpet manucode, may have so much tracheal dead space that it does cause a problem, and in fact, these birds do not migrate and are reported to be somewhat sluggish.

Crossing the Species Barrier

John Terborgh’s “In the Company of Humans” (5/00) explains why different species sometimes herd together, and so explains an instance of animal behavior that puzzled and amused my husband and me. Driving around the Catskill Mountains, admiring scenic views from empty roads, we often saw deer respond to our unexpected appearance by leaping into a field of grazing dairy cows and trying, it seemed, to hide from us among them. They never persuaded us that they were cows; we thought they were clowns.

Now I understand.

Naomi Bliven
New York, New York

As I walked along a country road near the small village where I live, a jackrabbit bounded into the road from behind some bushes and came on full tilt. Spying me, it hesitated a split second, then kept coming, passing within arm’s reach. Suddenly a red fox appeared, following the jack’s trail, but as soon as it saw me, it wheeled about and disappeared.

Normally the jack would have jumped aside and cut across the fields to avoid me. It must have known that the fox wouldn’t dare follow it past me—and so saved itself.

Who says animals can’t reason?

Peter S. Brody
Casselton, North Dakota

Exceptions to the Rule

Peter A. Thomas makes the general point that to live long, a tree must remain small (“A Tree’s Old Age,” 5/00). Several tree species are striking exceptions, perhaps the most notable being the world’s most massive tree, the giant sequoia. Even though the total leaf mass of mature sequoias appears to change little over time, most show robust ring growth, even at diameters exceeding 25 feet and even through their third millennium of life. In a single year, a large old sequoia can add a volume of wood equivalent to that held in a tree 1–2 feet in diameter and 100–200 feet tall.

Nathan L. Stephenson
Three Rivers, California

Peter A. Thomas comments that a tree’s bank account “dwindles” with age and that there comes a point where its rings “cannot get any narrower.” Yet as dendrochronologists (those who analyze tree rings for the purposes of archaeological dating or climate research) have long appreciated, trees in semiarid regions sometimes skip wood production altogether, often for several years during a particularly dry period. When the going gets tough, new rings become an unaffordable luxury, and trees allocate scarce carbohydrates instead to the growth of other critical tissues, such as fine roots.

Peter J. Marchand
Florence, Arizona

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Steve Grenard ("Is Rattlesnake Venom Evolving?") is an authority on the medical management of venomous snakebites. He published his first herpetological article (on a marsupial frog in his own collection) at age fourteen. Grenard’s Medical Herpetology (Reptile and Amphibian Magazine, 1994) was the first comprehensive survey of amphibians’ and reptiles’ importance to medicine and is also a compendium of information on treating envenomation by snakes and lizards. Currently clinical coordinator of the Sleep Apnea Center at Staten Island University Hospital, he has directed critical care for respiratory emergencies at both Mount Sinai and Lenox Hill hospitals in New York City.

Geologist and paleontologist Lowell Dingus ("Death in the Dunes") has served since 1991 as chief geologist on the ongoing American Museum of Natural History/Mongolian Academy of Sciences joint expedition to the Gobi. President of the InfoQuest Foundation, an organization that promotes scientific research projects, Dingus, left, was director of the Museum’s fossil hall renovation, which was completed in 1996. He has cowritten two books for children and is coauthor, with Timothy Rowe, of Mistaken Extinction (W. H. Freeman, 1997). David Loope, recruited by Dingus for the Gobi crew in 1996, is a specialist in windblown sediment. He became interested in that particular aspect of geology after seeing the sandstone formations of Utah, and he has also studied modern phenomena such as the Sand Hills of Nebraska. Loope holds the Schultz Chair of Stratigraphy and is a professor of geology at the University of Nebraska, Lincoln.

Adrian Bailey ("A Matter of Survival") is based in Johannesburg, South Africa, where, he says, he “tries to spend as little time as possible.” A full-time photographer, Bailey has been traveling in Botswana for four years with his journalist wife, Robyn Keene-Young, photographing the land, the people, and the wildlife. Okavango: Africa’s Wetland Wilderness (New Holland/Struik, 1998) is Bailey’s first book of photographs; his second, Wild Botswana (Sunbird Publishing) is forthcoming in fall 2000. Three times in the past four years, Bailey won the British Gas Wildlife Photographer of the Year competition.

Roderick Whitfield ("Fascination of Nature"), who holds the Percival David Chair of Chinese and East Asian Art at the University of London, attributes his early captivation with China to his parents. “My mother was a bookbinder and weaver,” he explains, “and my father a distinguished scholar of Italian literature. Both were fascinated by Chinese art.” Home-schooled until age eleven, Whitfield (pictured here with his father) holds degrees from London, Cambridge, and Princeton universities and is fluent in French, Italian, and Mandarin. His book Fascination of Nature: Plants and Insects in Chinese Painting and Ceramics of the Yuan Dynasty (1279–1368) was published in Seoul, South Korea, in 1993 by Yekyong Publications.

In 1997 Guy C. Brown ("Symbionts and Assassins") entered a competition sponsored by the Wellcome Trust to induce working scientists to write for the public. “All you had to do,” reports Brown, “was write a sample chapter and outline for a book.” To his great surprise he won, but had to finish the book to claim the £25,000 prize. The result was The Energy of Life (Free Press, 2000). A Royal Society Research Fellow in the biochemistry department at the University of Cambridge, Brown says that a desire to understand living things at a more and more detailed level ultimately led him to mitochondria, the subject of his research for the past eighteen years.

Papua New Guinea’s Kimbe Bay, says photographer Fred Bavendam ("The Natural Moment"), gives scuba divers a “wide view,” a reefscape “rich in large filter feeders.” Among these creatures is the big gorgonian that serves as the vibrant red backdrop and scaffold for the golden feather star in this month’s photograph. Bavendam majored in art and zoology at the University of New Hampshire. In 1985, after working as a commercial photographer and learning to dive, he decided to devote all his efforts to underwater photography. He has documented an array of sea creatures and their behavior in photographs that have appeared in periodicals worldwide.
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With breakers surging past and the sand washing out from under my feet, I stared intently into the water. Through the choppy reflections of a golden Pacific sunset, I soon spotted a small wedge clam. And it was not alone: it had a hydroid hitchhiking on its back.

The wave-washed edge of a sandy shore, devoid of permanent physical structure and subject to constant change, is a difficult habitat for any living thing. Yet this so-called swash zone—defined by the run-up and backwash of the frothy surf—is home to a number of organisms. One requirement for residency is the ability to adjust to daily tides as well as to lunar and seasonal cycles that continually shift sand and water levels. And if the potential swash-zone resident is a filter-feeding organism that needs to stay anchored on the sandy bottom, it must have the agility to quickly regain a favorable position if dislodged by wave action or temporarily buried by sand.

The list of common swash-zone animals includes a number of diminutive burrowing crustaceans (shrimplike organisms such as ostracods) and annelids (worms) that live below the sand surface. But one of the most familiar inhabitants that stays up near the action is a small clam known on Atlantic and Gulf of Mexico beaches as the coquina and on the Pacific coast as the bean, or wedge, clam. (It is also called the sea butterfly for the resemblance of its empty shell, when agape, to butterfly wings.) Though these clams (all in the genus *Donax*) are subject to population swings at specific locations, one or more species can be found
almost anyplace that has warm water and a sandy beach, from the Americas to Africa, Asia, and Australia.

The success of this cosmopolitan mollusk has much to do with its prowess as a swash rider. Using its foot and siphons much like a sail, a Donax clam surfs landward and seaward with flowing and ebbing tides, then digs in quickly between waves to maintain itself in the wet sand just above the tide line. It has been demonstrated in the laboratory that Donax respond actively to loud wave sounds and that this sensitivity is cued to an internal biological clock. This may be how the clam knows when it is time to push out of the sand and ride the surf up and down the beach, remaining within the swash zone regardless of the tide cycle. For animals that spend most of their time sitting in the sand feeding, wedge clams can move surprisingly quickly. Some investigators have reported seeing Donax jump out of the sand with a single thrust of the foot, and I have seen many small individuals bury themselves from a standing start in less than four seconds.

Despite such impressive abilities, the clam I was currently watching had been upstaged by an even more unlikely actor—the small hydroid on its back. Organisms that look more like plants than animals, hydroids are tubelike filter feeders classified in the same phylum as jellyfish and sea anemones. They are free swimming only in their brief larval stage. Early in their adult lives, hydroids anchor themselves in one place and grow thereafter by clonal duplication, forming branching chains of polyps that soon resemble small bushes. Remarkably, a few species of hydroids have found their way into the rich, turbulent waters of the swash zone by attaching themselves to the posteriors of swash-riding clams.

I mused over this adaptation while my clam, with hydroid attached, dug into the sand until only the hydroid remained visible. Though I could no longer see the clam, I knew it had pushed its siphon to the surface for feeding, and it occurred to me that the hydroid, by creating an eddy in the swash, might actually help the clam obtain food. But the advantage seemed mostly the hydroid’s. As I watched a well-scoured cobble and pieces of larger shell tumbling in the constant wave action, I could see that a hydroid attached to either of these inanimate objects would soon be ground into organic matter for other filter feeders. I knew, too, that sometime in the night, long before this spot was left high and dry by the outgoing tide, the hydroid’s “anchor” would have pulled itself up and moved, with its hitchhiker, back down the beach to continue the incessant task of filtering seawater. Getting hooked up with an animal like Donax seemed a very clever trick of hydrozoan evolution.

The next day I returned to the same beach at low tide and walked out to the edge of the swash zone. The sand was firm and glistening, almost metallic. Spent waves lapped at my feet. The beach appeared devoid of life, as if everything had returned to the sea during the night. Then a large breaker shattered the illusion. As the roiling backwash streamed past, it scoured around me, and when the froth cleared, there beneath my feet were multitudes of clams, all small and without hydroids. I dropped to my knees and scooped frantically before the next wave rushed in. Two hundred fifty-three clams in a single square foot of sand—and six feet farther up the beach from the tide line, not one.

To me, these would never again be just coquinas or bean or wedge clams. I not only marveled at their remarkable mobility and acute sensitivity to an ever changing environment but saw in them an endless procession of potential rides for the next generation of hitchhiking, swash-riding hydroids.

For sky watchers, the appearance of Vega directly overhead is a sure sign of summer. But this year it also marks the 150th anniversary of a different kind of high point. On July 17, 1850, astronomer William Cranch Bond, working with photographer John Adams Whipple, focused the light from Vega onto a highly polished, iodine-fumed silver plate to produce a daguerreotype that was the first-ever photograph of a star.

Photography's infancy was full of astronomical breakthroughs: first daguerreotype of the Moon, 1840; first of a solar eclipse, 1842; first of the Sun, 1845. In a way, the feat Bond and Whipple performed on a clear summer night in 1850 was simply one more first. But unlike the earlier astronomical photographers, Bond and Whipple weren't relying on photographic equipment alone: they were also using the Harvard College Observatory's new telescope.

The appearance in March 1843 of a comet described by one contemporary as being "of surpassing size and splendor" had fostered in Cambridge a widespread curiosity about astronomy, but Harvard's then-modest observing facilities couldn't begin to satisfy it. A public subscription campaign soon raised $25,000 toward the construction of a 15-inch telescope—the largest in the United States, a rank it would hold for nearly twenty years and the reason it was known as the Great Refractor.

In 1848, only a year after the telescope went into operation, Bond (the observatory's director) and his son George Phillips Bond (himself a future director) discovered Hyperion, the eighth satellite of Saturn. But it was their ongoing interest in the application of photography to astronomy that perhaps most distinguished this telescope's early contributions. Their daguerreotypes of the Moon won a medal at the Great Exhibition of 1851 at London's Crystal Palace. A few years later, after the addition of a new clock drive to the telescope, the younger Bond embarked on an ambitious program of photography-based stellar astrometry (the measurement of the positions, parallaxes, and proper motions of celestial bodies) and photometry (the measurement of light).

Taken together, all these firsts added up to a revolution in astronomy. Unlike individual observers' drawings and descriptions, which had always sufficed as astronomical data, photography promised a form of evidence that would be both objective and permanent. Astronomers realized that photographic stock absorbs more light than the human retina, especially over long exposures. In 1895 a New York Times article declared: "The naked eye never sees more than 6,000 stars in the whole of the 'azure vault of heaven'; the large telescopes increase this number to 50,000,000, while the combined photographic and telescopic eye catches at a single 'look' the images of 160,000,000 twinkling silver points of light."

The 1850 daguerreotype of Vega, alas, no longer exists. But Vega the star is still here, as is the principle behind what Bond and Whipple set out to do 150 years ago. Today a sky watcher can go outside and compare what's there with what someone else saw on another night in another city in another century. For the next two months, blazingly blue-white Vega is the first star to appear overhead and slightly to the east; it's then joined by Deneb and Altair, the other two vertices in the Summer Triangle. On July 17, Vega reaches its zenith at
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Thursday of each month, the university hosts “Observatory Night”—an evening that begins with a public lecture and continues with a tour of the facility. Visitors can examine a collection of old scientific instruments as well as a plaque commemorating the original donors to the construction of the Great Refractor. The list includes the Revere Copper Company, an appropriate name to find in the birthplace of a revolution.

Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens (Penguin, 1999).

THE SKY IN JULY AND AUGUST

Mercury is at inferior conjunction on July 6, when it passes between Earth and the Sun. It should become visible again during the last week of July and the first week of August, rising between 4:30 and 5:00 A.M. local daylight time (LDT) low in the east-northeast. It reaches its greatest elongation west of the Sun on July 27. After August 9, Mercury is overwhelmed by the bright morning twilight and disappears as it moves toward superior conjunction with the Sun on August 22.

Venus is buried deep in bright evening twilight through most of July but finally begins to emerge during the final weeks of the month. Look for it as a brilliant silvery “star” shining with a steady light and hovering very low over the west-northwest horizon immediately after sundown. Viewing Venus becomes easier during August as the planet slowly pulls away from the Sun, setting forty-five minutes to an hour after sundown.

Mars is not visible during July or the first half of August. It then appears very low in the eastern sky at about an hour and a half before sunrise. By the end of August, it rises in complete darkness, before 5:00 A.M. LDT.

Jupiter and Saturn are a prominent pair in the predawn summer sky. At the start of July, they rise in the east-northeast at about 3:00 A.M. LDT. By the beginning of August, Saturn rises about half an hour ahead of Jupiter, at about 1:00 A.M. LDT. At the end of the month, both planets rise before midnight.

Earth is at aphelion, reaching its farthest point from the Sun on July 3 at 8:00 P.M. The maximum distance this year is 94,511,887 miles—about 3.3 percent farther than at its closest point (perihelion, this past January 3).

The Moon is new on July 1 at 3:20 P.M. and on July 30 at 10:25 P.M. Both new Moons nearly coincide with perigee (the Moon’s closest point to Earth), so extremely high tides are expected. First quarter is on July 8 at 8:53 A.M., full Moon comes on the 16th at 9:55 A.M., and last quarter is on the 24th at 7:02 A.M. In August, first quarter is on the 6th at 9:02 P.M., full Moon on the 15th at 1:13 A.M., last quarter on the 22nd at 2:51 P.M., and new Moon on the 29th at 6:19 A.M.

A new comet has been found, according to the Central Bureau for Astronomical Telegrams, which disseminates information on recent observations and discoveries. The comet, C/1999 S4 (aka LINEAR), is heading for a mid-July encounter with our part of the solar system and is due to pass within 67 million miles of the Sun on July 18. Through the remainder of July, LINEAR appears low in the west-northwest sky at dusk. Early projections suggest that it might become as bright as magnitude 0.3, but this is uncertain. Will LINEAR develop into a good naked-eye object or turn out to be a dud? We’ll just have to wait and see.

A partial eclipse of the Sun is visible on July 1 over Patagonia and Antarctica. A total eclipse of the Moon occurs on July 16, and its early stages are visible from some areas of North America—specifically, west of a line running diagonally from westernmost Montana down to westernmost Texas. The eclipse begins at 4:57 A.M. Pacific Daylight Time (PDT), and totality begins at 6:02 A.M. PDT. Hawaii is the best spot for viewing the entire eclipse. Totality lasts 107 minutes, making this the longest total lunar eclipse until the year 2123. On July 30 there is a second partial eclipse of the Sun. It begins in Alaska (at 20 to 40 percent) during the early afternoon, while coverage of 30 percent or less is visible at sunset over portions of northeastern Montana and northern California. Remember that viewing any solar eclipse requires safe observation techniques.

The Perseid meteor shower is obscured by the light of a nearly full Moon, which conceals all but the brightest streaks. The best viewing opportunity will come on the morning of August 12, during a narrow window from moonset until the start of morning twilight.

Unless otherwise noted, all times are given in Eastern Daylight Time.
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Excursion to the Arctic Circle

The Yukon Territory’s Dempster Highway takes motorists through mountains and tundra.

By Robert H. Mohlenbrock

During the late nineteenth century, the great Klondike gold rush created a well-beaten path to Dawson City, but the northern reaches of Canada’s Yukon Territory long remained relatively inaccessible. The construction of the Dempster Highway, which was completed in 1979, established a road link from near Dawson City (now simply called Dawson) all the way to Inuvik, in the Northwest Territories. This gravel (and sometimes dirt) road is one of just two public highways in North America that cross the Arctic Circle; a third is under construction. Intent on exploring the environment along this route, my wife and I set out on the highway very early one August morning, with plans to drive north and reach the outpost of Eagle Plains, 255 miles away, by nightfall. Because no services or facilities are available in between (except for a couple of government-operated campgrounds), we made sure our vehicle—appropriately, a GMC Yukon—had a full tank of gas.

Early morning is a great time to observe wildlife, and very soon we saw moose, bald eagles, red foxes, and ptarmigan. For some distance, the highway passed through boreal forest, where white spruce and balsam poplar are the dominant species. Before long, the Ogilvie Mountains came into view in the distance, and eventually we neared the craggy peaks of Tombstone Mountain. Approaching the visitors center for the Tombstone campground, located at kilometer 71.5, we saw a grizzly bear feeding halfway up the mountainside. Unfortunately, it was scared away when a highway-department truck came rumbling along the road.

As we continued our drive northward, the forests soon began to thin and patches of tundra appeared. At North Fork Pass (4,265 feet above sea level), we crossed the Continental Divide. The highway then passed through two river valleys before again crossing the divide, which zigzags through the territory. Our journey continued on a relatively flat, high plain. Along the way, we stopped several times to make short forays on foot to get a closer look at the tundra. Our boots were absolutely essential for traversing the flooded ground.

Dominated by low-growing vegetation, tundra is a habitat that extends from the polar ice cap south to the boreal forest. The ground is underlain by permafrost, a layer of soil that remains frozen throughout the year and that may extend deep into the earth (in Siberia, it has been reported at a depth of 4,757 feet). Generally, permafrost develops in glacier-free polar regions because glaciers are excellent insulators and keep the ground beneath them from freezing. The northern Yukon (not covered by ice during the last continental glaciation) is primarily tundra, while the southern Yukon (once covered by glaciers) is now mainly boreal forest.

Tundra soil is usually acidic and poorly aerated, and although high in organic matter, it offers limited nutrients for the growth of vegetation. Roots cannot penetrate the permafrost, so tundra plants have shallow root systems. And because water cannot penetrate it either, there is little drainage after rain or snowmelt. As a result, numerous shallow pools develop during the summer, transforming the tundra into an extensive wetland. When vegetation is removed from the tundra—for example, as a result of construction
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HABITATS

Tombstone Mountain offers such wildflowers as fireweed, bluebells, grass-of-parnassus, Jacob's-ladder, Labrador lousewort, a bright yellow daisylike groundsel, monkshood, larkspur, arctic shooting star, three kinds of purple gentians, and the poisonous death camas of the lily family. A small butterwort found here is considered insectivorous because it is able to trap tiny organisms and use them as nutrients. Among the shrubs are bearberry, black crowberry, dwarf birch, Labrador tea, blackberry, and lowbush cranberry. The principal trees are white spruce, balsam poplar, and quaking aspen.

Tundra plants are usually dwarfed, although here and there a black spruce may grow three or four feet high. Common shrubby species are baked-apple (a type of blackberry with tasty yellowish fruits), bearberry, Labrador tea, lowbush cranberry, black crowberry, and dwarf birch. Wildflowers include sweet coltsfoot, lousewort, and cotton grasses. Sphagnum moss and flat, leafy-looking lichens abound.

Rocky ridge vegetation includes reindeer moss and other lichens, along with black crowberry, bearberry, dwarf birch, Labrador tea, northern rose, scattered spruce trees, and lousewort. Baked-apple and sphagnum moss are conspicuously absent in this relatively dry habitat.

It was nearing 8:00 P.M. when we arrived at Eagle Plains, an outpost settled just before the completion of the Dempster Highway. This oasis in the tundra consists of a hotel, a restaurant, a gift shop, and a service station. The hotel is built on an outcrop of bedrock—the only place in the area where the ground is not permafrost. After refueling our vehicle, checking into the hotel, and getting a quick meal, we headed north again for another twenty-two miles so that we could say we'd reached the Arctic Circle. Here, at 66°33' north latitude, the Sun remains visible for a continuous twenty-four hours on the summer solstice. Although we finally got to bed in the Eagle Plains Hotel at about midnight, it was 2:30 A.M. before the Sun went down, only to rise again a couple of hours later. By 7:00 A.M., we were on our way back to Dawson via the same exciting route.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

Black spruce muskeg is also home to larch (tamarack) and at least one fairly tall species of willow. The shrub layer hosts dwarf spirea, dwarf birch, Labrador tea, baked-apple, lowbush cranberry, black crowberry, gray alder, and buffalo berry. Other plants are lady's slipper, cotton grass, and a horsetail.
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The Narthex of San Marco and the Pangenegetic Paradigm

Either the world was built up step by step or it unfolded according to a predetermined design—or both.  

By Stephen Jay Gould

I do realize that the biggest of all bosses labored with maximal sweat and diligence during those first six days. So “perhaps it would be wise not to carp or criticise,” as the Sergeant of Police once remarked in a different context (in Gilbert and Sullivan’s Pirates of Penzance). Still, I must confess that I’ve always been puzzled by the relative paltriness of accomplishment on the second day, for the import of this episode seems almost derisory compared with the scope of all the others: light created on the first day, in the grandest of all opening acts (and especially necessary for noticing any subsequent event); earthly land, waters, and even plants in a foretaste of life on the third day; Sun and Moon, with stars as a mere afterthought, to populate the heavens on the fourth day; animal denizens of the sea and air on the third day; and inhabitants of the land, culminating in our exalted selves, on the sixth day.

But on this second day of relative nodding, God limited his efforts to installing a plane of division (called the firmament in the King James Bible and the sky in many modern translations, but closer to a thin metal plate in the original Hebrew), simply to distinguish the water above the plane from the water below. Big deal. Compared with all the makings and shakings of the other days, this second effort created nothing new but only constructed an artificial division within an existing homogeneity. Did God need a breather right after his initial effort in the creation business? Did he have to pause after the first step in order to recoup his courage for pushing through to the end?

The light dawned on my pugnacious ignorance (thus validating the product of the first day) several years ago, when I studied the thirteenth-century mosaics of this creation story (Genesis 1, of course) in the south dome of the narthex (the covered western porch just in front of the main entrance) of the great cathedral of San Marco in Venice—thus explaining the first part of my cryptic title (I shall soon shed light on the second and even more cryptic part, but all in good time, as the Wicked Witch of the West said, also in a different context).

In this wonderfully animistic set of scenes, radiating downward in three circles from the apex of the dome, each episode of creation features the youthful, beardless God of Byzantine tradition doing his appointed tasks for the day, while an appropriate number of angels either help out or look on (Otto Demus’s authoritative 1984 four-volume work on the San Marco mosaics argues convincingly that the scenes of the dome derive from an illuminated fifth-century Greek manuscript of the book of Genesis).

In the scene for the second day—and begging an authorial pass for my irreverent anachronism in explication—God goes bowling to divide the waters by rolling a globe horizontally through the middle of the homogeneous mass, thus carving a barrier to define “above” and “below” (see detail of the mosaic on page 30). The two angels of the day stand awkwardly at the right of the scene, more in the way (for the waters remain undivided to their right) than as auxiliaries in this case. (Demus explains that the mosaic has been heavily restored and that the separation may originally have extended all the way to the right edge.)

But I understood my error only when I backed up a scene to contemplate the work of the first day. God, at
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the left edge (see below), creates light by making a vertical division this time—with a dark globe representing night at the right edge and the light globe of day closer to him on the left. The single angel of the first day, in a lovely touch, spreads one luminescent wing in the realm of light above his right arm (the angel faces us, so his right arm lies in the left domain of light) and one dark wing in the nighttime of his left side. Six rays, representing the work of the six days of creation, emanate from both globes.

And now I grasped the maximal depth of my error. I had denoted the second day because I had failed to appreciate the controlling theme of the entire story! I had always regarded the narrative of Genesis 1 as a creation myth based on the theme of sequential addition, as I think most people do, given our current cultural preferences for viewing history (at least its technological achievements) as a tale of accreting progress, and as my childhood instructors, both secular and religious, had certainly taught: light on day 1, something about water on day 2, land and plants on day 3, Sun and Moon on day 4, birds and fishes on day 5, mammals and humans on day 6.

But the mosaics in the San Marco narthex clearly expressed a quite different organizing theme in their charmingly naive iconography. These mosaics, at least for the first three days, tell a story about the successive separation and precipitation of concrete items from an initial inchoate mass that must have contained, right from the beginning, all the seeds or prototypes for later realizations—in other words, a tale of progressive differentiation from unformed potential rather than successive addition, piece by novel piece, in a sequence of increasing excellence.

The striking device of drawing these divisions as alternating vertical and horizontal planes illustrates the case in a wonderfully direct way—thus emplacing, in a million mosaic tesserae, the organizing theme that, I feel confident, the author of the text intended and that artistic translators understood and expressed for at least a millennium or two before changes in Western culture blurred this context and subtly led us to read the story in a very different manner.

Our primal myths teach us about the limits and capacities of the human mind for organizing complex material into sensible stories.
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(along with earth, fire, and air, at least in the classical Greek formulation) as one of the few fundamental principles of cosmic construction. Our ancestors did not understand that ocean surfaces evaporate to form clouds that return water as rain. Thus for them, the location of life-giving water in two maximally separated realms—at their feet in rivers and seas, and from the upper reaches of the sky as rain—must have generated a major puzzle demanding resolution at the fundamental level of creation itself. The work of the second day achieves full centrality and importance once we recognize the story of Genesis 1 as a tale about differentiation and once we acknowledge water as both a primary element and a source of all sustenance. The separation of life-giving waters into two great reservoirs, located at opposite poles in the geography of existence, certainly merits a full day of God’s creative effort.

Second, the substitution of differentiation for addition also suggests that the author of Genesis 1 probably conceived of the nature of plants in a radically different manner from our understanding today. We make a primary distinction between organic and inorganic—with plants unambiguously in the first category, although usually relegated to the bottom of a rising sequence of plant, animal, and human. (Vernacular language sometimes even restricts “animal” to mammals alone, as in a kiddie card game called “Bird, Fish, Animal,” which I, as a professional biologist, simply couldn’t fathom until I thumbed through the deck and realized that “animal” meant only lions and tigers and bears, oh my!—and then the name of the game just drove me nuts. I shall die content if I ever persuade the manufacturers to rechristen this otherwise harmless and even instructive item as “Bird, Fish, Mammal.”) Our conventional taxonomy of organic and inorganic reinforces the false view that Genesis 1 should be read as a tale of addition, for the primitive plants of day 3 should originate before any more advanced animal on day 5. But why, then, does the intervening day 4 neglect organisms altogether?

The first three days of Genesis 1 should be read as a tale of differentiation rather than addition.

However, when we reinterpret Genesis 1 as a differentiation myth, an alternative taxonomy best explains the discontinuity between the appearance of plants on day 3 and the creation of a sequence of animals that begins on day 5 and then continues, with no further break, right to the end of the story. Day 3, with both vertical and horizontal divisions in San Marco’s narthex, marks the episode of differentiation for the earth’s physical potential: the division of the primal chaos below the firmament into its major components of water and land. The subsequent origin of plants on the same day (and in the next verse) suggests to me that the author of Genesis 1 viewed plants as the culminating aspect of the land’s differentiation and not as a later addition from a separate organic realm, merely rooted within the substrate of another category of material stuff. In short, I would bet that the taxonomy of Genesis 1 intends to rank plants with earth, and not with animals.

In advocating the importance of ancient creation myths for our modern understanding of natural history (and hence as an appropriate subject for this magazine), I make no argument about empirical truth. Rather, I think that our primal myths teach us something important about the limits and capacities of the human mind for organizing complex material into sensible stories.
All cultures must generate creation myths; how else can we infuse order into the buzzing and blooming confusion of nature's surrounding diversity and complexity? Anthropologists, ethnographers, and folklorists have long noted the striking similarities among creation stories devised by people living in distant lands and without any known contact.

Two explanations for these similarities have generally been offered: (1) perhaps the story really arose only once and then passed from one culture to another by more efficient routes of sharing than anthropologists have recognized, or (2) perhaps the stories arose in true independence but with striking similarity guaranteed by inherited mental preferences and images—the archetypes of Jungian psychology—deeply and innately embedded in the evolutionary construction of the human brain.

But I think that we should add a third possibility, invoking logical limits to the structure of stories rather than explicitly similar content derived either by direct transfer or evoked from common residence in all human brains. (Of course, such logical limits also represent quirks of our own mentality, but this principle invokes a different and much more general aspect of consciousness than the specific images of Jungian archetypes.) After all, comprehensive stories can only "go" in a certain number of ways, and the compendium of independently derived creation myths includes so many stories that, inevitably, several tales must fall under each of the few conceivable rubrics.

These rubrics, although far fewer than the stories they must organize, still span a fairly ample range. For example, creation stories may be primarily eliminative, as when a promiscuous creator begins by populating the cosmos with all conceivable forms and then grants to nature the task of weeding out the malformed and the nonop-
eration. Or creation stories may be cyclical, as when new generations arise to replace their perfectly adequate ancestors and to enjoy their own transient ascendency—so the gods of Jupiter's generation succeed their Saturnian ancestors, while Wotan and his cohort perish in Wagner's Göttterdammerung as a new day dawns at the end of four very long operas.

But only two basic frameworks of explanation can be invoked when a culture chooses to organize a creation myth as a successive and progressive series—surely a common, if not the preferred, theme among most human tales about the origin of the natural world (for whatever set of complex reasons, involving both mental preferences and natural appearances). Such tales of sequential improvement may invoke either successive addition (first make this, then add this at a higher level, and so forth) or refining differentiation (start with a big soup containing all eventual products as unformed potential and then separate/coagulate/harden, separate/coagulate/harden, and so forth). Perhaps other alternatives exist, and creation myths certainly can (and usually do) include aspects of both primal tales. But addition and differentiation surely define the primary mental territory of creation myths constructed under the guiding principle of sequential progression.

I now reach the point of necessary confession for my cryptic and self-indulgent title. You have probably excused me for the narthex part, already explained above. But the term "pangenetic," and the resulting full title, requires an abject plea for your indulgence. In using "pangenetic," first of all (and legitimately, for this aspect alone), I honor my hero and the inspiration for this entire series of essays: Charles Darwin. In his longest book, The Variation of Animals and Plants Under Domestication (1868), Darwin proposed, as a "provisional hypothesis," in his own words and judgment, a theory of heredity that he called pangenesis. History forgot this incorrect theory, both rightly and entirely—although curiously and by a complex route, our most salient modern word, "pangenesis" expresses a pure theory of differentiation, rather than addition, for the explanation of organic development. The initial fertilized cell, like the primal chaos of Genesis 1, includes all components of the complex adult, but in unexpressed and inchoate form. Embryology then unfolds as the realization of an initially unformed but completely self-contained potential. Thus, the pangenetic paradigm, honoring Darwin's version of a larger theme, encompasses a class of models based on differentiation rather than addition, for the generation of progressive complexity in a temporal series.

Now for the self-indulgent part: The most widely cited technical paper I ever wrote (with the exception of my first article on punctuated equilibrium,
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coauthored with Niles Eldredge of this Museum) bore the title “The Spandrels of San Marco and the Panglossian Paradigm” (written with my colleague Dick Lewontin, the smartest man I have ever known). For a variety of reasons happily beyond (and truly irrelevant to) the subject of this essay, the spandrels paper has been unmercifully attacked by a substantial group of biologists (and also appreciated, I trust, by an even more substantial group) committed to the strictly adaptationist account of evolution that Lewontin and I questioned. Among the many published attacks, several have parodied our original title—as in “the scandals of San Marco” and even “the spaniels of St. Marx.” So I thought I’d indulge myself, after all this *tsuris*, by writing a paper with my own title parody, albeit on a quite different subject. Sorry, folks, but at least I have laid down all my cards, and I now bare my throat.

I have little doubt that the first three days of Genesis I should be read as a tale of differentiation rather than addition. I also tend to view the fourth day as a continuation in the same mode—that is, God differentiates the earth below into water and land (with plants) on the third day and then, on the fourth day, differentiates the light of the sky above into Sun, Moon, and stars. But I must confess mixed feelings and signals about the fifth and sixth days. Does God now switch modes to utilize the alternative theme of addition in populating a cosmos (prepared by differentiation) with living creatures? Or does the origin of animals continue the theme of differentiation—as the air and water precipitate their living counterparts on day 5, while the land generates its appropriate forms of life on day 6?

San Marco’s depiction of Adam’s creation might be read as support for a continuing theme of differentiation right to the end of the story. Adam arises, dark as the earth, from the substrate of his origin. (He is not imposed upon the earth as a separate creation from astral realms. A familiar Latin pun—*homo ex humo* [man from the earth]—expresses the same thought, as does the familiar injunction “for dust thou art, and unto dust shalt thou return.”)

My own, utterly nonscholarly intuitions lead me to view the first four
days as pure differentiations: light divided from darkness on day 1, the upper water of rain from the lower water of rivers and lakes on day 2, land from sea on the earth of day 3, and Sun from Moon (the coagulation of previously diffuse light) in the heavens of day 4. I then view days 5 and 6 as, in part, emplacements (more additive than differentiative) into appropriate surroundings but also as the final differentiations of each realm—as water, air, and land all bring forth their appropriate living expressions.

Other interpretations abound, of course. In one popular scheme, advocated in two books that I have read and in several letters received from readers of these essays, the six days of creation fall into two equal cycles: three days of preparation followed by three days of population (of the heavens by Sun, Moon, and stars on day 4; of the sea and air by swimming and flying animals on day 5; and of the earth by terrestrial animals and humans on day 6). In this reading, one might view the first three days as differentiative (whereas I would interpret the first four days under this theme) and the last three as primarily additive. Nonetheless, however one explicates the story, I don’t see how our usual reading of progressive addition for all six days can possibly be supported. At least the first three days—probably the first four, and perhaps all six—must be reconceived as a creation myth based on the great alternative theme of differentiation from unformed potential, rather than addition piece by piece.

This contrast of differentiation and addition as the two primary modes of organizing stories about sequential and progressive development becomes relevant to students of natural history both as a framework for analyzing our oldest classics of the discipline (the creation myths in our earliest historical documents) and as a guide to understanding our current problems and conflicts. In particular, when we rec-
recognize that we derive our concepts of history not only from the factual signals that scientific research has extracted from nature but also from internal limits on the logical and cognitive modes of human thought, then we can appreciate the complex interaction of mind and nature (or inside and outside) that all great theories must embody.

The ancient creation myths of our cultures become particularly interesting in this context, because they originated when our ancestors possessed no direct data at all about the actual pathways of life's history as revealed in the fossil record. These myths therefore represent nearly pure experiments in the range of mental possibilities for existential development toward greater complexity. (I do not believe that either process, especially evolution, must yield stories in this mode, but I do not challenge the pattern for our own particular case.) Both the history and the current variety of views on human embryology and evolution may be regarded, without gross caricature or oversimplification, as one long exercise in the interplay of shifting preferences for stories about differentiation or addition.

The study of vertebrate embryology, from the invention of the microscope in the early seventeenth century to our modern understanding of genetics, has featured a set of conflicts between differentiative and additive interpretations for a process that features increasing size and complexity, from a tiny, homogeneous egg to a neonate with all the anatomical intricacies of adulthood. From the seventeenth through the early nineteenth centuries, the debate between “epigenesis” and “preformationism” virtually defined the territory of study for embryology. The epigeneticists embraced an additive model, arguing that the initial egg should be interpreted as its literal appearance suggests—that is, merely as a mass of promiscuous potential, devoid of structure and eventually shaped to the particular anatomy of the complex neonate only because formative principles then operate upon this initial homogeneity to build, step by step and in an unerring manner (so long as embryology follows its normal course), the complexity of the final product. (“Epigenesis” means, literally, generated upon—that is, one step after the other.)

By contrast, the preformationists rallied behind a differentiation story that envisaged all the structural complexity of the neonate as already present within the initial cell and only brought to visibility during embryological development. In the caricatured version, preformationism has usually been ridiculed as the belief that a perfect homunculus lies within each sperm or egg cell. No serious scientific preformationist held such a view. Rather, they argued, all structures must be present in the initial cell—but in too tiny, too transparent, and too diffused a state to be visible (like the chaos at the outset of Genesis 1, not like a homunculus). The development of the embryo then becomes a differentiative process of concentration, coagulation, solidification, and growth.

When evolutionary ideas pervaded embryology in the nineteenth century, the two leading interpretations continued to uphold contrasting stories of addition or differentiation. Ernst Haeckel's famous theory of recapitulation held, in a purely additive account, that sequential steps in embryonic complexity repeated the evolutionary accretion of successive adult stages—so that a complex animal, in its embryology, literally climbed its own family tree. The primary alternative, Karl Ernst von Baer's theory of differentiation, argued that the visual simplicity of an early stage does not represent an ancient ancestor that must then be augmented (as in Haeckel's additive theory) but rather a more general form of greater homogeneity and lesser differentiation, holding all potential for the definitive complexity that eventually develops in each lifetime. Thus we know, at an early stage of its development, that the embryo will become a vertebrate, then (at a later stage) a mammal, then a primate, then a hominoid, and finally a human being—a process of increasingly finer specification, contrasted with Haeckel's additive model of ever increasing complexity in accretion.

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longer evolutionary construction of Homo sapiens in geological time, rather than the embryological generation of each individual Homo sapiens in nine months—concepts of evolution may also be classified into additive and differentiative models. Darwinism embodies an additive view. Because the Darwinian style of explanation has prevailed within science, we tend to forget that several abandoned theories of evolution advocated differentiative models. These accounts imagined that the first vertebrate, more than 500 million years ago, already contained all the parts and potentials that evolution would necessarily elaborate into human form in a distant future. The supposed mechanisms for such a “programmed” differentiation spanned the full gamut from God’s direct actions (in a few overtly theological accounts) to principles embodied in unknown, but entirely physical, laws of nature (for some atheistic versions, at an opposite speculative extreme).

If allegiance to an additive or differentiative model implied no consequences for skewing our views of life in disparate directions, then we could blow off the entire subject as an effete intellectual game. But our preferred theories act as biases that strongly influence our basic conceptions of the natural world. Additive and differentiative views of historical sequences do not hold the same intellectual weights, properties, and implications. We might summarize the differences, looking at lessons from the history of science, by saying that each basic model features a defining property and struggles with a major problem.

Stories of differentiation work primarily from the inside out. That is, the sequence begins with all eventual results already preformed within an initial homogeneity. Stories of differentiation work primarily from the inside out. That is, the sequence begins with all eventual results already preformed within an initial homogeneity.

mass be carved by external agents into such an exquisitely complex final product (an even worse problem for embryology than for evolution, because the carving must follow the same basic path each time for normal embryos within a species, whereas evolutionary results only arise once)?

In the major distinction between the two models, stories of differentiation work better for determined systems in a predictable world, whereas stories about addition hold the conceptual edge in a contingent world, where any historical sequence may follow innumerable (and unpredictable) options, and the actual result then proceeds from the particular set of external prods that the rolling ball of promiscuous potential (if I may be excused this metaphor) happens to encounter in its trajectory through time. For this primary reason, our modern embryological models tend to be primarily differentiative, and our evolutionary models primarily additive.

After all, embryology does generally follow an internally prescribed route specified not by the preformed parts of preformationists but by the programmed instructions of modern genetic understanding. (We should not
accuse the preformationists of stupidity for placing the right idea into the wrong substance. After all, their intellectual world did not include a concept of programmed information, except perhaps as embodied in the old trifle of music boxes or the newfangled invention of the Jacquard loom, whereas no sentient person in our age of genes and computers could fail to assimilate such informational models as an intellectual centerpiece.)

By contrast, the evolution of any lineage wanders along contingent and unpredictable paths of a uniquely complex history. The few lineages, including our own, that do become more complex through time may add their increments of sophistication in a sequence that makes sense after the fact. But even an omniscient observer could never designate, for certain, the next step in an unpredictable future. Therefore, as a description of evolution, additive models that introduce sequential steps from the outside work better than differentiative models that must envision an entire future already implicit and enfolded within any current form.

Under this analysis, we should not be surprised that Genesis 1, despite our usual and unconsidered readings, tells a tale of differentiation rather than addition. After all, if God proceeded with the usual care and thought conventionally attributed to his might, he probably had a pretty accurate idea about the finished product even before he began the work. Biological evolution, on the other hand (at least as viewed under the limits of our eminently fallible mental machinery), seems to wander along a wondrously erratic set of specific pathways within its broad predictabilities.

Our preferred intellectual models do make a difference, and we must therefore be sensitive to the disparate implications of additive and differentiative models as we struggle to understand the history of life. Still, I think that any passionate and curious person can feel the same emotional thrill emanating from either intellectual interpretation. We live in one helluva fascinating universe, whatever its modalities of construction. Thus, if I may beg one last indulgence from my readers (this time for ending with the same image that I invoked just two essays ago, in a different treatment of Genesis and evolution), I happily embrace the common sentiment behind two maximally different views of organic order: the differentiative model of Genesis 1, with its ending of sublime satisfaction: “And God saw every thing that he had made, and, behold, it was very good” — and the additive model of natural selection, so lovingly described by Darwin in the last paragraph of the Origin of Species: “There is grandeur in this view of life.”

Stephen Jay Gould teaches biology, geology, and the history of science at Harvard University. He is also Frederick P. Rose Honorary Curator in Invertebrates at the American Museum of Natural History.
F or many years, biologists who studied insects thought that learning ability would be found only in such highly social species as honeybees and bumblebees, which have evolved a notable capacity for identifying resources within their environment as well as sophisticated ways of communicating this information to their nest mates. Butterflies, in contrast, have been viewed as indecisive and perhaps even indolent insects—no doubt because of their sometimes languid and seemingly random flight and their propensity for sipping nectar and basking in the sun. Recent work, however, shows that butterflies are adept and flexible learners. In some ways, learning ability may be even more important for butterflies (as well as moths, flies, and other solitary insects) than for the highly specialized workers in a beehive or other social colony, because each individual must carry out all the tasks necessary for its own survival and reproduction. It must forage for food and locate a mate—and the female must find the appropriate host plant or other suitable place on which to lay her eggs—all within the relatively brief span of its adult life.

Like many insects, newly emerged butterflies have some inborn preferences that get them headed in the right direction. They may be innately attracted to certain colors that help them locate flowers against a green, leafy background (yellow and blue are favorites of many species), and they may respond to certain tastes or odors that help them recognize plants that will make good hosts for their offspring. But butterflies also have a capacity for associative learning—that is, they can connect a color, shape, or other cue with a biologically important stimulus, such as nectar or a chemical that tells them they have found the appropriate plant on which to lay their eggs.

Most butterflies subsist entirely on a diet of floral nectar and, in return, help pollinate the flowering plants they visit. Not so surprisingly, they are good at learning to recognize flowers. Given an odorless droplet of sugar water in association with an object of a particular color, an inexperienced butterfly will quickly begin to choose that color from an array of colors. Several species have been shown to make the connec-
tion between a color and a sugar reward during just one exposure, a rate of learning comparable to that of honeybees. A learned preference can also be modified by subsequent experience. Kentaro Arikawa and his colleagues at Yokohama City University have demonstrated that Japanese yellow swallowtails conditioned to a given color can change their preference after only one exposure to a new rewarding color (you can teach an old butterfly new tricks!).

This capacity to learn is vital in a relatively unpredictable or seasonally changing environment. An inflexible innate preference for the color blue, for instance, could mean death for a butterfly that emerged from its chrysalis in a meadow filled with yellow and pink flowers. Migrating species in particular can benefit from learning to associate color with nectar. As a monarch butterfly travels all the way from Michigan to its wintering grounds in central Mexico, for example, it is bound to encounter a great variety of flowers.

With experience, butterflies also become more adept at extracting hidden nectar from complex flowers. Alcinda Lewis, of the University of Colorado at Boulder, found that on its initial visit to a clover flower, a cabbage white butterfly was apt to take more than ten seconds to locate the nectar. By the second visit, it could tap the nectar in less than five seconds, having learned to insert its proboscis into the appropriate spot and at the proper angle.

An ability to learn can also help female butterflies with the task of laying eggs. The females of many species deposit their eggs on just the few plant species that serve as food sources for the emerging larvae. Using her senses of sight and smell, a female butterfly detects a potential host plant from a distance but makes a final determination only after alighting on a leaf and tasting it with the receptors on her tarsi, or feet. She drums her foretarsi against the leaf surface, and if she detects the appropriate chemicals (biologists call them oviposition stimulants), she may lay eggs on the plant. If the chemicals are absent, she moves on. Research by Mark Rausher, of Duke University, and Dan Papaj, of the University of Arizona, has demonstrated that female pipe-vine swallowtails can learn to associate leaf shape with the oviposition stimulant present in the leaves of host plants (and even with the stimulant painted on leaves of nonhost plants). After laying eggs on such a leaf, the females will then tend to alight on plants with similarly shaped leaves.

Like bees, some butterflies may even be able to recognize landmarks. Larry Gilbert and his colleagues at the University of Texas at Austin have found that a number of species of the genus Heliconius visit the same flowering plants in the same sequence on a regular daily circuit within their home range. Much the way a trapper checks a trapline, these butterflies avoid sites where they have been caught and released with a net, and they also regularly return to the same roosting sites night after night.

I became interested in the subject of butterfly learning as a result of my work on flowers that change color. In many flowering-plant species, belonging to more than eighty families, individual blossoms undergo dramatic color changes before they begin to wilt. For example, Lantana camara flowers (which are pollinated by butterflies) are bright yellow when they open, then turn orange the second day and red the third. Similarly, the white flowers of horse chestnut trees (pollinated by bees) have bright yellow marks on the petals to show the insects where to probe; these nectar guides turn orange and then deep red. And the white spot on the upper petal of some blue lupines (also pollinated by bees) turns a deep magenta. Only during the first color stage do these kinds of flowers contain pollen and/or nectar and have receptive

finding various toxins that attack mammals' hearts and nervous systems, the researchers isolated a powerful sleep-inducing compound—apparently a kinder, gentler way of stopping predators in their tracks. Rats injected with the toad-skin extract immediately ceased their activities and fell asleep. The scientists monitored the rats' brains and detected alterations of serotonin levels and other chemical changes associated with deep sleep, brought on by the extract. ("A Sleep Inducing Factor From Common Indian Toad [Bufo melanostictus, Schneider] Skin Extract," Toxicon 38, 2000)

**EVOLUTION OF ALCOHOLISM** Human problems with alcohol addiction may well have an evolutionary explanation. Tropical biologist Robert Dudley, of the University of Texas at Austin, believes that scientists studying addiction should not assume that attraction to alcohol is a historically recent aberration.

During his five years of research in tropical forests, Dudley became interested in the connections between primates and fruit-bearing plants. Fermenting fruit (high in sugars and calories) can be a significant source of energy for mon-
keys and apes. Since wild fruit trees may be sparse and may grow far apart in the forest, competition among fruit-eating animals (which also serve as seed dispersers) is intense. Ethanol fumes from fallen, fermenting fruit permeate the air, signaling the presence of the trees to hungry frugivores. Being able to sniff out overripe, alcohol-laced, high-energy fruit may have resulted in a nutritional advantage for several kinds of creatures, including our primate ancestors.

People who habitually consume small amounts of alcohol, according to current medical research, may enjoy enhanced longevity and a lower incidence of cardiac disease. Dudley believes, however, that "genetically based behaviors adaptive in the ancestral environment become disadvantageous in a modern human environment that provides unlimited access to alcohol." This hypothesis is similar to those that link high rates of obesity and diabetes in humans to the historically unusual volume of fats and carbohydrates available in industrialized societies. ("Evolutionary Origins of Human Alcoholism in Primate Frugivory," Quarterly Review of Biology 75:1, 2000)

DOZING DOLPHINS Dolphins sleep differently than land mammals do. Slow-wave, or deep, sleep occurs in only one of their brain hemispheres at a time, so they are literally half asleep. They sleep with one eye open, and while dozing, they swim slowly in a counterclockwise direction, spaced tightly together in schools.

Patricia Goley, of Humboldt State University in California, wondered if there was any pattern to the dolphins' vigilance. Did one individual

stigmas. The initial question I wanted to answer was, Why does the plant retain the older flowers at all?

I focused on lantana flowers, which grow on bushes in clusters, each of which typically contains new as well as older blooms. By manipulating the clusters to create floral displays that differed in size, color, and amount of nectar, I found that a large display of both young and old flowers attracts the attention of butterflies from a distance, while at close range the color differences direct the insects to the younger, rewarding flowers. Both plant and butterfly benefit from this arrangement: the plant gets efficient pollination service, and the insect does not waste time probing flowers that lack nectar.

These observations led me to wonder about the importance of learning in guiding the butterflies' behavior. On a lantana bush in bloom, only about a quarter of the open flowers will be yellow. Foraging butterflies, however, probe hundreds of yellow flowers in succession, rarely inserting their proboscises into the red ones. I wondered if this behavior reflected an innate response to yellow, a learned response, or a combination of the two.

To investigate this question, I raised my own Gulf frilllary and pipe-vine swallowtail butterflies so that I could study individuals that had never been exposed to flowers or colors. To determine whether the butterflies had innate color preferences, I constructed daisy-like flower models out of colored paper in saturated hues of red, orange, yellow, green, blue, and purple. Yellow proved to be innately attractive. Inexperienced individuals of both species probed the yellow models most often, followed by the blue and purple ones. The butterflies also preferred yellow lantana blooms to red ones, even if the yellow ones were emptied of nectar.

Learning also played a role, however. When I provided these butterflies with lantana clusters that had nectar in the yellow flowers, they concentrated their probing to an even greater degree on these blossoms. And if they encountered clusters in which the nectar pattern had been artificially reversed, they focused their visits on the rewarding red flowers. When the color of the rewarding blossom was changed, butterflies trained to one color switched their responses to reflect the new nectar patterns within five to ten flower visits.

In an even more complicated feat, butterflies can learn to associate one color with nectar and a different color with an oviposition stimulant. Dan Papaj and I first trained female pipe-vine swallowtail butterflies to associate one color (either red, yellow, blue, or green) with an extract made from the leaves of the plant on which they lay their eggs. We then trained the same butterflies to associate a second color with the presence of a nectar reward. When we offered these butterflies an array of colored paper models (lacking any oviposition stimulant or nectar), most of them alighted on their two assigned colors, inserting their proboscises into models whose color signaled "nectar" but not into models whose color suggested that it was a good place to lay eggs (on these, they often drummed with their tarsi or even curled their abdomens as if to lay eggs).

Biologists have recorded some capacity for associative learning in almost every animal species that has been tested. But in many lineages, learning ability has likely been elaborated through natural selection. David Ste-
Capable of navigating long distances, monarch butterflies would have a hard time surviving if they had a built-in preference for only a few kinds of flowers.

live in such an environment. And indeed, most of those investigated have been shown to be capable learners.

Research done by Almut Kelber while she was at the University of Tübingen, Germany, has demonstrated that the hummingbird hawkmoth can learn to associate colors with sugar rewards and that these learned preferences are readily reversible. Tsukasa Fukushi, of Miyagi College of Education in Japan, has shown that sheep blowflies learn to associate sugar rewards with colors as quickly as honeybees do. The ability of male hover flies to return to precise midair locations after a chase, noted by Thomas Collett and his colleagues at the University of Sussex, England, suggests an ability to learn landmarks. And Nick Strausfeld and his colleagues at the University of Arizona have shown that cockroaches have a spatial learning ability: their facility for using distant visual cues to locate a cool spot on an uncomfortably hot surface improves rapidly with experience.

Investigation of the learning abilities of butterflies and other nonsocial insects may help us unravel much more than the evolution of learning. Flowering plants arose at least 130 million years ago, while social bees appeared sometime between 40 million and 80 million years ago. Other insects, including beetles, flies, butterflies, moths, and nonsocial bees—some of which predate flowering plants in the fossil record—have undoubtedly played an important role in the evolution of floral features. By studying both the learning abilities and the sensory capacities of these pollinators, we may discover the pathways by which flowers evolved.

Martha Weiss is an assistant professor of biology at Georgetown University in Washington, D.C.
Get a Grip

The gecko owes its superior climbing skills to atomic

acing up a tree at three feet per second, a gecko seems to defy physics. This lizard can generate enough sticking power with one toe to support its entire weight, yet it uses no detectable force when pulling away from the tree to take its next step. The secret to this climbing prowess, according to a group of researchers who call themselves the Gecko Team, is a special sort of stickiness. Geckos, the team has found, do obey physical laws, but it's the subatomic realm that makes the rules governing their ascension.

Led by environmental physiologist Kellar Autumn, of Lewis and Clark College in Portland, Oregon, and bioengineer Robert Full, of the University of California, Berkeley, and supported by IS Robotics (ISR) in Massachusetts, the Gecko Team studies on a microscopic scale how geckos climb. Thin leaves of tissue, arranged like pages in a book, cover the animal's toes. Each leaf is covered with hundreds of thousands of tiny hairlike growths called setae; a single gecko may have 2 million of them on its feet. These setae, in turn, branch into hundreds of spatula-shaped tips, each only 200 nanometers in diameter (smaller than a bacterium).

In the laboratories of Tom Kenny, at Stanford University, and Ron Fearing, at UC Berkeley, team members isolated individual setae and used a microscopic sensor to measure adhesive force. Simulating the movements of a gecko's foot, the researchers first pressed the seta against the sensor and then pulled it away. They discovered that a single seta could resist their efforts with surprising force—enough, in fact, to support the weight of an ant.

According to the Gecko Team, this reptile owes its sticking power to a faint interplay between the atoms on the seta's spatula-shaped tips and the atoms on the surface of whatever the animal is climbing. This interplay stems from a phenomenon known in quantum physics as van der Waals forces.

An atom is composed of a positively charged nucleus surrounded by a cloud of negatively charged electrons. If the positive charge of the nucleus equals the negative charge of the electrons, the atom as a whole carries no charge. But electrons flit unpredictably around the nucleus. Sometimes a number of them will pile up—just for an instant—on one side of the atom. When that happens, the atom temporarily has a
negative charge on one side and a positive charge on the other.

These fleeting charges can affect neighboring atoms. Picture a seta slapped up against the trunk of a tree. Now imagine that an atom on the seta's tip becomes charged and that its positive side is closer to the tree. This positive charge will attract the electrons of the closest atom on the tree trunk, drawing the two atoms together.

As the electrons of the seta atom continue to flit about, some hop over to the side of the atom nearer the tree. Since like charges repel each other, the electrons of the tree atom—which a moment ago were attracted to the then-positive side of the seta atom—are now pushed away. This in turn exposes the positively charged nucleus of the tree atom, which attracts the electrons of the seta atom and, once again, pulls tree and seta together. The on-again, off-again dance of electrons is enough to hold the atoms together.

Van der Waals forces also act between your hand and a wall—but weakly. On the atomic level, your skin is like a jagged mountain range, and only the atoms at the peaks come into close contact with the wall. But the design of geckos' feet, with their huge number of spatulate tips on every seta of every toe, allows many atoms to become intimate with a wall and act as a sort of glue.

If a gecko's toes were covered with real glue, of course (or with suction cups, as scientists once thought), a lot of energy would be required to break the seal whenever the gecko lifted its feet. But the Gecko Team found that changing the angle at which a seta meets a surface was enough to make it drop off the wall: tilting the seta may steadily increase the distance between the hundreds of spatulae and the wall until the seta peels off. The researchers suspect that when geckos walk up walls, the angle of the setae changes as they peel back their toes, allowing them to raise their feet.

Currently the Gecko Team is trying to turn its discoveries into inventions—better adhesive tape, for example. Tape made with artificial gecko setae would be powerful and reusable. The stickiness of gecko tape would be unaffected even in a vacuum (unlike ordinary tape, which owes part of its stickiness to tiny bubbles of trapped air). Astronauts could use gecko tape to attach equipment to the outside of a space station; computer engineers could use it to handle chips manufactured in vacuum chambers. Meanwhile, Fearing and Kenny are fabricating artificial gecko hairs to put on the feet of ISR's biologically inspired robots so that these devices can walk up walls. Perhaps someday the Gecko Team's research will change rock climbing forever. Simply by donning a pair of gecko gloves, covered with trillions of artificial gecko hairs, any weekend adventurer will be able to play Spider-Man.

Science writer Carl Zimmer's second book, Parasite Rex, will be published by the Free Press in September.
Few creatures, except perhaps the armadillo or the wild turkey, are as emblematic of the New World as the rattlesnake. Before Columbus's voyage, Europeans had never seen one. Rattlers are not found in Europe, Africa, or Asia, but almost every state in the Union (Maine, Alaska, Hawaii, and Delaware are the exceptions) has at least one species. Arizona boasts eleven. A total of seventy species and subspecies—ranging from gigantic diamondbacks, which may exceed seven feet, to an eighteen-inch subspecies native to only a few mountains in Arizona—are found in North, Central, and South America.

The most distinctive feature of this reptile, of course, is its rattle, made of two to ten hollow interlocking segments of a light, fingernail-like material. When the rattlesnake vibrates its muscular tail, each separate segment bounces against the adjoining segments, creating a buzzing sound that signals sensible folks to stay away. Unfortunately, not everyone does.

Recent reports suggest that the venom of North America's rattlesnakes is growing increasingly potent, making their bites more difficult to treat. BY STEVE GRENAARD

ones at fifty cycles per second, creating a buzzing sound that signals sensible folks to stay away. Unfortunately, not everyone does.

Most rattlesnakes are peaceable, retiring animals that flee for the underbrush when they encounter humans. Unless they are hunting rodents, rattlers strike only in self-defense. But if you step on one or try to capture it, a rattler will retaliate with a rapid strike that can be debilitating or even lethal. In the United States, about 8,000 people a year are bitten by rattlers or their cousins in the pit viper subfamily, which includes copperheads and water moccasins. In 1988 two doctors at the University of Southern California Medical Center analyzed 227 cases of venomous snakebite, covering more than a decade, and found that 44 percent occurred during accidental contact, such as stepping on the animal. More than 55 percent, however, resulted from the victim's grabbing or handling the creatures, and in

A western diamondback rattlesnake strikes, its fangs extended. The snake's forward lunge has been clocked at eight to eleven feet per second.
Neurotoxic venom makes the Mojave rattlesnake, above, the most deadly of all American snakes. Right: The northern Pacific rattler, a subspecies of the prairie rattlesnake, ranges over Oregon, Washington State, and northern California.

28 percent of these cases, the victims were intoxicated. The doctors' conclusion was that the typical snakebite victim is male and under thirty, with a blood-alcohol concentration of more than 0.1 percent at the time he is bitten. Yet only 0.2 percent of all snakebite victims die each year, and most of them receive no medical treatment or first aid.

Rattlesnake venom is not a simple poison. The snake's venom glands, located at the rear of the upper jaw and connected by ducts to its pair of hollow fangs, produce a complex brew of toxic peptides, polypeptides, and enzymes. In the venom, these toxins are combined in differing proportions that vary throughout a species' range and even during an individual snake's lifetime. Rattlesnakes harbor so many biochemical mixtures for venom that toxinologists who analyze the stuff confront a range of variations rather than a standard formula for each species. Some of this variability seems to reflect recent changes in the venom of certain rattlesnakes, from the hemotoxic and proteolytic type (which affects blood and other tissues) to the neurotoxic type (which attacks the nervous system). The first type hasn't changed into the second; rather, the proportion of neurotoxins in the mix appears to have increased in some areas of the country. Consequently, victims may now receive a significant dose of both types of poison from a single bite.

Matters seemed a bit simpler a few decades ago. Scientists knew that pit vipers produced a hemotoxic venom that was rarely deadly to humans. Except in Arizona and parts of Texas and California—home to the deadly, neurotoxic Mojave rattlesnake—most humans bitten in the United States could expect to survive. But they did experience depressed blood pressure associated with shock, destruction of tissue near the bite, massive swelling of the affected area, and hemorrhaging both near the bite and internally (caused by anticoagulants in the venom). If untreated, the area around the bite would become gangrenous and
Death from a neurotoxic bite can occur in as little as ten minutes and is usually caused by paralysis of the diaphragm.

Some people bitten by a neurotoxic snake turn black. Sometimes the venom would also attack the kidneys. People lost fingers or toes, but few died—particularly after the introduction in the 1930s of an antivenom made from horse serum. In the worst cases, a bite victim usually had an hour or two to get to a hospital before the situation turned dire.

Neurotoxic venom, on the other hand, doesn’t allow for such leisure, because it blocks nerve impulses to muscles, including those in the diaphragm that are used in breathing. Usually associated with members of the cobra family, a neurotoxic bite can cause immediate shortness of breath, weakness or paralysis of the lower limbs, double vision, inability to speak or swallow, drooping eyelids, and involuntary tremors of the facial muscles. Death can occur in as little as ten minutes, usually due to abrupt cessation of respiration. In the 1970s, researchers at the Veterans Administration Hospital in Salt Lake City, Utah, identified the Mojave toxin that makes this little reptile the most deadly rattler in the United States—even when its victims have been treated with antivenom.

Over the past few years, however, neurotoxic symptoms have appeared in several people who apparently were bitten by other species of rattler. In 1999 in Hesperia, California, an eighteen-year-old reptile hobbyist received a bite on the hand while trying to grab a local rattlesnake with his bare hands. The species was believed to be a southern Pacific rattlesnake, a subspecies of the prairie, or western, rattler. Within minutes, the young man developed general weakness, had difficulty breathing, and showed the classic neurotoxic symptoms of double vision, facial twitches, and an inability to swallow or talk. He recovered only after being treated with thirty-five vials of antivenom. The doctors who treated him, Sean Bush and Eric Siedenburg, of the Loma Linda University Medical Center, published a report of the episode, calling it the first known case of neurotoxicity associated with a suspected southern Pacific rattlesnake envenomation. Yet the victim also showed several classic symptoms of hemotoxic poisoning, such as hemorrhaging and swelling of the hand and arm. The doctors observed that even if the snake had been misidentified and was really a Mojave rattlesnake, the case would still be noteworthy “because envenomation demonstrating both venom A [neurotoxic] and venom B [hemotoxic] effects has not been reported previously from southern California.”

Do all populations of Mojave rattlesnakes have neurotoxic venom? While doing their work a quarter century ago, the Salt Lake City researchers found that they didn’t. In the western and southern parts of the species’ range in Arizona and southeastern California, many individuals had the more virulent Mojave A, whereas populations in other parts of Arizona and Texas had the nonneurotoxic Mojave B toxin. But it wasn’t long before populations with both A and B surfaced. Some herpetologists thought those results suggested the likelihood of interbreeding among local populations of the same species.

Of the fifteen species of rattlesnake found only in the United States, at least ten have been verified as having neurotoxins in their venom. Until recently, however, the low levels of these chemicals in the overall mix were not considered much of a threat to humans. The southern California case, along with a scattering of recent clinical reports from far-flung parts of the country, raises the possibility that the situation is changing. In 1998 in
Below: The canebrake rattler, a southern variant of the timber rattlesnake, has a more neurotoxic venom than its northern cousins. Overlapping territories on the distribution map, bottom, show possible areas of rattlesnake hybridization.

Alabama, the minister of a snake-handling sect died within ten minutes of being bitten by a timber rattlesnake during a church service. And last year in Florida, an army ranger on maneuvers in the Florida Panhandle stopped breathing only thirteen minutes after being bitten by a timber rattler. Fortunately, he had already managed to reach the hospital at Eglin Air Force Base, where he was resuscitated and successfully treated with forty vials of antivenom—four times the usual dose.

Are the genes for Mojave A toxin moving from Arizona westward and across the prairies to the East and Southeast? If so, one would have to consider the possibility that contiguous populations of rattlesnakes are interbreeding, creating hybrids at the borders of their ranges. Rattlesnakes have been known to produce such hybrids in captive situations. A captive-bred Mojave-diamondback hybrid is on exhibit at the Reptile World Serpentarium in Saint Cloud, Florida, and similar hybrids (some of which escaped into the surrounding countryside) were bred at the San Diego Zoo in California about fifty years ago. Mojave A toxins have been identified in the venom of some populations of prairie rattlers, western diamondbacks, timber rattlers (but not northern timbers), and eastern diamondbacks, even though researchers have not yet detected any direct evidence of their interbreeding.

Some scientists are convinced that they have found proof of rapid molecular evolution in the venoms of related rattlesnake populations. Others have difficulty believing that significant evolutionary change could be occurring within the space of a few decades. Another mechanism that might be capable of driving the development of rattlesnake venom to more lethal levels is the continual escalation of an evolutionary “arms race” between predators and prey. Texas A&M researcher John C. Perez and colleagues have studied forty species of mammals that are the natural prey of rattlesnakes in Texas, and they found that sixteen had substances in their blood serum that blocked the hemorrhagic effects of western diamondback venom. Selection may thus be favoring rattlesnakes with a more powerful venom that can subdue animals endowed with these chemical blockers.

Supporting this hypothesis is the work of James Biardi, Richard Coss, and David Smith, all from the University of California, Davis, who recently demonstrated that the California ground squirrel (Spermophilus beecheyi) suffered little after being bitten by its traditional nemesis, the northern Pacific rattlesnake. A factor in the blood serum of this squirrel actively inhibits enzymes (or proteases) in the venom that cause local tissue destruction, rupture of capillaries, and hemorrhage. The researchers found that the blood serum of squirrels in habitats...
where the northern Pacific rattler is abundant combat venom more effectively than does the blood serum of squirrels from locations where these rattlers are rare. Nevertheless, a good many squirrels (probably younger ones, with less resistance) still manage to get eaten by the snakes.

As an alternative to the arms race and the hybridization hypotheses, James Biardi has advanced a third explanation for the possible changes in rattlesnake venom. Such a shift, he suggests, could simply be a by-product of changes in snake demographics. For some years, researchers have known that juvenile rattles often have stronger venom than that of their larger, more mature counterparts—a difference that may have arisen because small snakes inject much less venom than adults and may go after different or faster prey. In some species, young snakes have a higher proportion of neurotoxins in their venom than do older individuals.

Because humans often kill, capture, or intentionally run over larger snakes when they encounter them, Biardi argues, we may be affecting the age of the overall rattlesnake population. One need only look at the annual “rattlesnake roundup” in Sweetwater, Texas, where in 1997 more than 18,000 pounds’ worth of rattlers were killed during the weekend hunt. Prizes go to those who bring in the largest and heaviest ones. To qualify for the competition, a hunter must submit at least 100 pounds of rattlesnakes. According to Biardi, if humans continue to selectively eliminate older rattlesnakes, it will be mostly younger ones—with the neurotoxic venom—that remain in the wild.

Whether the apparent shift to more neurotoxic venom in rattlesnakes is attributable to snake demographics, to hybridization and gene flow, or to the coevolution of predator and prey, doctors must now use much more antivenom to treat bites. Whereas five to ten vials used to suffice, patients today don’t seem to improve until they have been injected with between thirty and seventy. This is not simply a question of using a more massive dose of a known cure: like the venom itself, the antivenom is also a complex mixture.

Made by injecting horses (or rabbits or sheep or goats) with small, sublethal doses of particular venoms, antivenom is a biological concoction of antibodies. It can combat only the specific venom that was injected into the animals, however. In the United States, the only rattlesnake antivenom now available is made from the serum of horses injected with the venoms of several kinds of pit vipers.

While this preparation does not specifically include anti-Mojave antibodies, these may be present if Mojave A or B toxins are constituents of some of the venoms used. The presence of anti-Mojave antibodies in the current U.S. antivenom formula may be just as variable as it is in wild snake populations, and this unpredictability may explain why many vials are often needed to counteract neurotoxic venom. By administering vials from a number of batches, a physician may eventually find one with enough of the right kinds of antibodies to combat Mojave neurotoxins. Meanwhile, a British company is awaiting U.S. Food and Drug Administration approval of a new antivenom made from the serum of sheep that have been injected with Mojave toxins as well as with the venom usually injected into horses.

As the search for effective antivenom goes on, the rattlers continue in their propensity for remaining placid until disturbed. If we don’t bother them, they won’t bother us. It isn’t hard to see why rebellious eighteenth-century American colonists placed a rattlesnake across the thirteen stripes of the first Navy Jack flag, along with the warning “DON’T TREAD ON ME.”
A desert covering some half a million square miles, the Gobi arcs across vast portions of Mongolia and China. Every summer since 1990, a joint expedition from the American Museum of Natural History and the Mongolian Academy of Sciences has ventured into the remote reaches of the Gobi of Mongolia in search of fossils. The land, which appears so

Death in the Dunes

What killed the famous fossil creatures of the ancient Gobi? Geologists examine the rock-hard evidence.

By Lowell Dingus and David Loope

Ukhaa Tolgod, right, is the world's richest site of late Cretaceous vertebrates, such as the juvenile Protoceratops above.
desolate, is actually a paleontological paradise, and our discoveries of new and varied fossil animals in the region's rocks have been widely chronicled. But why, in this desert, is such an array of ancient animals coming to light? How is it that so many animals perished and are so finely preserved here? What was the ancient environment like, and how did the creatures die? We are finding answers not only in the fossil bones but also in the rusty red sandstones that contain them.

At Ukhaa Tolgod, a single small site discovered in 1993, expedition members have unearthed more than one thousand fossils of twenty species of mammals and reptiles. These date from the end of the Cretaceous and are from 71 million to 75 million years old. Ukhaa Tolgod contains the richest assem-
blage of fossil vertebrates of this age known anywhere in the world. Many specimens are of previously unknown species, and some have bridged gaps in our knowledge of the evolution of birds and mammals. What’s more, the bones are in excellent condition. Skeletons range from twelve-foot remains of the armored dinosaurs known as ankylosaurs, with almost every piece of bony plate intact, to two-inch skeletons of early mammals, complete down to their fragile, microscopic ear bones. Dinosaur nests, eggs, and embryos have also been preserved. Some of the animals have been captured not in death throes but in the ordinary (although last) acts of their lives—such as the theropod dinosaur Oviraptor sitting on its clutch of eggs.

The unusual fidelity of fossil preservation and the articulation of the bones—they were not jumbled by scavengers or scattered by the elements—indicate that many of the animals at Ukhaa Tolgod were killed quickly and buried quickly in a catastrophic event. In addition to identifying the creatures and their attributes and relationships, we wanted to know what was responsible for the mass mortality and swift burial. To find out, we needed to examine the rocks, because they hold the clues to the area’s ancient environment.

Today the Mongolian Gobi is a land of windswept basins and rugged ranges (“Gobi” is Mongolian for “waterless place”). Sand dunes, shaped and moved slowly by the wind, migrate across the valleys. Violent sandstorms and thunderstorms occasionally interrupt our hikes across the sparsely vegetated ridges and ravines in search of bones exposed by erosion. A sandstorm can instantly send a tent careening across the landscape. The only way to avoid being sandblasted by wind-blown grit is to run for the cover of our expedition’s trucks and jeeps.

Some of the sandstones at Ukhaa Tolgod represent the solidified remnants of ancient sand dunes and have a distinct structure of thin, inclined layers, called cross beds. Similar layering is apparent today in dunes in the Gobi and other sandy deserts. It comes about when sand grains, blown by strong winds, bounce up the gently sloping windward side of a dune and then tumble down the steep leeward side. Over time, the dune will migrate in the direction of the wind. At Ukhaa Tolgod, the cross-bedded rocks consistently lean about 25° toward the northeast. This indicates that during the late Cretaceous, the dunes here migrated in that direction, driven by winds from the southwest.

The cross-bedded sandstones and the natural mobility of dunes have led to a popular hypothesis that the fossil animals of the Gobi were killed by violent sandstorms. At first, this is an appealing idea. But we have searched the travel literature and have found no modern analogies, no descriptions of animals being buried alive by drifting sand during such storms in the deserts of either central Asia or Arabia. Whether ancient or modern, no healthy animal is likely to let itself be inundated by sand to the point of suffocation. Furthermore (and contrary to popular belief), deserts in continental interiors, such as the modern and the ancient Gobi, are much less windy than those in humid coastal areas. Along a sandy coast, the frequent passage of atmospheric fronts and the differences between land and sea temperatures lead to more wind and more active dunes. In addition, many geologists view the Cretaceous as a “greenhouse” period in Earth’s history, when, even in high-latitude continental interiors, winter temperatures remained above freezing, reducing air pressure gradients and windiness. This view is based on fossil evidence of crocodiles from the Gobi. All these factors argue against sandstorms as an explanation for the burial of the Gobi animals, but we have found that the structure of the rocks at Ukhaa Tolgod makes an even more compelling case against this cause of death.
None of the fossil bones from this site were collected from the layered sandstones generated by Cretaceous dunes. In rare instances, within a layer of cross-bedded sandstone we have found deformations that resemble a stack of bowls in cross section and that record footprints—complete with toe and claw impressions—of dinosaurs that had trekked across the dune field. But these layers contain no bones. All the skeletons we have excavated come from a second type of sandstone: massive, structureless slabs that contain none of the internal layers typical of dunes. When we looked closely at these, we saw that some contained large, isolated pebbles too big to have been wafted into the deposit by wind. We needed to find a different agent to account for these structureless sandstones.

To complement our work in Mongolia, we have been studying a modern site half a world away. Nebraska's Sand Hills give us a modern analogue of how the Gobi sandstones may have formed. A large, relatively young dune field in the western part of the state, the Sand Hills rise as high as 400 feet and are stabilized by vegetation. In early summer during wet years, the grass-covered landscape looks more like Ireland than Arabia. As with the layered sandstones at Ukhaa Tolgod, the leeward sides of the Nebraska dunes slope 25° to 30°. Most of the rain falling in the Sand Hills infiltrates the permeable sediments, seeps downward, and slowly leaves the groundwater reservoir through springs. Heavy rains during summer thunderstorms, however, can trigger sudden avalanches of wet sand, called debris flows. One rancher showed us a photo of his pickup half-buried in sand during a cloudburst. Other residents tell of their calving sheds—built on the leeward sides of big dunes for protection from the wind—being rapidly filled by slurries of sand. In other parts of the world, such debris flows carry large pebbles that "float" in the sand as it moves, as did those at Ukhaa Tolgod. Are the conditions that generate the Nebraska debris flows closely analogous to forces that acted on the Gobi dunes 75 million years ago? Did rain-soaked sand act like wet cement to trap the denizens of Ukhaa Tolgod? While Nebraska debris flows can deliver a slab of heavy, wet sand up to 900 feet long, 4 feet thick, and 50 feet wide, they are not likely to annihilate larger animals in their path. We have never encountered a farmer who has lost a cow to such an event. And because the Sand Hills lie northwest of the route taken by most of the tropical storms that could soak the dunes, rainfall of more than an inch an hour over several hours is rare. Any similar sand slide in the Gobi would have had to be on a much larger scale to have caused the demise and fossilization of the animals there.
During intervals when the climate of the ancient Gobi was dry, dunes migrated in the direction of the wind.

During less arid intervals, lasting hundreds to thousands of years, dunes were held in place by vegetation, and layers of cementlike caliche formed under their leeward slopes.

Based on the cross beds' thickness, which represents only a fraction of the height of an original dune, estimates for the heights of the Gobi dunes during the Cretaceous range from a probable 300 feet to possibly more than 800 feet. We also know that in the late Cretaceous, mountains rimmed Mongolia's basins to the west of the Pacific Ocean, which was then quite warm. The ancient dune fields of the Gobi were most likely subject to occasional drenchings whose magnitude would dwarf any that hit western Nebraska today.

More evidence of wet periods comes from the Flaming Cliffs, another of Mongolia's rich fossil sites. Here the expedition discovered near-vertical, mud-filled burrows less than one inch in diameter but reaching nine feet in length. The burrows were probably made by creatures with life cycles similar to those of modern crayfish. These animals thrive during rainy periods, but during droughts, they excavate burrows to reach the water table and escape death from desiccation. The expedition team found branches off the main tunnels, indicating that the animals repeatedly dug themselves out after muddy floods had clogged their burrows. More clues to climate came from discontinuous mudstone layers, representing ephemeral ponds between dunes, and from the fossilized roots of dune plants.

In 1996 we found evidence that the huge dunes at Ukhhaa Tolgod migrated only intermittently. Beneath the dune slopes we detected thin bands of sand grains cemented together by calcium carbonate. Such bands, called caliche, form two to three feet below the sediment surface and become cemented only after hundreds to thousands of years of dune stability in a low-wind setting.

Not until 1998 did we realize that the caliche might help us interpret how the fossils were preserved. Because it blocked the infiltration of rainwater through the dune during heavy rainstorms,
the caliche caused a steeply sloping slab of wet sand to build up above it, setting the scene for giant debris flows. The recent devastating debris flows (of mud rather than sand) on the mountain slopes of coastal California and in Central America were triggered when heavy rains infiltrated the soil but were then blocked by bedrock. The saturated soil was "lifted" by the water between sediment grains, decreasing the friction between the soil and the bedrock. Under dry conditions, such friction stabilizes the slopes, but the heavy rains undermined their stability and led to deadly cascades of mud. In the Gobi, similarly weighty, water-saturated sand above the cemented caliche zone would have broken loose and quickly moved down the long dune slope, entombing any nesting *Oviraptor*, foraging ankylosaur, or small scurrying lizard or mammal in its path. In the process, the slide ensured the preservation of their remains.

The two types of sandstone formations at Ukhaa Tolgod probably represent two distinct climatic regimes that prevailed there at different times. During the late Cretaceous, the Gobi's climate was not always hostile. Long periods of aridity were interrupted by warm, wet—or at least semiarid—intervals that lasted from thousands to perhaps tens of thousands of years.

The cross-bedded sandstones represent dunes from the dry intervals, when plant and animal life was less abundant. They give us a picture of a dry desert subject to sandstorms, with moving dunes that, in rare cases, captured the footprints of larger animals traversing them but that contain no bones. By contrast, the large, structureless, fossil-rich sandstones were formed by debris flows from huge, nonmigrating dunes. When atmospheric circulation changed, bringing rain from the warm Pacific, vegetation grew upon and anchored the dunes, and caliche cemented the sand just below their surfaces. The animal community was full and varied. The plants supported a variety of large and small herbivores that in turn were prey for carnivores and scavengers. To fully explain the presence of the Gobi fossils, all the key elements—large, steep dunes, heavy rainfall, caliche, and abundant animal life—had to coincide in time and space. Some 75 million years ago in the Gobi, they did just that—and left us a rare treasury of fossils.
Animals were suffering and dying in the southern Kalahari Desert in October 1995. It had not rained in more than a year. One afternoon, I spotted a starving old lioness lying in the sparse shade of a camel thorn tree near the Bedinkt water hole in what is now Kgalagadi Transfrontier Park. At first I thought she was dead. I positioned myself nearby with my camera, wondering whether her bony carcass would attract any scavengers.

Before long, a brown hyena loped over the rise and began staring at the motionless cat. Rather than approach her, it descended the slope and waded into the water for a drink. Instantly the lioness got to her feet and began to stalk the hyena with silent concentration. Summoning her last reserves of strength, she leaped into the muddy pool and grabbed it. Although the hyena struggled furiously, the old lioness was resolute. One or the other was going to survive this day. The desperate, prolonged growls and screams of their ten-minute death match will always remain with me. Although pitifully weak, and with her canine teeth worn down to stumps, the lioness nevertheless managed to drown the hyena in the shallow water.

She dragged her prey to a nearby bush, but her attempts to rend the carcass failed, because her teeth were practically useless. I had to return to camp and never saw the old lioness again. The next day, however, I went back to read the tracks and other signs around the water hole. They showed that she had in fact managed to feed on the hyena. Soon afterward, the drought broke and the area teemed once more with life.
Matter of Survival
Fascination
of
Nature
by Roderick Whitfield

Since ancient times, Chinese philosophers, poets, and artists have taken time to observe the tiniest and humblest denizens of the natural world. No subject was too small to be worth studying, none too familiar to be included. A willingness to empathize with other creatures and to study their behavior resonated with the Daoist way. In one of the most celebrated stories from his fourth-century B.C. text, *Zhuangzi*, the philosopher Zhuang Zhou recalls a dream in which he was a butterfly. Awakening suddenly, he was quite confused, not knowing if he had been dreaming of the butterfly or if he were a butterfly dreaming of Zhuang Zhou.

A fourteenth-century silk handscroll, its title translated variously as "Glimpses of Life in Heaven and Earth" and "Fascination of Nature," exemplifies this close attention to the natural world. Eleven inches wide, twelve feet long, and signed in 1321 by an artist named Xie Chufang, the painting is a depiction of insects' struggle for survival and perhaps an allegory of political events during the Yuan dynasty (1280–1368), when the whole of China was under Mongol rule.

At the end of the scroll are four poems by contemporary Chinese literati that seem to be oblique expressions of frustration with Mongol rule. One poem by a loyalist scholar reads:

Small insects labor to eat, each to his own. Hiding and spying, ambushing, they prey on each other. Inheritance and profit are not according to justice, Their knowledge is no more than carefree boldness.

—Chen Shen (1260–1344)

During the Yuan dynasty, many scholars and civil servants dropped out of government service and turned their talents to painting and writing; the state examination system by which they were recruited and promoted had been suspended, and they did not wish to serve under the Mongols. Thus, the scroll's images of a lizard on the prowl, a snail steadily climbing up the underside of a cabbage leaf, the industry of ants, and a hapless cicada clinging to a weeping willow and falling victim to a predatory mantis—all may be interpreted as subversive commentaries on the oppressive authority of the Yuan dynasty.

Plant and insect painting—caocheong—had been a recognized genre of Chinese art during the Northern Song dynasty (960–1127). In that period, most representations of nature carried auspicious meanings: bamboo, for example, signified resilience in the face of adversity, while the cicada, a paper wasp carries a leaf fragment to its nest, hidden among bamboo shoots intertwined with a morning glory in bloom.

A fourteenth-century Chinese scroll minutely records the ordered world of insects and hints at turmoil in the human domain.
The scroll (which reads from right to left) opens with a dragonfly attacking its prey. A toad, partially hidden under a plantain, prepares to catch some ants with a lightning flick of its tongue. The seal in the bottom right corner is that of the early-eighteenth-century collector Geng Jiazuo, who once owned the painting.

How did the scroll turn up in late-eighteenth-century England, where Chinese painting was virtually unknown?
because of its long underground pupation and its supposed ability to exist only on dew, bespoke immortality. The morning glory, opening its blooms daily for only a few hours, was celebrated for its shy beauty.

One views the Robinson Scroll, as Xie Chu-fang's painting is known, in the traditional way—from right to left. In midair a dragonfly, with unmistakable predatory intent, engages a much smaller insect. On the ground below, which is barely indicated by a few scattered clumps of bright green dots arranged parallel to the lower edge of the scroll, ants mill around and drag along a small butterfly (its upper and lower left wing are seen from the underside), already partially dismembered. An ant procession, with another wing in tow, leads past a fine specimen of Asian plantain—Plantago asiatica, known in Chinese as the "weed under the wheels"—shown laden with flowers and seeds. Under the largest of its leaves, already fading and worm-eaten at the tip, a toad lies in wait to prey upon a stream of ants as they pass close by. An astonishing variety of other creatures—a lizard, a snail, a tree frog, a moth, a bush cricket, as well as grasshoppers, cicadas, and wasps—are depicted in and around the flora. No one who sees the painting can fail to admire the remarkably lifelike qualities of the animals and plants.

The signature on the inner cover of the scroll, "W. Butler 1797," is that of William Butler, a writing master in a school for young ladies in London's East End. How did the scroll turn up in late-eighteenth-century England, where Chinese painting was virtually unknown (except for wallpapers and
“Company paintings” of Chinese scenes, commissioned from Cantonese artists by East India Company traders? We shall probably never know for certain, but the date suggests a possible connection with Lord Macartney, leader of the first British diplomatic mission to China in 1792–93. Following Butler’s death in 1822, the scroll was acquired by Sir Thomas Phillipps (1792–1872), whose vast collection of books (some of which had indeed come from Lord Macartney’s library) included a handful of Chinese works of art. Then in 1946, bibliophile Philip Robinson purchased a large portion of Phillipps’s collection.

Entranced with the scroll despite experts’ dismissal of it as inconsequential, Robinson brought it into the British Museum on June 29, 1982, to ask my opinion. It was an exciting moment. Although the object was in a fragile state, I immediately recognized it as the most important discovery of my sixteen years as assistant keeper in the Department of Oriental Antiquities. Once it had undergone conservation in the museum’s Oriental mounting studio, I was able, with Robinson’s enthusiastic encouragement, to research the scroll’s authorship and history.

Toward the end of the Yuan dynasty, scholar-painters moved on to landscape painting and calligraphy. But the established repertoire of plants and insects, brought to vivid life in the Robinson Scroll, had found its niche. In succeeding dynasties, artists working in a new genre—the decorative blue-and-white underglaze painting of porcelain vessels—continued to render leaves, flowers, insects, and animals in minute and accurate detail.
No subject was too small to be worth studying, none too familiar to be included in the portrayal of the natural world.
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SYMBIONTS AND ASS

INSIDE OUR CELLS LIVE
THE MITOCHONDRIA—
MYSTERIOUS LIFE-FORMS
THAT ARE THE SOURCE
OF ALL OUR ENERGY
AND PERHAPS OUR
MORTALITY AS WELL.
BY GUY C. BROWN
The modern cell, now found throughout our bodies, arose a billion years ago from the fusion of two different cell types: big and little. Big ones swallowed little ones but for some reason did not digest them, and the little ones ended up living inside the big ones. Over time, the little ones lost their independence; they handed over most of their DNA and molecular machinery but gained a safe haven within the large cell. The little ones became the mitochondria, and the big ones became modern cells.

Of all the beasts on this Earth, mitochondria most resemble bacteria. They are the same size as bacteria (about 1 billion would fit into a grain of sand); they are bounded by two thin, membranous walls like those of bacteria; and inside they have similar machinery and a similar type of DNA. Our bodies contain roughly 10 million billion of these bugs. They are so used to living inside us—and we are so used to having them around—that we cannot live without each other now.

The single mitochondrion takes many shapes and forms. Caught in an unflattering snapshot, it looks a little like a worm—but a worm that writhes and splits in two and fuses with other worms. Sometimes we catch a mitochondrion looking like a zeppelin, sometimes like a multi-headed and multitaloned beast, sometimes like a weird snarl of crisscrossing tubes and plates. The mitochondrion is a dragon with a monstrous appetite. It eats again everything that we eat and

**LEAKY POWERHOUSES**
Mitochondria produce virtually all of a cell's energy. They use the oxygen we breathe in to burn the food that we eat. Just like a power station burning coal or gas, the mitochondria use the energy released from the burning process to produce electricity. So our cells are really powered by electricity. The mitochondria's electric machines (called respiratory electron transport chains) are minute, as are the mitochondria's spinning electric motors. Driven by proton electricity, these produce adenosine triphosphate, or ATP—a convenient form of energy for the rest of the cell.

But the mitochondria's "power stations" appear to have one spectacular design flaw: they leak. Electrons slip out into the cell and produce the toxic, highly reactive chemicals known as free radicals. These have unpaired electrons that are driven to bond with any other electrons they can find, causing mayhem and chaos in the cell. Proton electricity leaks out, too. Up to one-quarter of the energy our bodies generate is apparently wasted this way.
breathes it forth as fire: virtually all the food and oxygen taken into the body are consumed by the mitochondria, and they produce most of our energy and body heat.

How the first living cells got their energy, we do not know, but within the first half-billion years of life’s history, some were able to harvest light from the nearest star, our Sun. This simple yet powerful process, photosynthesis, enabled life to take off in a big way. But the oxygen released as a by-product of photosynthesis built up until, about a billion years ago, it reached the level it remains at today (one-fifth of the air is now oxygen). This was the first global pollution event and ecological disaster. With oxygen at such a high level, many types of cells must have been killed off (just as many types of bacteria are killed by oxygen today). Some survived because they evolved an enzyme machine that could consume the oxygen at a rapid rate. Cells with such respiratory machinery seized the opportunity and thrived, using the extra energy to do useful internal tasks. When these cells were engulfed by larger cells, they did the work of respiration for their hosts.

The larger cells may have made a devilish bargain, however. The very machinery the mitochondria use to produce energy and consume oxygen also leaks electrons, producing superoxide and other toxic free radicals. The name “free radicals” may suggest a benign group of political intellectuals, but in fact they are a subversive group of chemicals that create havoc within the cells and are suspected of causing aging and many diseases. Thus, the modern cell bought its greatly enhanced energy supply at a high price.

Extensive new research shows that in harboring the mitochondria, our cells may also have taken in their own executioners. That the mitochondria would carry out the death sentence of the cell makes a lot of sense. The stupendous juggling act that is cell life depends on a continuous supply of energy from the mitochondria; without it, the cell literally falls apart. Mitochondria are extremely sensitive to damage by such things as toxins, free radicals (some of their own making, some not), excessive calcium, and lack of oxygen. When the mitochondria are damaged, the energy supply to the rest of the cell fails. Molecules that are meant to be kept outside the cell cannot be stopped from coming in, and molecules that are meant to be inside cannot be stopped from leaking out. The knock-on effect is that the whole cell spins out of control. Its death is inevitable.

Cells can die in two different ways, however: chaotic explosion or controlled suicide. The former is known as necrosis and the latter as apoptosis. Necrosis is a frenzied, savage form of killing, leaving the blood and gore of the cell all over the place. The mitochondria and other parts of the cell blow up like balloons and explode. Necrosis can be a big problem for the rest of the body, too, because the release of a cell’s total contents, including toxic chemicals and enzymes, damages...
surrounding healthy cells and causes general inflammation. Apoptosis, also known as programmed cell death, is a much more orderly process, in which the cell is gradually disassembled from within and then engulfed and digested by white blood cells.

But why would a cell commit suicide? Usually apoptosis occurs because the cell is not needed anymore (excess brain cells, for example, are discarded during human embryonic development, as are the cells in a tadpole's tail when the larva metamorphoses into an adult frog) or because it is diseased (a cell that is cancerous or infected by a virus). So apoptosis plays a vital role in protecting the body. The problem is that this suicide program occasionally gets out of control. When apoptosis is overactivated (as in stroke and such neurodegenerative conditions as Alzheimer's and Parkinson's diseases), an excessive number of brain neurons die. On the other hand, the inactivation of the apoptotic machinery is one of the key changes that allow cancerous cells to survive.

The hara-kiri of apoptosis is executed by molecular machines called caspases. These are molecular "scissors" that, once activated, go around the cell cutting up other kinds of molecular machines. Caspases are activated by being cut, so once the process gets started, it snowballs into an avalanche of molecular snipping, reminiscent of the finale of a slasher movie.

In 1996 the new but rapidly expanding field of apoptosis research was agog when Xiaodong Wang, of the University of Texas, reported that this orgy of cutting was initiated by the release of cytochrome c from mitochondria. Cytochrome c is a small and venerable protein discovered by David Keilin in 1933 and long known to be central to energy production in virtually all forms of life. What was it doing initiating cellular suicide? Nobody I talked to at the time believed it, but it turned out to be true. Cytochrome c is normally

FROM MOTHERS ONLY
Mitochondrial DNA divides, evolves, and is inherited separately from nuclear DNA. Virtually all the mitochondrial DNA in our bodies comes from our mothers, because when a sperm penetrates an egg cell during conception, it delivers a full load of nuclear DNA but only a few or no mitochondria. The huge egg cell, however, contains tens of thousands of them. This maternal inheritance of mitochondrial DNA is important in a number of ways. It means that mitochondrial defects are inherited down the maternal line only. Thus, if you are lethargic (or hyperenergetic), you may have to blame your mother's mitochondria. Although there are many contributing factors to lethargy apart from defective mitochondria, and although the coding for many components of the mitochondria comes from nuclear rather than mitochondrial DNA, we now know of many maternally inherited mitochondrial DNA diseases that cause chronic tiredness and other, more serious symptoms.
condition, so the cell is seemingly condemned to necrotic death; second, cytochrome c is released, triggering apoptosis.

This seems to be what happens to our cells during a heart attack or a stroke, both of which do their damage by blocking the blood vessels supplying the heart and brain, respectively. In these unhappy circumstances, the heart and brain cells cannot obtain sufficient oxygen for their mitochondria. The mitochondria respond by opening their pores. Apoptosis is not always quick enough to preempt necrosis, and if the damage is severe enough, there will not be enough energy to power apoptosis. Some cells (probably those that were most damaged by the blockage) will die by necrosis. Others die by apoptosis and are rapidly cleared away.

Drug companies are now racing to develop drugs that block apoptosis or stop the opening of the pores. However, it is unclear whether blocking apoptosis would be beneficial, because a “rescued” cell may end up dying by necrosis, thereby causing further damage. Even if necrosis, too, is blocked, the damaged cell may function abnormally or produce free radicals—resulting sooner or later in dysfunction in the body.

**EVOLUTION OF WARM-BLOODEDNESS**

Toward the end of the reign of dinosaurs, some animals (the future mammals and birds) evolved endothermy, or warm-bloodedness. This was a risky business: in order to produce so much heat, the animals had to eat ten times as much food. But the payoff was that everything in the body would work faster, and body temperature could be independent of how cold or hot the environment was. The heat was produced by the mitochondria’s normal energy-producing machinery—only there was more of it, and the machinery was leakier than in cold-blooded animals. The result of all this is that today’s warm-blooded animals, such as mice and men, are very inefficient energy users compared with lizards and crocodiles.

An animal’s energy situation is somewhat similar to that of a car. When a vehicle is not being used in cold weather, its engine temperature falls. The car may not start well and works rather sluggishly until the engine warms up. To overcome this problem, we could allow the engine to run all the time (even when the car is not moving). The obvious disadvantage of this strategy is that it is very inefficient in terms of fuel consumption. Warm-blooded animals seem to have adopted it, however. But because it is almost impossible to determine the history of a biological process, we may never know the role of the mitochondrion in the evolution of warm-bloodedness.
The revelation that our mitochondria, these ancient monsters that we once thought were our tame and benign pets, are in fact our potential executioners has reawakened the sleeping field of mitochondrial research with a jolt, putting it at the forefront of biological and medical research. Are the mitochondria friends or foes? As one researcher recently put it, mitochondria are like the legendary Scandinavian sea monster, the kraken. When left alone in their deep evolutionary slumber, mitochondria are certainly our friends, but when roused they can destroy us. As Tennyson wrote of the kraken,

There hath he lain for ages, and will lie
Battening upon huge sea-worms in his sleep,
Until the latter fire shall heat the deep;
Then once by man and angels to be seen,
In roaring he shall rise and on the surface die.

MITOCHONDRIA AND AGING

Mitochondrial DNA mutates and evolves at something like ten times the rate of nuclear DNA. Most of these mutations are harmless, but some compromise energy production in the cell. Very few such mutations are detectable in our cells before the age of thirty or forty; after that, however, they rise exponentially. In old age, the proportion of mutant mitochondrial DNA may be so high that it significantly damages our ability to generate energy. We do not know what causes human aging, but one promising theory proposes that it arises from dysfunctional mitochondria.
The Lobster Pickle

All’s well with the American lobster population. Or is it?

By Robb Walsh

Rusty Court steers the Casey Anne, his forty-two-foot lobster boat, around Maine’s Boothbay Harbor as if it were the family station wagon. Zigzagging between moorings and dodging sailboats, he stops alongside another lobster boat to compare notes on the day’s catch. While he navigates, I try to interview the old salt.

“So, Rusty, have you been lobstering all your life?” I ask.

“Not yet,” says Rusty, straightforward. He leans overboard with a grappling hook and snags the pink-and-black float that identifies one of his lobster pots, tosses the float aside, hooks the line onto a power winch, and pulls a footlocker-sized, rubber-coated wire trap up from the bottom. Two undersized lobsters snap at his fingers when he reaches in to free them. Rusty points to an escape hatch in the pot through which small lobsters can exit, but these creatures were evidently too engrossed in their herring-bait dinner to try to get away.

Like all lobstermen, Rusty carries a gauge for determining the size of a lobster. The gauge is hooked onto the back end of the crustacean’s head section and extended from there to the eyeball. The distance must measure at least three and one-quarter inches or the lobster can’t legally be taken. Rusty says as he shows me the gauge, but he doesn’t bother to use it on these two small fry—he simply throws them overboard.

In the slate blue waters of the harbor—among the reflections of expensive wood-shingled summer homes, Victorian inns, and canvas-swathed sailboats—thousands of color-coded lobster-pot markers are bobbing around. Boothbay Harbor (about twenty-five miles northeast of Portland, as the crow flies) is a port of call for the yachting crowd and a summer address for the rich and powerful. For most of its existence, though, it was just a humble lobstering town.

To remind you that they aren’t like their rich neighbors, lobstermen love to complain about how poorly their work pays. “Did you hear about the lobsterman who won a million dollars in the lottery?” Rusty inquires. “They asked him what he was going to do with all that money. He said, ‘Just keep lobstering till it runs out, I guess.’”
Lobster fishing in New England is traditionally done from June through the New Year. Few lobstermen fish in midwinter, when lines, decks, and tackles get coated with ice. The ordinary American lobster, _Homarus americanus_, inhabits Atlantic coastal waters from Labrador to North Carolina but is especially prevalent along the New England coast. Until the end of the nineteenth century, lobster was so plentiful that it was commonly used for fish bait. Lobstermen claim that the _H. americanus_ population is still very healthy, but some marine scientists think that unless steps are taken soon, lobstering may collapse as completely as the cod fishery did in the past decade.

When I ask Rusty if the lobster supply is declining, he says, “No, the catch has been pretty constant over the last few years.” That’s Rusty’s experience. And in fact, the catch for all of Maine has been steadily increasing since the late 1980s: from 9,860 metric tons in 1988 to 21,335 metric tons in 1998. According to Rusty, Maine keeps tight control over lobster fishing. In 1999 the state issued 8,160 lobster licenses, and 5,927 of those were commercial. Each license holder must abide by the statewide limit of 800 traps, although certain areas, such as Boothbay Harbor, have a lower limit of 600 traps per license. That’s just “too many licenses and too many traps,” maintains D. Winsor Watson, a University of New Hampshire zoology professor who studies the lobster population.

What about Rusty’s contention that the fishery is robust? “He’s right,” Watson says. “It’s a strong fishery right now. But one of the scary things we see is that we are catching something
like 90 percent of the legal lobsters every year. I am concerned that we don’t have enough reproductive-sized lobsters out there. We are harvesting lobsters just as they reach the age at which they can begin to reproduce.” That age varies from five to nine years.

Aside from direct observation in the lab and tagging experiments that track the fate of individual lobsters, there’s no way to determine the age of a lobster. The crustaceans grow faster in warm water, and before becoming sexually mature, they may reach the size at which they can legally be
gotten when they get too big to exit through the escape hatch.

Lack of pressure from predators may be another reason that the lobster population has been able to support a strong fishery. Small lobsters were once eaten by cod and other large fish, but overfishing has removed most of these fish from New England waters. What if a new lobster predator were to arise?

In another University of New Hampshire study, video cameras recorded predators attacking lobsters that had been tethered to the ocean floor. The surprise dinner guests in these tapes are

Overfishing has removed most of the cod and other large fish that once ate small lobsters in New England waters. What if a new lobster predator were to arise?

caught. Big lobsters are getting rarer and rarer.

In the past, the only way to monitor the lobster fishery was through the statistics of the catch. Now Watson and his students have done a number of studies that give a better picture of the population. In one study, a baited lobster trap with a video camera attached was lowered into the sea at different depths in various habitats. Replayed at high speed, the video recordings are somewhat comical. One of them shows a dozen or so small lobsters that appear to enter and exit a cage every few minutes, although Watson warns that it’s not really clear they’re the same lobsters, since they often go beyond the camera’s reach before returning. Lobster pots, the video suggests, not only trap lobsters that are big enough to harvest but also act as feeders for undersized ones. In heavily fished waters, such as Boothbay Harbor, the undersized animals probably learn to depend on the traps for food, thus guaranteeing their being har-
skates, which aren’t usually regarded as lobster predators. The cameras recorded hundreds of graceful, raylike skates honing in on the crustaceans. So far, skates haven’t had much impact on the lobster population, but the absence of cod and other big fish has made the ecosystem more unpredictable.

How the lobster population maintains itself is baffling, Watson concedes. Maybe the 10 percent of it that the lobster traps miss are incredibly fertile, he suggests; more likely, however, large offshore lobsters are supplying new individuals and making up for the absence of sexually mature lobsters inshore. One would expect a graph of the size and frequency distribution of Atlantic inshore lobsters to show a bell curve, says Watson, but the graph actually describes “half a bell curve,” falling away to nothing at the point where the legal size limit is reached. Meanwhile, the graph for lobsters 100 miles offshore indicates the presence of more big ones there than inshore. In Watson’s view, it’s time to reconsider lob-
ster fishing limits in the United States, especially in light of what has happened to the cod and other New England fisheries. He believes that raising by half an inch—from three and one-quarter to three and three-quarter inches—the size at which lobsters can legally be caught could make a big difference. The problem with proposing tighter limits is that environmentalists and marine scientists have been predicting doomsday for the past twenty or thirty years, and doomsday has not yet occurred. Watson knows that tackling the problem presents “a political nightmare.”

Lobstermen like Rusty Court are part of a revered New England fishing tradition. To side with environmentalists, marine scientists, and other doomsayers against the wisdom of these old-timers seems like a betrayal of our heritage. And nobody knows this better than the scientists. “The lobsters think we’re crazy, and maybe we are,” says Watson. “I’m just a scientist. I don’t have all the answers. But I don’t have any financial interest in what happens one way or the other, either.”

Watson would love to see the United States adopt seasonal limits such as those used in Canada. He also points to the tightly regulated and extremely lucrative Australian lobster business as a model of a well-managed lobster fishery. A complete overhaul of the U.S. lobstering industry is unlikely, but a number of small steps—raising the size limit, reducing the number of pots per license, or instituting a defined season—could have a positive effect on the H. americanus population. “If we wait until the lobster harvest starts shrinking, then it’s going to be too late,” Watson warns. “When the lobster population crashes, it’s going to crash in a major way. And we are not going to see it coming.”

Robb Walsh writes about food for the Houston Press.
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WHO'S ON FIRST?

There's still no end to the controversy over when and how humans populated the New World.

By Anna Curtenius Roosevelt

A little less than 13,000 years ago, as the Ice Age was drawing to a close, big-game hunters crossed the Bering land bridge from Siberia into the Americas. By 12,000 years ago, they had made their way south from the interior of Alaska through an ice-free corridor to the high plains of North America. Hunting effectively by using spears tipped with fluted, flaked stone points (called Clovis points, after an archaeological site in New Mexico), these Paleo-Indians decimated the game herds of the plains in less than a thousand years. Some then migrated farther south through the highlands of Central America and the Andes, reaching the tip of South America about 10,000 years ago, just as global warming and rising sea levels marked the end of the Ice Age, or Pleistocene epoch. Only then did people spread to the coasts and big rivers; develop new varieties of triangular, stemmed points; and begin to subsist on small game, fish, shellfish, and wild plants. The game-poor tropical forests remained off-limits until after New World peoples had developed agriculture, about 5,000 years ago.

This attractively simple tale, still enshrined in some textbooks, is unraveling as a result of archaeological evidence accumulated over the past two decades. Nearly seventy years after excavations first revealed the Clovis big-game hunting culture, new sites and new dates in both North and South America are challenging Clovis's claim to priority. But a new consensus has not yet emerged. Instead, scholars are engaging in acrimonious public disputes while dramatic press releases with conflicting claims incite the media.

Two new books on the first Americans offer to clarify the picture. One is by Thomas D. Dillehay, the T. Marshall Hahn Jr. Professor of Anthropology at the University of Kentucky, Lexington; the other is by E. James Dixon, the curator of archaeology at the Denver Museum of Natural History. Both books are definitely worth reading, but they require considerable effort and a critical eye. Both use terms and dating criteria inconsistently and contain inaccuracies or out-of-date information that will confuse the general reader.

Although the books differ in several respects—for one thing, Dillehay's emphasizes South American discoveries, while Dixon's focuses more on North America and the Clovis sites—both take it for granted that people entered the New World before the rise of Clovis culture. The idea of an earlier migration is not new. For more than thirty years, Alan Bryan and Ruth Gruhn, as well as other archaeologists, have argued that people who lacked projectile points for big-game hunting entered the Americas more than 30,000 years ago. Recurring claims for such early cultures have been based on a handful of sites, along with analyses of Native American linguistic and genetic diversity suggesting that people have lived in the New World for a long time. But with the exception of evidence for the Nenana culture (known from several sites in central Alaska), the data supporting all pre-Clovis cultures have failed to withstand careful scrutiny. C. Vance Haynes and others have shown that the sites in question do not provide a consistent series of early dates that are securely tied to unambiguous evidence of human presence.

Neither Dillehay nor Dixon can marshal a consistent pattern of evidence for an arrival prior to 12,000 years ago. The new claims for pre-Clovis sites are no stronger than the old ones, and the old ones continue to circulate despite their evident flaws. A number of the sites championed by one or both authors—for example, Putu and Bluefish Caves—have no evidence of human presence at an early date. Some, such as Meadowcroft Rockshelter, have questionable dates due to possible contamination, and others, such as Cactus Hill, a new site in Virginia, have inconsistent dates, vague stratigraphy, and inadequate artifact samples that disqualify them from scientific acceptance, at least for the present. (On the accompanying map, I have indicated which early sites I think do—and which I think do not—meet stringent criteria.)

Even Dillehay's Chilean site of Monte Verde—which he, Dixon, and many others believe to be about 12,500 years old—can be challenged. (After these two books went to press, the magazine Discovering Archaeology carried an acerbic article by Stuart Fiedel criticizing the quality of the data.) As Fiedel, Dena Dincouze, Tom Lynch, and I have pointed out, this site presents many problems. Located in boggy terrain along a stream, Monte Verde has discontinuous stratigraphy, suggesting a mixing of strata. Few of the objects unearthed are indisputably tools, and there are no flakes from the manu-
Contenders for early sites are indicated along with their characteristic cultures (if known) and their carbon 14 dates. A “questionable” site is one that may well be sound in many respects but has at least one shortcoming—such as equivocal dating, the mixing of early materials with later ones, or the absence of unmistakable human artifacts. —A. C. R.
facture of such tools. Three narrow points found at Monte Verde are tapered at both ends, a “bipoint” form common in established sites in Chile and Peru that have more recent dates—Holocene rather than Pleistocene.

The tools at Monte Verde cannot be firmly connected with the dates, which were obtained on the basis of bog material, not from incontrovertible artifacts or food plants. And the dates are too widely spaced—from about 14,000 to 12,000 years ago—to fit the brief occupation that Dillehay believes the site represents. Furthermore, the site contains possible carbon contaminants, such as bitumen, which are known to make materials dated by the carbon 14 method appear older than they are (two very early dates of more than 33,000 years ago are typical of those recorded for petroleum material such as bitumen). Human traces could be the result of intrusion by later peoples. The mastodons believed to have been killed and eaten could be mined fossil fauna, and the supposed remains of shelters could be snags from fallen trees—similar to natural deposits found elsewhere in the region.

For their part, scholars skeptical of the validity of pre-Clovis sites typically fail to apply the same rigorous criteria to the Clovis sites they do accept. As a consequence, the age of Clovis, which many still claim is the ancestor to all other cultures in the New World, has been exaggerated. It is regularly put at 11,500 or sometimes even 12,000 years old, but no indisputably valid Clovis site has such early carbon 14 dates. (When carbon 14 results are that old, they turn out to be from sites that yield only isolated single dates, dates with a margin of error greater than 300 years, or dates based on carbon that has no certain connection with a human presence.) Even Dixon, despite his pre-Clovis yearnings, perpetuates this exaggeration of Clovis’s antiquity.

The inconsistent treatment of dates has given the false impression of a rapid wave of colonization by groups descended from Clovis peoples and has drawn attention away from numerous valid sites that are contemporaneous with Clovis but very different culturally. Most archaeologists ignore such sites because they do not have the cachet of being pre-Clovis. For now, though, their age and location provide the most reliable basis for an account of the migrations and ecological adaptations of the first Americans.

What, then, would be a more accurate picture? My conclusion is that the first people to venture into the eastern Bering Strait region, a bit before 12,000 years ago, may have been a group like the Nenana people, who were not specialized big-game hunters but rather foragers of small game, fish, fruits, and nuts. Instead of fluted spear-points they made triangular points that they probably used as knives. During the ensuing thousand years, their descendants penetrated diverse ecological zones throughout the Americas. Clovis was only one of these descendant cultures and not, therefore, either the earliest in the Americas or a culture that set an adaptive pattern for the hemisphere. None of the other descendant cultures were characterized by specialized big-game hunting.

No one type of environment seems to have been colonized before others, and people did not create one single style of artifact or survive on one particular kind of resource. Most Clovis-age peoples in the far north lacked fluted points; they used microblade tools (small blades struck off a prepared core) to hunt and gather a variety of resources. Even the Clovis fluted point (with its shallow channel on one or both sides and its parallel edges), which spread widely in the interior continental United States, is conclusively associated with big-game hunting only in the high plains. In South America, by about 11,000 years ago, specialized maritime foragers had already settled the Pacific coast, guanaco hunters were living in the southern grasslands, and riverine tropical-forest foragers inhabited the eastern lowlands. The peoples of the far south used fishtail points with expanded stems, and the forest and coastal peoples used triangular points, often with tapered stems.

The earliest migrants used various resources and habitats; only some of them hunted big game.

With their pre-Clovis emphasis, both Dillehay and Dixon miss the broad significance of these sites, and neither manages to sketch a coherent picture of colonization that fits the pattern of current data. Dixon argues that the earliest migrants followed a coastal route from the Bering Strait region southward to Tierra del Fuego, yet he cannot demonstrate that coastal sites were occupied any earlier than interior sites. As Ted Goebel and John Erlandson have pointed out, there are no securely dated maritime sites in North America as old as Clovis, and those in South America are the same age as interior sites, not older.

Dillehay believes that the first migrants in South America could have been pre-Clovis big-game hunters who arrived at least 15,000 years ago and used fishtail projectile points. However, he can identify no fishtail-point sites earlier than 11,000 years ago, and these are in the far south, not the north, as would be expected. And, as he admits, few early South American human sites include the bones of now-extinct Ice Age game animals. In addition, Dillehay distinguishes another South American tradition of foragers with only unifacial tools (made by flaking one side), but no such culture has been shown to exist. All the sites that have been adequately sampled and dated yield bifacial as well as unifacial tools.

Both authors try to make sense of the current heated debate about the bi-
BOOKSHELF

I Will Tell of My War Story: A Pictorial Account of the Nez Perce War, by Scott M. Thompson (University of Washington Press, 2000; $26.95)

This 1877 war is perhaps best known for Chief Joseph’s moving surrender speech. But now the discovery of a Nez Perce artist’s drawings of these events allows us to see not only the exploits of war but also camp scenes, ceremonial dances, and abstract representations of tribal belief.

The Redrock Chronicles: Saving Wild Utah, by T.H. Watkins (Johns Hopkins University Press, 2000; $24.95)

At the heart of the Colorado Plateau—135,000 square miles of uplifted rock “like a huge island in the earthly continental sea”—is Utah’s red-rock canyon country. Watkins gives an evocative account of its geology, ecology, and peoples, with many maps and photographs.

Tyrannosaurus Sue: The Extraordinary Saga of the Largest, Most Fought Over T. Rex Ever Found, by Steve Fiffer (W. H. Freeman, 2000; $24.95)

The 1990 discovery of forty-one-foot “Sue”—the most complete T. rex fossil find to date—resulted in legal, political, and scientific wrangles and pitted federal government claims against those of the Cheyenne River Sioux. Finally sold at auction for $8.36 million, Sue now belongs to Chicago’s Field Museum.

PHOTOGRAPHY

Weeds, by Howard Bjornson
(Chronicle Books, 2000; $19.95)
Young Naturalist Awards 2000

For the American Museum of Natural History’s third annual Young Naturalist Awards, students in grades 7 through 12 were invited to do a research project, document an expedition, or create an exhibition related to the fields of biodiversity, earth science, or astronomy. This year’s theme was “Looking Back, Looking Ahead,” from 1900 to the present and onward into the future. The winning entries (selected from nearly a thousand) are summarized below. Full-length versions are available in a catalog published by the Museum’s National Center for Science Literacy, Education, and Technology and also online at www.amnh.org/youngnaturalistawards.

The Big Chill: Calming Signals Among Wolves, by Claire Esker (Sacred Heart Schools, Chicago, IL; Grade 8)
The wolf has been Claire Esker’s favorite animal since the age of nine.

She documents a range of behaviors in a wolf pack in Peoria Wildlife Prairie Park, especially their calming signals—the gestures they make to reduce aggression, fear, and stress within the pack. “As we enter the twenty-first century, I believe the use of calming signals among wolves will eventually become less pronounced,” Claire concludes. “As the wild wolf population decreases, more wolf refuges will be created. The aggressive tendencies of these wolves will decrease due to contact with humans and the fact that hunting will no longer be essential to their survival.”

Agricultural Genetic Engineering, by Elaine Gould (Toll Gate High School, Warwick, RI; Grade 10)
Elaine Gould designed a four-room exhibition that would explain the role of DNA in genetic engineering, plant biotechnology, and the alteration of animal traits, and that would examine some of the risks and benefits of genetically engineered foods. Perhaps the most innovative of her installations is the Cell Theater, representing the inside of a cell and its complex processes. “The aim of this museum exhibit,” Elaine explains, “would be to educate the public about the ever increasing advances in agricultural genetic engineering.”

Fiddler on the Marsh, by Gaurav Gupta (Thomas Jefferson High School for Science and Technology, Alexandria, VA; Grade 9)
“The cold, salty wind blows over the marsh, invisible, detected only through the swaying of the knee-high cordgrass and the faint ripples on the surface of the creek,” writes Gaurav Gupta in a report of his class’s expedition to study the fiddler crab. He observes the crabs clustered together in mudflat burrows and muses on the kinds of threats they face—from pesticides, parasites, and viruses to earthen dams, ditches, and rerouted water. “I suddenly know I am observing a dwindling and precious...
resource,” he states. “It is important that we preserve this key decapod. If fiddler crabs were to die out, the marsh would die with them.”

**Mars—Past, Present, Future, by Andrew Walker (Briscoe Middle School, Beverly, MA; Grade 7)**

“Maybe one day we will need to live there,” speculates Andrew Walker, who summarizes what has become known about Mars since the Babylonians first observed the planet 2,400 years ago. Today we know about the geography, atmosphere, and climate of the red planet, but Andrew believes we will learn much more in the twenty-first century, particularly in the next thirty years. He describes some of the proposed missions to the planet and talks about the possibility of colonizing Mars. “One thing that might be done in the next century,” Andrew says, “is terraforming.” This, he explains, “is when scientists change the temperature and atmosphere of a planet to allow life to exist on it.”

**Operation: Human Genome Project, by Wambui Kamuiru (Divine Savior Holy Angels High School, Milwaukee, WI; Grade 11)**

Wambui Kamuiru is one of several young naturalists fascinated by the recent advances in genetics. Wambui’s design for an interactive exhibit on the Human Genome Project (HGP) encompasses three rooms, or “pods,” organized around a giant 3-D model of a chromosome. She focuses particularly on ethical, legal, and social issues and hopes to convince “mature museum visitors” of the relevance and seriousness of the HGP’s primary goals: identifying the more than 100,000 genes in human DNA and determining the sequences of its 3 billion chemical bases. “Not only will the knowledge of one’s own genetic makeup change the way we see ourselves,” writes Wambui, “but it may alter the way others perceive us as well.”

**The Indian Ricegrass, by Jayrene June (Page High School, Page, AZ; Grade 12)**

After analyzing 300 samples of Indian ricegrass from three areas of northern Arizona and southern Utah, Jayrene June recommends that the Bureau of Land Management revise its grazing limits and base them not only on plant height but also on diameter. Navajo elders told her of a time on their reservation when “the grass would grow up to their knees and waists,” but today there is little vegetation. Jayrene writes, “In the future, I plan to help my people by educating them about overgrazing. My goal is to make this land a yellow ocean once again. The future of our land depends on how we use it today.”

**Genetics: An Increasingly Important Field of Science, by Janet Lee (Troy High School, Fullerton, CA; Grade 10)**

“The whole idea that genes can control so many aspects of our lives

**Events**

**DURING JULY AND AUGUST**


Beginning July 1, in addition to *Dolphins* (a film about the complex behavior of these marine mammals in the wild, with a soundtrack by Sting), the Museum’s IMAX theater is also presenting *To Be an Astronaut.* Featuring a NASA team, the movie follows the astronauts through their extensive inflight training to countdown and the final launch into space.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100. Visit the Museum’s Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are now available online.
fascinates me,” writes Janet Lee, who describes genetics as “the science of our future.” Providing a concise summary of the history of genetics research—from Gregor Mendel to Thomas Hunt Morgan, James Watson, and Francis Crick—Janet (who would like to have a career in this field) sets the stage for new developments as the completion of the Human Genome Project draws near. “It will be a new age,” she writes, “one in which scientists work diligently to prevent currently incurable diseases.”

Seeing Double: An Exhibit on Cloning, by Amy Tsao (Bergen Academy, Hackensack, NJ; Grade 11)
The purpose of Amy Tsao’s interactive exhibit is to help people realize why cloning is such an important scientific breakthrough. “After visiting the exhibit,” she says, people “should be able to realize why Dolly the sheep made headlines.” Text, images, videos, and interactive games provide background information on DNA and genetics. Amy focuses on the potentially beneficial uses of cloning, and she writes, “These uses of cloning include bringing animals back from extinction, repopulating endangered species, creating organs for transplants through donor pigs with human DNA, and producing medicine through the milk of cloned animals.”

The Circle of the Food Chain and Decomposition, by Hallie Woodward (Olive Branch Middle School, Olive Branch, MS; Grade 7)
During the spring of 1997, half a year after Hallie Woodward moved into a new neighborhood, her family had the backyard sodded and they began to plant trees, shrubs, and flowers. The woods behind the house, however, had been “bulldozed and graded flat for more new houses.” When the spring rains came, their backyard was flooded, then covered by a mudslide, and their landscaping efforts were ruined. This set Hallie to wondering about “the development of our city and its effect on the soil and the ecosystem.” A year and a half later, after researching soil composition and learning composting techniques, Hallie was replenishing the soil with the natural nutrients and microorganisms from her own kitchen-garbage compost. “Due to the industrial and residential boom, our area’s woodlands, wildlife, and waterways are being destroyed,” Hallie laments. “If laws are not passed, we will probably have future problems of pollution, flooding, and erosion.”

Can Tropical Fish Survive in a Lake in Southwestern Montana? by Amber Overstreet (Reed Point Schools, Reed Point, MT; Grade 8)
To find out why tropical fish (introduced thirty years ago by a pet store owner) have survived in southwestern Montana’s thousand-year-old Trudau Lake, Amber Overstreet examined the lake’s water quality, temperature, and aquatic fauna. Discovering that she was the first person to study the lake systematically, Amber rafted across it and “dropped some corn into the lake to attract the fish. Five minutes later, the two most beautiful fish I have ever seen slowly swam up. The first was about four inches long and one inch tall, yet it was skinny; he was a sort of clearish white. The second one was bright orange with a forked tail and long and clear fins.” Amber identified a number of tropical species and concluded that the fish were well adapted to Trudau Lake’s year-round warmth, high pH, high mineral content, and low oxygen.

Paleontology and Stratigraphy of the Rochester, New York, Area, by Kevin Swain (Churchville Chili Junior High School, Churchville, NY; Grade 9)
As a way of studying Earth’s past and of learning “about the climate and environment in the Silurian and Devonian periods of the Paleozoic Era,” Kevin Swain searched through layers of shale in three areas around Rochester, New York. There he found invertebrates such as trilobites, bryoza, and brachiopods—fossil remains that serve as a window on deep time. “When I uncovered these fossils,” he writes, “it was the first time they had seen light in 400 million years.” Disappointed at not finding an example of a eurypterid (also known as a sea scorpion), the state fossil of New York, Kevin resolved to make it his “goal in life to find a complete eurypterid” this summer.
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Spanning ten feet, individual gorgonians, or sea fans, at Kimbe Bay (on the north coast of New Britain, an island of Papua New Guinea) are minihabitats unto themselves. Like giant sequoias or great-grandfather oaks in terrestrial landscapes, these upright, rooted coral animals attract an array of more mobile creatures. Reef fish probe their latticework, sponges grow on them, shrimp and crabs climb about on their two-dimensional branches. Photographer Fred Bavendam framed a close-up of one lodger, an eight-inch yellow feather star. Ambulatory relatives of the stalked sea lilies, feather stars use their arms to walk (slowly) and to climb. After scaling a sea fan, the feather star might stay for a while, hanging on by means of tiny hooks called cirri. Both the fan and the feather star are filter feeders. Once stabilized, the star unfolds its arms, embraces the current, and culls edible particles floating by.

—Judy Rice

Photograph by
Fred Bavendam
MINDEN PICTURES
Armadillos, and Dangerous

By Robb White

A nine-banded armadillo feigns innocence.

Back in the forties, we didn’t have any armadillos here in South Georgia. I learned a bit about Florida armadillos from my cousin Mike, who lived down around Holopaw. Every time he came up to our place for a visit, all I would hear was “my armadillo this” and “my armadillo that.” I tried not to be envious, but I couldn’t help telling him about how I had a cotton rat once and a jaybird for a little while. Mike would just smugly proclaim that they had plenty of cotton rats and two kinds of jaybirds down in Holopaw. Panthers too. But he liked armadillos best. One time Mike came up to Georgia with a busted nose and two black eyes. “Bingey,” he warned me, “armadillos are unpredictable. They can jump eight feet straight up. That is one of the ways they fight off their attackers.” I told him next time he might try to find something better than his nose to attack one with. So I kept my dignity, but I sure did want to see one of those wonderful animals.

The first time I ever had any personal dealings with a real armadillo was in the early sixties. I was riding my motorcycle back from a trip to Pigeon Key, and I didn’t see one until I got all the way up to Payne’s Prairie, just below Gainesville. This armadillo was digging out in the wet weeds beside a culvert embankment. I coasted my motorcycle up as close as I dared and watched it for a long time. Single-minded, the armadillo kept on working. I decided to catch and examine it as best I could. I got off my bike and slipped up on the animal in my best baby-quail-catching style. Somehow it detected me even over the din of the traffic and was into that culvert in a flash.

I was beginning to believe some of the old Mike talk, and it got even more credible after I crossed the highway, parked around in the short grass, and looked through the far end of the culvert and even in the water. No armadillo. I never did find out exactly how such a stupid-looking animal had outfoxed a person of my experience and ability.

When I got back to my motorcycle, the armadillo was rooting around by the kickstand. I grabbed it by the tail and picked it up, but not before it flipped about three quick divots of sod into my eyes with its hind feet. When it quit squirming and I could see again, I began my inspection at the stern, as that part was up. I immediately became fascinated by a peculiar movement of the anus. It appeared to be alternately protruding and retracting, sort of like the lips of toothless old people when they do that involuntary, fruitless chewing motion. When I leaned down for a closer look, I found the action far from fruitless. He (for that was what he was) sprayed liquid excrement all over my face, arms, hair, clothes, even the tops of my bare feet. It smelled just like fish-bait worms allowed to die in the can. I managed to put the armadillo into my old GI surplus knapsack, which had held many other creatures (some much further up the evolutionary scale), and waded out into the weedy water to wash off.

When I got back to the motorcycle, the armadillo was back digging around under the kickstand as if nothing had happened. There was a round hole, just about as big as an armadillo, in the corner of my old coon-proof knapsack.

Around 1973, my home place in Georgia (within the Tallahassee metastasis zone) became the exact point of intersection of two expanding populations of armadillos, just moving back up from where they were pushed during the last ice age. One group came in from the west. Somehow they crossed the Mississippi, and they kept moving east until they met the Holopaw bunch, which had walked up from South Florida. I was glad to see both groups, and I have found out many things about armadillos since then. Mike was wrong about their mean disposition (my own observation has yet to reveal any disposition whatsoever), but they can jump straight up when they detect danger from above. I once tried to lean over and write a number on one that was smelly my toe. When he felt the little Wite-Out brush, he jumped up so hard that it busted my lip and loosened two teeth.

Boat builder and biologist Robb White lives in Thomasville, Georgia.
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When it comes to lifestyle, Madagascar's prosimians are as different from one another as they are from other mammals.
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ILLUSTRATIONS BY DEBORAH ROSS

COVER The fat-tailed dwarf lemur (Cheirogaleus medius) is one of eight lemur species in Madagascar's Kirindy Forest.
STORY BEGINS ON PAGE 58
ILLUSTRATION BY DEBORAH ROSS
Discover Where The Great Museums Get Their Inspiration.

Museums play an important and irreplaceable part in our education and appreciation of the world we inhabit. Each visit broadens our understanding of nature and the environment. Yet, beyond the walls of a museum lies the natural world.

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Sven-Olof Lindblad
Words or Pictures

The hackneyed saying that one picture is worth a thousand words was, it turns out, the brainchild of an American advertising executive, Frederick R. Barnard. (Hoping to get more respect for his slogan, which he thought up in 1921, Barnard put out the word that it was a Chinese proverb.)

Some of the editors at *Natural History* are awfully fond of words and reluctant to admit that any amount of text can easily be trumped by a picture. But when it came to planning “Biomechanics,” a column that made its debut in the magazine’s July-August 1999 issue, we editors became real Barnardites: we started worrying about pictures right away. Reporting on biophysical discoveries—how toads unfurl their tongues to catch insects, how baby skates pump water over and through their egg cases, why blades of grass spring back after being blown down, how geckos climb walls, how flies fly—was, we reasoned, a challenge no wordsmith should face alone. We needed an illustrator, and no ordinary one. Enter Sally Bensusen.

An artist who had a brief career as an astronaut, Bensusen is blessed not only with visual imagination but with a passion for attacking diverse and difficult subjects. Undertaking the illustration of “Biomechanics” in every issue means reading and mastering scientific papers on a variety of subjects. It means working in close concert not only with the writer (Carl Zimmer), the editor (Rebecca Finnell), and the designer (Tom Page) but also with the scientists who have made the biomechanical discoveries in question. The outcome of all this collaboration invariably turns out to be a striking image. Proof of Bensusen’s success? The magazine staff is happy, readers write to tell us how much they enjoy her illustrations—and the scientists often ask to buy her paintings.

Thanks, Sally.—*Ellen Goldensohn*
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D I S C O V E R  N E W  Y O R K
Venomous Exchange?
Steve Grenard contends that the venoms of many rattlesnake species across North America have grown more potent within the past two to five decades (“Is Rattlesnake Venom Evolving?” 7/00–8/00). The notion of such rapid evolution is suspect when one considers the relatively long time span between generations—five years or more. (These snakes are not exactly *Drosophila* in a bottle!)

Even if we assume that such a change has taken place, Grenard fails to present convincing explanations. Most preposterous is the concept of rapid introgression of Mojave toxin genes from Mojave rattlers into timber rattlers. Since only a handful of hybrid rattlesnakes have ever been found in the wild, it is difficult to conceive of the mechanisms by which genes from one population would enter another and increase in frequency so rapidly that we could detect them in a matter of decades.

Rather than spending so much time discussing a hybridization hypothesis, the author could have explored the possibility that Mojave toxin genes arose in an ancestral species and have been variably preserved or expressed in different species and populations.

Unfortunately, Grenard’s sweeping assertion about venom toxicity will be read as gospel and lead to increased persecution of rattlesnakes, many of which are already imperiled.

Andrew T. Holycross
Department of Biology
Arizona State University
Tempe, Arizona

STEVE GRENARD REPLIES:
While evidence for increases in the toxicity of rattlesnake venom is still anecdotal, many medical facilities I’ve contacted are concerned about recent cases of apparently neurotoxic envenomation—several of which have been reported in medical journals. (See, for example, S. P. and E. Siedenburg, “Neurotoxicity Associated With Suspected Southern Pacific Rattlesnake [Crotalus viridis helleri] Envenomation,” *Wilderness and Environmental Medicine* 10, 1999.) My article presented hybridization as only one of several hypotheses that might explain alterations in rattler venom. Documented cases of hybridization between various wild and captive rattlesnake species have established that gene flow is possible in the wild. I also stressed that venom does not come in standard formulas for each species but in a range of variations, so small quantities of neurotoxins may always have been present in some populations. This possibility is not inconsistent with Andrew Holycross’s view that the trait may have derived from common ancestors.

I did not claim that venoms have changed composition in the past ten to fifty years, only that unexpected neurotoxic symptoms of snakebite began to appear during that time. Certainly the evolution of venoms in response to prey resistance has occurred over millennia.

As for the complaint that my assertions foster increased persecution of rattlesnakes, I emphasized that rattlers will not bother people if people don’t bother them and that most species in the United States are severely threatened by habitat degradation and by “rattlesnake roundups.”

Runs, Hits, and Errors
Although Stephen Jay Gould (“Jim Bowie’s Letter and Bill Buckner’s Legs,” 5/00) warns against the way humans “misstate easily remembered and ascertainable facts in predictable ways” because we need our myths about those facts, he unfortunately falls victim to this very disease. In the tenth inning of the amazing sixth game of the 1986 World Series, the Red Sox were leading by two runs, not three. And when Wilson’s ball went through Buckner’s legs, Ray Knight scored from second base, not third.

As Mr. Stengel said, “You could look it up.”

I love the professor, and I would prefer to think he is testing his readers to be certain that they understand his point.

Robert Nelson
Brooklyn, New York

Early Warming
In his article on mitochondria (“Symbions and Assassins,” 7/00–8/00), Guy C. Brown restates the common misconception that birds and mammals evolved endothermy “toward the end of the reign of dinosaurs.” In reality, the first mammals and dinosaurs appear in the fossil record at about the same time, in the late Triassic period. The ancestors of mammals, the pelycosaur and therapsids, may have been warm-blooded as early as the late Carboniferous period, a full 235 million years before the end of the dinosaurs’ reign. Birds show up in the Jurassic and coexist with dinosaurs for at least another 85 million years. Moreover, dinosaurs themselves may have employed endothermic mechanisms for some parts of their life cycles.

Jason Bringham
American Museum of Natural History
New York, New York

Natural History’s e-mail address is nhmag@amnh.org.
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A Virginia native, Laura A. Sessions (“A Floral Twist of Fate,” page 38) traveled to New Zealand in 1996 as a Fulbright scholar. She earned her master’s degree in botany at New Zealand’s University of Canterbury in Christchurch, studying the effects of introduced brush-tailed possums on New Zealand mistletoes. Along the way, Sessions notes, “I realized that I enjoy learning and writing about science more than I like actually doing it.” She is currently pursuing a doctorate in science communication and the media, as well as continuing work on the effects of introduced animals in New Zealand. An “introduction” herself, Sessions says she has come to love New Zealand’s “beautiful landscapes and relaxed pace of life.”

In search of material for his new book, Parasite Rex, science writer Carl Zimmer (“Attack and Counterattack: The Never-Ending Story of Hosts and Parasites,” page 44) spent a lot of time traveling. In Costa Rica he watched parasitologists dissecting frogs, turtles, and iguanas and finding new species of parasites in each group. He went to southern Sudan, where people struggle with guinea worms, blood flukes, and many other such organisms. His search also took him to the U.S. National Parasite Collection near Washington, D.C. Zimmer says he used to think of parasites as minor oddities. Now he realizes they’re “the dirty secret of nature: they’re everywhere, and they shape the course of evolution itself.”

Alan Rabinowitz (“The Price of Salt,” page 52) got his start as a field zoologist for the Wildlife Conservation Society (WCS) in Belize, where he set up the world’s first jaguar preserve. He later went to Southeast Asia to study big cats and other endangered large mammals, including clouded leopards. In 1993, when Laos and Myanmar opened their borders to foreign scientists, Rabinowitz (right, with his son, Alexander) led some of the first wildlife surveys there in decades. He is currently director of WCS’s Global Carnivore Program. His latest book, Beyond the Last Village, about his expeditions to northern Myanmar, is forthcoming from Island Press. Photographer Steve Winter, who accompanied Rabinowitz to Myanmar, says he is extremely lucky to work in such remote areas when “most people believe there are no wild places left on Earth.” His pictures have appeared in many publications, including National Geographic and Geo.

Peter M. Kappeler (“The Lemurs of Kirindy,” page 58) is head of the Department of Behavior and Ecology at the German Primate Center, which has maintained a research station in the Kirindy Forest since 1993. The virtues of Madagascar are many, he says, and include the pleasant circumstance that the island has no big carnivores or venomous snakes. Kappeler stresses that studying the lemurs of this forest is a joint venture with several students and colleagues (notably Jörg Ganzhorn and Jutta Schmid). Plans for Kappeler’s own long-term research include investigations into lemur communication and cognition. He is also engaged in intensive conservation efforts on behalf of the animals of Kirindy.

Coauthor Alexandra Dill recently graduated from Würzburg University, where she studied animal ecology and tropical biology. For her thesis, she investigated how Verreaux’s sifakas rear their infants.

Based in New York City, wildlife artist Deborah Ross, right, took two trips to Madagascar—one in the dry season, one in the wet—to paint Kirindy’s animals. Other paintings by Ross, from her numerous visits to Africa, were featured in the 12/96–1/97 and 4/98 issues of Natural History. Back home in New York City, she studies West African dance.

Jürg Alean (“The Natural Moment,” page 82) earned a doctorate from the Swiss Federal Institute of Technology in Zurich with a study of glaciers, but his interests eventually turned from ice to fire. With Italian colleague Roberto Carniel, of the University of Udine, he set up a seismic station on the island of Stromboli and collaborated on a Web site (stromboli.net) that features pictures of the eruptions there. Since activity on nearby Mount Etna has become more spectacular, they have shifted some of their attention to Stromboli’s “big neighbor.” Whenever he ventures near an active volcano, says Alean, he is torn by two strong, conflicting feelings: “the wish to be as close to the dramatic action as possible and the desire to survive my visit unharmed.”
Great Performers

Psuedo Domingo:
"Se quil guerrier io fossi" from Verdi's Aida 1001
Enrico Caruso: "Spunta Genil" from La Favorita
(Donzelli): 1001
Vanessa-Mae: Bach: Toccata and Fugue in G minor 1002
Yehudi Menuhin: Bach: Partita in G minor 1003
Kristen Flagstad/Lauritz Melchior: Love Duet from Wagner's Tristan und Isolde (live from Covent Garden, 1933): 1004

20th-Century Music

Barber: Adagio for Strings 1362
Prokofiev: "Classical" Symphony, Allegro 1363
Copland: Fairewell for the Common Man 1363
R. Strauss: Four Last Songs: III. "Beim Schlafengehen" (Elisabeth Schwarzkopf): 1364
Gershwin: Rhapsody in Blue (with George Gershwin): 1365
Britten: "Moonlight" Interlude from Peter Grimes 1006
Beverstone: Interlude to Candide 1366
Stravinsky: "The Firebird" 1367

Maria Callas

"Casta Diva" from Bellini's Norma 1006
"Vissi d'Arte" from Puccini's Tosca 1368
"O rendetemi la speme" from Bellini's Puritani 1369
"Io dolce suono" (Mad Scene) from Donizetti's Lucrezia Borgia 1369
"Pentimons, qui commence" from Saint-Saëns Samson et Dalilah 1006
"Suicide" from Ponchielli's La Gioconda 1369
"La blanca" from Verdi's La Traviata—Live 1368

20th-Century Music

Gottschalk: "Oos Criklos" (Danse Cupienne). Caprice Brillante" 1045
Samuel Barber: "Koralle Sommer of 1915" 1046
Traditional: "Shenandoah" (Paul Robeson) 1047
Traditional: "Ain't That Good News" (Barbara Hendricks) 1048

Basically Baroque

Albinoni: Adagio in G minor 1006
Pachelbel: Canon 1143
Handel: Messiah from Water Music (Sir Neville Marriner/ Academy of St Martin in the Fields) 1144
Bach: Violin Concerto No. 1, Allegro (Anne-Sophie Mutter) 1145
Bach: Suite for Unaccompanied Cello I, Preludio (M. Rostropovich) 1146
Bach: Air on the G String (Mariana Jongsma/Oslo Philharmonic) 1147
Handel: Bouree from Water Music (Riccardo Muti/Berlin Philharmonic) 1148

Songs of Schubert

Der Tod und das Mabechten (Dietrich Fischer-Dieskau) 1060
Frisch (The Trout) (Dietrich Fischer-Dieskau) 1061
Nacht und Tram (Ian Bostridge) 1062
Erkönig (Ian Bostridge) 1063
Die Lourdenbaum (from Winterreise) (Thomas Hampson) 1064
An die Musik (Margaret Price) 1065
Die Allmacht (Margaret Price) 1066

All-American Classics

Copland: "Appalachian Spring" 1047
Bernstein: "West Side Story" (orchestral highlights) 1042
Bernstein: "Tonight" from West Side Story (Robert Aspasia Angela Glover) 1043
Scott Joplin: "Maple Leaf Rag" 1044

Prokofiev: "Love Dance" from Romeo and Julie 1045
Listz: "Liebestraum" 1085
J. S. Bach: "Air on the G String" 1044
Grieg: "Solveig's Song" from Peer Gynt (Sir Neville Marriner) 1087
Mozart: Piano Concerto No. 21, Andante ("Aviva Madigan") (Anne Fischer) 1088

Perfect Piano

Bach: "Fugue Eliza" 1090
Schumann: "Tristan und Isolde" 1091
Liszt: Hungarian Rhapsody No. 2, 1092
Chopin: Mazurka in A minor, Op.59 no.1 (Martha Argerich, 1965) 1093
Debussy: La fille aux cheveux de lin (Prelude Villa) (Walter Gieseking) 1094
Benedetti: Sonata No. 30 in E Major, Op. 109, 1096
Mendelssohn: Overture to A Midsummer Night's Dream 1101
Rachmaninov: Piano Concerto No. 3, Allegro (L.O. Andsnes) 1096

Classical Broadway

Rodgers & Hart: "Bewitched, Bothered and Bewildered" from Polly (Joey đa (Frederica von Stade) 1101
Gershwin: "Love is Here to Stay" (Kiri & Kanawa) 1102
Jerome Kern: "Ol' Man River" from Showboat (Paul Robeson) 1103

Jerome Kern: "Only Make Believe I Love You" from Showboat (Lenny Howard) 1044
Cole Porter: "Night and Day" (Yehudi Menuhin / St. Germain / Paris) 1105
Sondheim: "Send In the Clowns" (Maurice Andre) 1106

Wagner: The Ride of the Valkyries from Die Walküre 1123
Bizet: Toreador Song from Carmen (Nicola Gugliemo) 1125
Puccini: "O! Il bel sogno di Dorabella" from La Rondine (Luba Organova) 1127

Best of the Classics

Beethoven: Fourth Symphony 1131
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Holey Waters

On a dry hillside, a rain-filled tree hole may be the only available nursery for gnats, midges, punkies, mosquitoes, marsh beetles, and a host of other small organisms.

The man looked skeptical as I explained how I had wandered onto his property in the woods of western Virginia—how I had been searching for tree holes that captured and retained rainwater, and that my interest lay in the aquatic organisms inhabiting these pools in places where there was no other water around. Expecting to be invited off the premises, I was not prepared for his response. "I heard one of my dogs lapping water out of a tree when we was up back of my cabin last week," he drawled. "If you want, I'll take you to it." Half an hour later, I was staring into a pool of tea-colored water caught between the twin trunks of a huge white oak. Mosquito larvae danced just below the surface, and as I probed the excelsior-like mesh of recalcitrant leaf veins and decomposing organic material at the bottom, I quickly turned up other organisms. It was perfect! Though I would find many similar water holes up and down the Appalachian Mountains during the next two weeks, none were more exemplary than what this woodsman had led me to.

In a landscape devoid of ponds, water-filled tree holes are sometimes hidden reservoirs of biodiversity, providing a habitat for upwards of 140 species, including protozoa, flagellate algae, swarms of bacteria, and numerous invertebrates whose larval stages are aquatic, as well as occasional mosses and vascular plants. Included among the invertebrates are moth flies, wood gnats, midges, punkies, mosquitoes, marsh beetles, and beelike or wasplike syrphid flies. A dozen or so insects in these families are seldom, if ever, found elsewhere.

While not uncommon in the deciduous forests of the eastern United States and western Europe, tree holes capable of supporting simple aquatic communities are found only under rather specific circumstances. Most occur where closely grouped trees grow together at their bases, eventually grafting and forming at their junctures a catchment basin (known as a pan) lined with seamless, waterproof bark tissue. In parts of the eastern United States, numerous hardwood stumps remained after the land was cleared during the nineteenth century; when the stumps resprouted, the clumping of new trees led to the formation of many of today's pans. Some large species—beech, for example—may also form pans in their buttressed roots and occasionally in the crotches of their branches. (These trees are an important source of water holes in Europe.) Tree holes can develop when bark is injured, allowing fungi and bacteria to enter the tree and create a cavity through decay. In this case, the tree often responds by producing callus tissue, which walls off the cavity and eventually enables it to hold water. Breakage caused by wind or ice storms often leaves branch stubs vulnerable to the formation of such decay cavities. Other possibilities exist as well; tree holes have been found in almost all broad-leaved genera and even in a few spruces and firs.

Not all tree holes are created equal, however. I have investigated many seemingly ideal cavities that failed to provide suitable habitat for aquatic insects for lack of two essential conditions. The first is an adequate supply of rainwater that is channeled down the tree trunk into the cavity or pan. During a rain, this so-called stem flow not only provides the water necessary to maintain the aquatic community (direct interception of rainfall or canopy drip is less likely to result in standing water in a tree hole) but also delivers nutrients washed off leaves and bark. And during storms, the stem flow may flush potentially toxic

Water channeled down the bark into a tree hole delivers nutrients washed from leaves and branches.

By Peter J. Marchand
accumulations of metabolites, such as ammonium and hydrogen sulfide, from the pool. The second requirement is a supply of organic matter sufficient to provide an energy base for the community. Food chains in this habitat generally involve the serial processing—in hand-me-down fashion—of successively smaller organic particles by a number of organisms that feed on dead plant matter, from leaf-shredding marsh beetles all the way down to protozoans. (Many browsers, such as mosquito larvae, also act as predators of protozoa and bacteria.) Without a source of material from the outside, the marsh beetles—keystone species that regulate food supply to lower-level consumers—have little to work with.

In deciduous forests, autumn leaf fall provides almost all the energy necessary to sustain the tree-hole community. The best tree holes, therefore, will be positioned so that they intercept both water and leaves. But the right combination of stem flow and leaf fall is critical. Too much organic matter often has a detrimental effect on the community, reducing both species diversity and population densities, probably because it reduces the amount of standing water.

Despite their sometimes tenuous nature, water-filled tree holes offer insects at least one major advantage over lakes and ponds: greatly reduced predation of their larvae. Once the insect leaves the tree hole as an adult, however, the score may be evened, for success isn’t counted until the life cycle has been completed. Both insects and habitat are widely dispersed, so the greatest challenges for organisms that breed only in tree holes are to find mates and to locate new tree holes where they can deposit their eggs. The pans or cavities must have sufficient resources to carry another generation of larvae into adulthood. How the insects find the holes in the first place remains a mystery, but one important criterion in site selection is probably the amount of standing water they hold.

Farther north along the Appalachians, I came across another pan in a large twin oak. Lazily lifting a dry leaf from the surface, I startled a red-backed salamander. This water hole, like a pond filling in, was near the end of its life span; it contained only saturated organic matter, and the terrestrial salamander had found a cool refuge inside it. “One taxon’s loss is another’s gain,” I thought. But this play doesn’t end with the dying of a pool. Through some accident of nature—two acorns sprouting side by side or a large branch collapsing under the weight of winter snow—another aquatic refuge will turn up on another dry hillside, and a small group of tree-hole breeding insects will find another home.

Asteroids have been getting a bad rap of late, which is better than the rap they used to get, which was none at all. But several developments in the past few months—including fresh data from a spacecraft’s visit to one asteroid and now the nightly appearances of another—have fostered a new interest by the give-and-take of gravity.

Maybe “maybe” doesn’t belong in the scientific vocabulary—though in the case of asteroids, astronomers were willing to make an exception. There seemed to be no end to the number of asteroids, and no compelling reason to seek one. Occasionally an observer would stumble across a new asteroid, how many asteroids there might be out there, and the estimates range from hundreds of thousands to billions. Ask whether any of the asteroids that are not part of the main belt between Mars and Jupiter might be on an eventual collision course with Earth, and the answer is even less precise. Nobody knows.

Close Encounters

in asteroids among professional and amateur astronomers alike.

Ever since January 1, 1801, when Italian monk and astronomer Giuseppe Piazzi discovered a relatively small celestial object he later christened Ceres, asteroids have been the orphans of the solar system—planets without portfolio. Maybe they were pieces of a planet that never quite coalesced. Maybe they were pieces of a planet that did coalesce but at some later point suffered a catastrophic collision. Maybe they were pieces of neither, but simply an odd assortment of space rocks left over from the solar system’s birth and swept over time into the gap between the orbits of Mars and Jupiter.

name it (often after a spouse, friend, or pet), and then pretty much forget about it. In 1887 a Scottish astronomer thought he’d found a new star, only to realize he’d rediscovered an asteroid that had first been sighted eighty years earlier. In 1916 U.S. astronomers Seth Nicholson and Harlow Shapley discovered a new asteroid (which they named after Shapley’s wife, Mildred), only to lose it for much of the rest of the century (it resurfaced in 1991).

Today the state of asteroid knowledge can still be as spotty as the sky during a meteor shower. Most meteorites, in fact, are fragments of asteroids; astronomers can now say at least that much with certainty. But ask

Thanks to Hollywood’s special-effects artists, as well as to an astronomer’s mistaken prediction a couple of years ago that an asteroid could potentially be heading for an impact with our planet some thirty years hence, it’s the apocalyptic possibilities of asteroids that have most captured the popular imagination. For scientists, however, these minor planets have begun to ignite a different kind of speculation: What if at least some asteroids are remnants of the primordial solar system?

Last February the spacecraft NEAR Shoemaker entered a close orbit with the asteroid Eros, specifically to investigate this possibility. Still, nobody
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at NASA had dared hope for what happened on May 4. For half an hour, while instruments on the NEAR tracked the 21-mile-long asteroid from a distance of only 31 miles, a flare from the Sun washed over Eros, causing its elements to radiate X rays—and, in the process, to reveal the asteroid's chemical composition. Preliminary results show a collection of magnesium, silicon, and aluminum that has never undergone the kind of intense heating and melting that would characterize the development of a more mature terrestrial body. Therefore, Eros is indeed very likely a relic from the first stage of the solar system's formation.

That's not true of all asteroids, however, and one prominent exception has been visible in the night sky in recent months. Spectroscopic studies of Vesta during the 1990s revealed that lava once flowed on its surface, which means that this rather massive asteroid is a kind of cousin to Earth. With its diameter of approximately 335 miles, Vesta is the third-largest asteroid in the main belt. It is also the only main-belt asteroid occasionally seen with the naked eye by observers on Earth.

As September begins, Vesta is wrapping up a four-month period of such visibility. For the first few days of the month, in the hours just after nightfall, it will be shining in the southern sky at magnitude 5.8—just about the limit of our unaided viewing capabilities. From about September 7–19 it will wash out in the glare from the Moon, but when Vesta returns, it will be appearing near a reasonably conspicuous marker in the sky: the 5.5-magnitude star SAO 188192. Although by that time you'll need binoculars to see Vesta, careful monitoring should reveal the asteroid moving against the background stars from one night to the next.

Vesta won't be visible to the naked eye again until February 2003. Until then it may be out of sight but, like asteroids themselves these days, no longer out of mind.

Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens (Penguin, 1999).

### THE SKY IN SEPTEMBER

**Mercury** is invisible this month, rising too low on the horizon—and at an hour when it is too deeply immersed in evening twilight—to be observed.

**Venus** shines at magnitude +3.9 and becomes increasingly visible in the western sky during evening twilight, setting sixty to ninety minutes after sunset. On the evening of September 19, the planet passes less than 3° north of the first-magnitude star Spica, which appears only about a hundredth as bright. Look for a two-day-old crescent Moon above and to the right of Venus on the evening of the 29th.

**Mars** is visible as it rises from the east between 4:30 and 5:00 a.m. local daylight time (LDT). On the morning of September 16, the planet slips almost 1° north of the first-magnitude star Regulus, in the constellation Leo. Because Mars is currently more than 230 million miles from Earth, it shines only a trifle brighter than a second-magnitude star, but its yellow-orange color should still contrast strikingly with the blue of Regulus. On the morning of the 25th, a waning crescent Moon forms an eye-catching triangle with Regulus and Mars.

**Jupiter**, glimmering at magnitude -2.4, rises from the east-northeast at about 11:30 p.m. LDT at the beginning of the month and two hours earlier by month's end. On September 7, Jupiter passes 5° north of ruddy Aldebaran, in the constellation Taurus. This is the first of three encounters Jupiter will have in the next year with this first-magnitude star, the other two coming in October and April. A waning gibbous Moon appears near Jupiter and Aldebaran on the night of September 19–20.

**Saturn**, looking like a yellowish white zero-magnitude "star," rises from the east-northeast at about 11:00 p.m. LDT at the start of September, but by the last day of the month it can be seen closer to 9:00 p.m. LDT. A waning gibbous Moon appears less than 2° south of Saturn late on the night of September 18. From our earthly perspective, Saturn, viewed through a telescope, appears even more three-dimensional than usual because the planet and its rings cast especially long shadows.

The **autumnal equinox** occurs on September 22 at 1:27 p.m., when Earth reaches a position in its orbit that brings the Southern Hemisphere closer to the Sun, making it appear as if the Sun is crossing the equator. Autumn begins in the Northern Hemisphere and spring in the Southern Hemisphere.

**The Moon** is at first quarter on September 5 at 12:27 p.m. The harvest Moon—the full Moon occurring nearest to the autumnal equinox—appears this year on September 13 at 3:37 p.m. Last quarter is on September 20 at 9:28 p.m., and the new Moon is on September 27 at 3:53 p.m.

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Carolus Linnaeus (1707–78), the founder of modern taxonomy, frequently cited an ancient motto to epitomize his view of life: *Natura non facit saltum* (Nature does not make leaps). Such unbroken continuity may rule in the material world, but our human passion for order and clear distinction leads us to designate certain moments or events as "official" beginnings for something discrete and new. Thus, the signatures on a document define the birth of a nation on July 4, 1776, and the easily remembered eleventh hour of the eleventh day of the eleventh month (November 11, 1918) marks the armistice in a horrible war supposedly fought to end all contemplation of future wars. In a small irony of history, our apostle of natural continuity also became the author and guardian of a symbolic leap to novelty, for the modern taxonomy of animals officially began with the publication of the definitive tenth edition of Linnaeus's *Systema Natuaræ* in 1758.

The current classification of animals may boast such a formally recognized inauguration, but an agreement about beginnings does not guarantee a consensus about importance. In fact, the worth assigned to taxonomy by great scientists has spanned the full range of conceivable evaluations. When Lord Rutherford, the great British physicist (born in New Zealand), discovered that the dates of radioactive decay could establish the true age of Earth (billions rather than millions of years), he scorned the opposition of paleontologists by branding their taxonomic labors in classifying fossils as the lowest form of purely descriptive activity, a style of research barely meriting the name "science." Taxonomy, he fumed, could claim no more intellectual depth than "stamp collecting"—an old canard that makes me bristle from two sides of my being: as a present paleontologist and a former philatelist!

Rutherford's anathema dates to the first decade of the twentieth century. Interestingly, when Luis Alvarez, a physicist of similar distinction, became equally enraged by some paleontologists during the last decade of the twentieth century, he invoked the same image in denigration: "They're not very good scientists; they're just stamp collectors." I continue to reject both the metaphor and the damning of all for the stodginess of a majority, for Alvarez had exploded in frustration at the strong biases that initially led most paleontologists to dismiss, without fair consideration, his apparently correct conclusion that the impact of a large extraterrestrial body triggered the mass extinction of species at the end of the Cretaceous period.

Linnaeus's classification scheme can be visualized as a series of nested boxes in which the species is the irreducible category.
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extinction of dinosaurs and about 50 percent of marine animal species 65 million years ago.

The phony assumption underlying this debasement of taxonomy to philately holds that the order among organisms stands forth as a simple fact plainly accessible to any half-decent observer. The task of taxonomy may then be equated with the dullest form of cataloging—the allocation of an admittedly large array of objects to their clearly preassigned places: pasting stamps into the designated spaces of nature's album, putting hats on the right hooks of the world's objective hat rack, or shoving bundles into the

The most natural classification may be defined as the scheme that best respects, reveals, and reflects the causes that generated the diversity of organisms.

proper pigeonholes in evolution's storehouse, to cite a standard set of dismissive metaphors.

In maximal contrast, the great Swiss zoologist Louis Agassiz exalted taxonomy as the highest possible calling of all when, in 1859, he opened Harvard's Museum of Comparative Zoology in his adopted land. Each species, Agassiz argued, represents the material incarnation on Earth of a single and discrete idea in the mind of God. The natural order among species—their taxonomy—therefore reflects the structure of divine thought. If we can accurately identify the system of interrelationships among species, Agassiz concluded, we will stand as close as rationality can bring us to the nature of God.

Notwithstanding their maximally disparate judgments of taxonomy, Rutherford and Agassiz rank as strange bedfellows in their shared premise that a single objective order exists "out there" in the "real world" and that a proper classification will allocate each organism to its designated spot in the one true system. (For Rutherford, this order rep-
NO TEN. THE WORLD'S ONE TRUE SUPERPREMIUM GIN. THE ONLY ONE MADE WITH FRESH BOTANICALS IN THE HEART OF THE GIN. THE KEY TO A TRULY FRESH MARTINI. DISTILLED ONLY IN SMALL BATCHES, IN OUR NO TEN SWAN-NECK STILL. EXCEPTIONALLY SMOOTH WITH A SUBTLE HINT OF CITRUS. FROM TANQUERAY LONDON.
history of changing classifications becomes far more than a dull archive or chronicle of successive purchases from nature's post office (discoveries of new species), followed by careful sorting and proper pasting into preassigned spaces of a permanent album (taxonomic lists of objectively defined groups, with room always available for new occupants in a domicile that can grow larger without changing its definitive style or structure). Rather, major taxonomic revisions often require that old mental designs be razed to their foundations so that new conceptual structures may be raised to accommodate radically different groupings of occupants.

How can Linnaeus, a creationist who lived a full century before Darwin, be the official father of modern—that is, evolutionary—taxonomy?

In the obvious example of this essay, Agassiz's lovely cathedral of taxonomic structure, conceived as a material incarnation of God's mentality, did not collapse because new observations disproved his central conviction about the close affinity of jellyfish and starfish (now recognized as members of two genealogically distant phyla, falsely united by Agassiz for their common property of radial symmetry). Instead, the greatest theoretical revolution in the history of biology—Darwin's triumphant case for evolution—revealed a fundamentally different causal basis for taxonomic order. Evolution fired the old firm and hired a new architect to rebuild the structure of classification, all the better to display the "grandeur" that Darwin had located in "this view of life." (Ironically, Agassiz opened his museum in 1859, the same year that Darwin published the Origin of Species. Thus, Agassiz's replica of God's eternal mind at two degrees of separation—from the structure of divine thought to the taxonomic arrangement of organisms to the ordered display of a museum—became an unintended pageant of history's genealogical flow and continuity.)

But the argument that the history of taxonomy wins its fascination, at least in large part, as a dynamic interplay of mind (changing theories about the causes of order) and matter (increased and more accurate understanding of nature's factuality) now exposes a paradox that defines the central theme of this essay and leads us back to the official founder of taxonomy, Carolus Linnaeus. Darwinian evolution has set our modern theoretical context for understanding the causes of organic diversity. But if taxonomies always record theories about the causal order
Linnaeus's creationist account just happened to imply a structure that, by pure good fortune, could be translated without fuss or fracture into the evolutionary terms of Darwin's new biology.

I will advocate a position between these two extremes of exemplary observational skill in an objective world and pure good luck in a world structured by theoretical preferences. Linnaeus was, no doubt, both the premier observer and one of the smartest scientists of his (or any) age. But following my central claim that taxonomies must be judged for their intrinsic mixture of accurate observation and fruitful theory, I will argue that Linnaeus has endured because he combined the best observational skills of his time with a theoretical conception of organic relationships that happens to mirror—but not by pure accident—the topology of evolutionary systems, even though Linnaeus himself interpreted his organizing principle in creationist terms. (As for the fascinating, and largely psychological, question of whether Linnaeus devised a system compatible with evolution because he glimpsed "truth" through a glass darkly or because his biological intuitions subtly and unconsciously tweaked his theoretical leanings in an especially fruitful direction—well, as for all inquiries in this speculative domain of human motivation, I suspect that Linnaeus took this particular issue, with his mortal remains, to the grave.)

We refer to Linnaeus's system as binominal nomenclature because the formal name of each species includes two components: the generic designation, given first with an initial uppercase letter (Homo for us, Canis for dogs, and so on), and the so-called trivial name, presented last and in all lowercase letters (sapiens to designate us within the genus Homo and familiaris to distinguish dogs from other species within the genus Canis—for example, the wolf, Canis lupus). Incidentally, and to correct a common error, the trivial
name has no standing by itself and does not define a species. The name of our species, using both parts of the binomial designation, is *Homo sapiens*, not *sapiens*. We regard the 1758 version of *Systema Naturae* as the founding document of modern animal taxonomy because in this edition and for the first time, Linnaeus used the binomial system in complete consistency and without exception. (Previous editions had delineated some species binomially and others by a genus name followed by several descriptive words.)

Linnaeus's taxonomic scheme designates a rigorously nested hierarchy of groups (starting with species as the smallest unit) embedded within successively larger groups (species within genera within families within orders and so forth). Such a nested hierarchy implies a single branching tree with a common trunk that ramifies into ever finer divisions of boughs, limbs, branches, and twigs. This treelike form just happens to express the hypothesis that interrelationships among organisms record a genealogical hierarchy built by evolutionary branching. Linnaeus's system thus embodies the causality of Darwin's world.

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Alternative ways of visualizing Linnaeus's scheme include a progressively inclusive hierarchy, top, and a branching diagram, bottom.

The binomial system includes several wise and innovative features that have ensured its continuing success. But for the theme of this essay, the logical implications of the system for the nature of interrelationships among organisms stand out as the keystone of Linnaeus's uncanny relevance in Darwin's thoroughly altered evolutionary world. The very structure of a binomial name encodes the essential property that makes Linnaeus's system consistent with life's evolutionary topology.
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This correspondence between the Linnaean hierarchy and life's evolutionary tree achieves its clearest expression in pictorial form. The illustration on page 18 shows a Linnaean ordering of box within box; for alternative expressions of this hierarchy, see the diagrams of sequential genealogical splitting, opposite. Here we have a successive carving of the kingdom of all animals into, first, chordates contrasted with all other animals; then, vertebrates contrasted with all invertebrates; mammals contrasted with all other vertebrates; the order Carnivora contrasted with all other mammals; the family Canidae contrasted with all other carnivores; the genus Canis contrasted with all other canids; and finally, dogs contrasted with all other members of the genus Canis. (I stated that binomial nomenclature expresses the first step of this hierarchical ordering—and thus presents a microcosm of the entire scheme—because the two parts of a species' name record the first act of embedding smaller units within more inclusive groups of relatives. The name Canis familiaris states that this particular smallest unit, the dog species, ranks as one member of the next most inclusive group, the genus Canis, which unites all other species [including the wolf, Canis lupus, and the coyote, Canis latrans] that originated from a common ancestor shared by no other species in any other group.)

Linnaeus thought that his chosen scheme of mapping biological relationships as smaller boxes within successively larger boxes, until all units nested within the most inclusive box of life itself, represented the best human device for expressing the eternal order that God had chosen when he populated the universe. I doubt that Linnaeus ever explicitly said to himself (for I suspect that his mental mansion included no room for such a thought): "But if, quite to the contrary, life evolved by a process of ever expanding...

(Please turn to page 66)
Leaf Reading in Oahu

A Hawaiian mountain trail provides plant detectives with plenty of exercise.

By Robert H. Mohlenbrock

The third largest of the 131 islands in the Hawaiian archipelago, Oahu boasts such famous locales as Honolulu, Waikiki Beach, Diamond Head, and Pearl Harbor. From the first Polynesian settlers to the latest real-estate developers, human beings have had a huge impact on the island’s environment, stripping away indigenous vegetation and introducing ornamental and crop plants from across the sea. But steep slopes and high elevations still harbor tracts of montane rainforest where many native species abound.

Oahu consists of two nearly parallel volcanic mountain ranges that run northwest to southeast. The rugged Waianae Range, on the island’s western side, is the older of the two and includes Oahu’s highest peak, 4,040-foot Kaala. On the eastern side is the Koolau Range, whose spectacular fissured cliffs front the windward side of the island. The Koolau mountains capture the greater part of the moisture shed by the trade winds, and their slopes were once completely cloaked in forest. Here the rainforest still survives above 1,650 feet.
View from Manoa Cliff Trail on Mount Tantalus
or so. But in the Waianae Range, only the upper slopes of Kaala are moist enough to support this habitat.

One of the most accessible places to see a bit of the montane rainforest is near Honolulu. The city has spread toward the Koolau mountains, and the suburb of Makiki Heights has penetrated the foothills below Mount Tantalus. This 2,013-foot mountain, which falls within the Honolulu Watershed Forest Reserve, lies northeast of the famous Punchbowl Crater, location of the National Memorial Cemetery of the Pacific.

A map of Mount Tantalus that shows various hiking trails is available from the Hawai‘i Nature Center on Makiki Heights Drive. I recommend the 3.4-mile-long Manoa Cliff Trail. After leaving the nature center, take Makiki Heights Drive eastward to where it turns into Round Top Drive and proceed on this circuitous route up the mountainside. The trail begins near a parking area, follows the cliff above Manoa Valley, and then continues around Mount Tantalus. It ends at Tantalus Drive, which is the continuation of Round Top Drive. At that point you can retrace your steps or, watching out for traffic, walk along the narrow vehicular road to your starting point. A shorter option is to hike the trail for about one and a half miles to the junction with the Pu‘u ‘Ohia Trail (which would take you toward the summit of Mount Tantalus) and then turn back.

At the beginning of Manoa Cliff Trail, numerous nonnative ornamentals grow rampantly. Six-foot-tall ginger plants, with their white and yellow flowers crowded into a club shape, complement the colorful ti plant, whose clusters of long, mottled red-and-green leaves grow from the tops of unbranched stems. Nonnative trees include strawberry guava, common guava, rose apple, kukui (a candlenut), and avocado, while two of the shrubs are lantana and a type of raspberry called olia. Farther along the trail are groups of banana plants.

**TELLTALE LEAVES**

Leaves arranged in pairs characterize many species, including three with leaf domatia (tiny chambers that house insects and mites). In ‘ahakea lau nui, the domatia are slightly elevated on the leaf surface, while in kopiko kea and Psychotria mariniana, they are sunken into the surface where the lateral veins join the main vein. ‘Akoko is a shrub readily identified by its milky sap, and ‘ohi’a ha leaves have pink or red middle veins. In Dubautia plantagina, the parallel-veined leaves are reminiscent of those of the common North American weed known as plantain. A shrub whose paper-thin leaves emit a foul odor when crushed is au, a member of the coffee family.

Leaves arranged in whorls forming circular patterns at intervals along the twig characterize just one shrub, Coprosma longifolia. The leaves on this slender, branched species are grouped in threes.

Leaves crowded at the tips of twigs or branches are found in three species related to lobelias. The easiest of these to identify is Cyanea grimesiana, because its leaves are fernlike; the other two have toothed leaves. Another plant in this category, kolea lau nui, has smooth-edged leaves.

Alternating leaves are apparent in koa, readily identified by its sickle-shaped leaves. Others in this category that are easily recognized include Perrottetia sandwicensis, which has red veins in its leaves; maua, which has red leaf stalks; and ala’a, a relative of the soapwort, which oozes milky sap from the stalk when a leaf is broken off. Kava‘u (a member of the holly family) has smooth-edged leaves with an intricate network of conspicuous veins. Perhaps the strangest of these plants is pamakani mahu, a shrub in which the tips of the branches tend to climb like vines.
The first native trees encountered are some koas that form a canopy over the trail. Mature koa leaves are sickle shaped, and the tree produces cream-colored flowers in powder-puff clusters and flat pods up to ten inches long. Highly prized, koa wood is used for both traditional and modern products.

Native species abound along much of the rest of the trail—wildflowers, vines, and, above all, trees and shrubs. They are easiest to identify when they are bearing their flowers or fruit, but most of the time the only clues are the leaves. One salient detail is the way the leaves are arranged on twigs or branches. In some species, they are crowded at the tips, a characteristic rarely seen in plants native to the continental United States. One such species is *Cyanea grimesiana*, a shrubby relative of the lobelia with fernlike leaves. (Lobelias in the continental United States are small wildflowers, but most of their Hawaiian relatives are shrubs or even small trees. Why plants on islands tend to be large and woody while their mainland relatives are not is a phenomenon that has intrigued biologists since the time of Darwin.)

In other species, the leaves may be arranged along the twig in an alternating pattern, in pairs, or in whorls. Additional leaf characteristics that help in identification are size, form, color, vein pattern, thickness, and texture. (The accompanying descriptions in “Telltale Leaves” illustrate some of these distinctions.)

The leaves of three closely related species have tiny chambers called domatia, which commonly serve as shelters for small insects and mites. Domatia were first described more than a century ago by Swedish naturalist Axel Lundstrom, who suggested that the residents they attracted helped protect the plant. This has been confirmed in some species, including these Hawaiian plants.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.
Molecule, Heal Thyself

Genetics is rapidly transforming how we think about disease.

By Ronald L. Nagel

"Disease enters and leaves man as through a door," wrote French philosopher Georges Canguilhem more than half a century ago, illustrating the notion that disease is a distinct "thing" that exists apart from the human body. This view has prevailed in many cultures since ancient times, although in various guises. While people once might have attributed maladies to demonic possession, we now talk confidently about disease-generating microorganisms and parasites. But a very different idea has also enjoyed favor throughout history—that disease is not a separate entity but a changed state of the organism, a disturbance of the natural equilibrium or harmony. An example is the belief, originating in classical times, that disease is caused by an imbalance among four bodily humors: blood, phlegm, yellow bile, and black bile. Hippocrates, considered the father of Western medicine, prescribed various remedies to restore the balance, including bleeding the patient and inducing vomiting to remove excess amounts of any of the humors.

Although these two views of disease may appear incompatible, physicians have learned to rely on both when striving to understand the diseased individual. Take, for example, malaria, which involves infection by a parasite transmitted by mosquitoes. When a person has a severe case of the disease, he or she experiences periods of calm interspersed with sudden, intense shaking chills and very high fever. This cycle reflects events within the patient's blood. First, the malaria parasites grow in synchrony, from early to late stages, within red blood cells. During this time, the disease symptoms are mild. When the parasites mature, the infected blood cells erupt, each liberating about twenty parasites along with all the by-products accumulated in the cell during their maturation. Among these by-products are chemicals that induce the host to release tumor necrosis factor (TNF) into the bloodstream. This ominously named substance—also found in cancer patients—is actually a first line of defense, since it inhibits parasite growth. But it also precipitates chills, fever, and other effects that do not appear to benefit the host. If the body does not properly regulate the release of TNF, the negative consequences may outstrip the good ones and possibly cause death. Thus, concepts of an external invader (the malaria parasite) and of disequilibrium (changes in the internal balance of biologically active molecules) coalesce to provide a picture of the disease.

With the emergence of molecular biology and genetics, these two points of view have become ever more synthesized. An important breakthrough was the concept of molecular disease, introduced in the late 1940s with Linus Pauling's elucidation of the underlying basis of sickle-cell anemia. Pauling linked the suffering and decreased survival of sickle-cell patients to a single abnormal molecule called hemoglobin S.

A diagnosis of "pneumonia" as an identical disease every time it occurs—even in the same patient—is just an abstraction.

Pauling's insight came after he heard Harvard physician William Castle's description of this type of anemia, in which the red blood cells appear in irregular sickle shapes. A student
of Castle's had observed a peculiar property of sickle cells not found in normal red blood cells: the interior of the cells became illuminated only when lit from certain angles. Pauling, a chemist who had revolutionized the science by focusing on the three-dimensional structure of molecules, realized that sickle cells probably contained an abnormal protein. Molecules of this protein were apparently capable of forming an orderly array that played tricks with the light shining on them. Pauling knew that hemoglobin was the preponderant protein inside red blood cells, so he suspected the culprit was an irregular form of it. Working with other researchers at his laboratory in Pasadena, he was soon able to confirm that the hemoglobin in individuals with sickle-cell anemia had a different electrical charge, detectable by electrophoresis. In 1949 he coauthored a landmark paper for Science, "Sickle Cell Anemia: A Molecular Disease."

By this time, geneticist James V. Neel had shown, through genealogical studies, that sickle-cell anemia was an inherited disease. And in 1957, Vernon M. Ingram, a Swedish researcher working in England, determined that sickle-cell anemia was due to a change in a single amino acid out of the 146 that make up each of the two beta-chain constituents of the hemoglobin molecule (the other constituents, two alpha chains, are normal). From there it was a short step to identifying the genetic mutation responsible for the disease.

The technological explosion of molecular biology has meant an exponential increase in our knowledge of pathogenic mutations in genes. Some mutations can be transmitted through inheritance, such as those responsible for Tay-Sachs disease (which leads to a fatal breakdown of the central nervous system) and phenylketonuria (a disorder
that prevents the body’s normal metabol-
ization of the amino acid phenyl-
alanine, which is found in many foods). Other mutations affect only the de-
cendants of the mutated cell and are not transmitted by inheritance; an ex-
ample of this is the bone-marrow dis-
order called paroxysmal nocturnal he-
moglobinuria. While such findings
were once novel, we are now con-
tantly bombarded with the news that
this or that disease has been traced to
some offending gene.

Something as seemingly random as breaking a leg has
a genetic component, which affects the way you fall,
the strength of your bones, the risks you take.

Probably the most important insight
of the past decade, however, is that all
diseases are always both genetic and en-
vironmental. Phenylketonuria, long
considered a prime example of a ge-
netic disease, is also environmental; if
one modifies the diet, eliminating or
greatly reducing the intake of foods
containing phenylalanine, the disease
disappears or is greatly ameliorated. On
the other hand, such bacterial, viral,
and parasitic infections as tuberculo-
sis, the common cold, and malaria—all
quintessential examples of disease as an
entity that invades the body—turn out
to have a complex relationship with the
genetics of the host, since individuals
vary in susceptibility and resistance to
most infections.

Common chronic diseases (athero-
sclerosis, high blood pressure, diabetes,
and many others) have major genetic
components. Even something as seem-
ingly random as breaking a leg while
skiing has a genetic component, be-
cause the way you fall, the strength of
your bones, your ability to ski, the risks
you take—all have a genetic compo-
nent. Is it so surprising, then, that
people who have a history of more
than one fracture are likely (at least ac-
cording to some studies) to come from
families in which such mishaps are
more common?

Along with the appreciation of ge-
netic factors in disease has come a real-
ization of the extraordinary individual-
ity of humans at the DNA level. The
expression of even a largely genetic dis-
ase is thus affected not only by the ab-
normal gene or genes that cause the dis-
ase but also by subtle differences in the
normal genes that are present. A gene
(and other sequences of DNA sur-
rounding it) that dictates the production
of a particular protein may be polymor-
phic—that is, it may exist in more than
one form in the human population.
Subtle differences in the genetic code
sequence from one individual to an-
other will result in proteins with minor
or major functional differences or in the
production of these proteins in different
quantities. Current data suggest that at
least 10 percent of genes are polymor-
phic and that some are highly so, owing
to natural selection. If the polymorphic
mutations affect the clinical course of a
genetic disease, they are called epistatic,
or modifier, genes.

For example, clinicians in the 1960s
who followed African American or
Italian American patients suffering
from sickle-cell anemia (and who had
the opportunity to observe patients
living longer as a result of better pre-
ventive and therapeutic approaches)
were struck early on by the fact that
individuals with the same mutation
had very diverse clinical presentations.
Some had few symptoms, but others
had severe complications and required
frequent hospitalization. In the past
twenty years, it has become clear that
in a severe case of sickle-cell anemia,
the patient probably has modifier
genes that intensify the illness, while
the patient with a more benign condi-
tion has a set of modifier genes that
ameliorate the disease.

Three important genetic modifiers
of the disease are known. First, sickle-
cell disease is less intense in patients
who also have alpha-thalassemia, a very
mild condition that in African and
other populations provides partial pro-
tection against death from malaria.
One out of four African Americans
is born with alpha-thalassemia; therefore,
at birth, one-fourth of African Ameri-
cans with sickle-cell disease have this
ameliorating condition.

Second, genes linked by proximity
to the sickle mutation can modify the
expression of the disease. The sickle
mutation arose at least four times in
Africa and once on the Indian subcon-
tinent, and each time a different set of
genes has ended up near the sickle mu-
tation. Although the reasons are still
not fully understood, these nearby gene
sets ameliorate the disease in two in-
stances—one of which is associated
with the eastern oases of Saudi Arabia
and the so-called tribal peoples of India
and the other with present-day Senegal
and surrounding countries. In contrast,
the disease is more severe in the other
three cases. One of them affects the in-
habitants of Benin and neighboring re-
gions of West Africa, and another (par-
ticularly severe) is found in Bantu
speakers, who live throughout the cen-
tral and southern parts of the con-
tinent. The third case is limited to the
Eton people of Cameroon—a distri-
bution so restricted that it probably rep-
sents the most recent mutation.

A third genetic modifier is related to
sex: all other things being equal, females
are apt to have less severe symptoms
than males do. This is because women
are better at making fetal hemoglobin
when they are anemic, and fetal hemo-
globin helps counteract the bad effects
of hemoglobin S. We do not yet know
which genes determine this, but they
are probably located in the X chromo-
some. In sum, while hemoglobin S, the
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The Euro-Pro Shark provides the power of an upright in a hand-held vacuum and sucks dirt from places ordinary hand vacs can't reach.

by Sandra Brosberg

I’m a neat freak. I admit it. But with a cat, two dogs and two children, it’s tough to keep everything clean. Everytime I turn around, there’s a new mess on the kitchen floor, the living room carpet or the bathroom tile. Whenever I spotted a mess, I had to go to the closet and drag out the upright vacuum cleaner. Thank goodness I discovered the Shark Turbo hand vacuum! With seven times the suction of ordinary hand-held vacuums, it gives me the cleaning power of a top-of-the-line upright.

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variant type of hemoglobin, can be attributed to a single gene, the genetic disease sickle-cell anemia is the combined result of many genes.

Similarly, the effectiveness of chemotherapy and of other pharmacological treatments depends on each individual's genetic makeup, which ultimately determines how cells process and eliminate pharmaceuticals. Among the responsible genes are the so-called multidrug-resistant genes (MDRs), which are involved in enabling the body to rid the interior of cells of toxic molecules. In the distant past, these genes may have protected hunter-gatherers who consumed toxins present in wild plants. Today the products of the genes often defeat chemotherapy given to combat cancer, because they pump the drugs out of the malignant cells before the treatment can do its work. Allergic reactions to medications (common immunological responses to an offending molecule) and idiosyncratic, very bad reactions on the part of some rare individuals are also defined by the genetics of the patient.

One can take this a step further. For example, suppose Jane Doe is diagnosed as having pneumonia, a lung infection that occurs when, for some reason, the immune system fails to produce effective antibodies to combat invading bacteria and/or the white blood cells fail to kill them. The severity of the disease will be defined not only by the intrinsic virulence of the infecting bacteria but also, more important, by Jane Doe's genetic makeup. Similarly, the effectiveness of antibiotics that may be prescribed depends on genetic characteristics of both the microorganism and the patient. Thus, what we have is a lung infection that is unique to this particular individual and this particular episode. Even if Jane Doe contracts pneumonia again, both the bacterium and her own body will likely have changed, along with environmental conditions (which can include nutritional choices, interactions with sick family members, exposure to pets carrying disease, and so on). A diagnosis of "pneumonia" as an identical entity every time it occurs even in one patient is thus only an abstraction in the physician's and patient's minds.

Recently, following the development of technologies that automate and vastly accelerate the sequencing and comparison of DNA, research teams announced they had generated a rough draft of the entire human genome. It is realistic to think that physicians will, in the not-too-distant future, have a road map of each patient's chromosomes, indicating all mutations that might bring about or modify the pathological process, and also those that could impinge on treatment. The constellations of symptoms and signs that we call diseases will still be useful, but only to focus clinicians' search for the relevant genetic data. Rather than treating a disease—whether conceived of as either a separate entity or a disturbance of equilibrium—physicians will be treating an individual who has become diseased, a whole organism that has painted its unique genetics all over the disease process.

Additional challenges will include defining and understanding with precision the environmental factors that contribute to the genesis of the diseased individual, as well as gaining deeper insight into lesser known areas of physiology, such as the workings of the mind. All this points to an ever-increasing role for medical knowledge based on rigorous, controlled studies. If anything, the physician of the future will have to be more of a scientist than his or her counterpart is today.

Still, neither our level of knowledge nor our treatment resources are likely ever to approach perfection. Consequently, the art component of medical practice—which, after all, has always separated medicine from pure science—will continue to count in the distant future. I see nothing wrong with that.

Ronald L. Nagel is the Irving D. Karpas Professor of Medicine and the head of the Division of Hematology at the Albert Einstein College of Medicine/Montefiore Medical Center in New York City.
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Jaws of Death

If you were an oyster, the last thing you’d want is a ray with a crush on you.

Sharks, rays, and ratfishes share a special burden: these cartilaginous fishes are saddled with a reputation for being somehow inferior to vertebrates blessed with bony skeletons.

Bone is certainly a wonderfully strong material. It lets hyenas crush carcasses with their jaws and enables elephants to support their massive bodies. Bone tissue is crammed with cells known as osteocytes and blood vessels that keep them nourished. The osteocytes release calcium, phosphates, and other minerals, which help make bones strong. They form layers that wrap around the outside of the bone and create a dense web of branching columns inside it.

The cartilage in sharks and rays, by comparison, consists primarily of a mesh of collagen fibers embedded in a gelatin-like matrix, along with a scattering of cartilage-generating cells called chondrocytes. (Sometimes the cartilage is surrounded by a thin layer of mineralized tissue that gives it a little extra stiffness.) The result is a softness and flexibility that imply a certain weakness. After all, it is backbone we admire in a person, not cartilage.

Dating back at least 420 million years, cartilaginous fishes are sometimes referred to as primitive—as if cartilage were an intermediate step on the climb from invertebrates to bony vertebrates. The development of a human embryo seems to replay this imagined evolutionary ascent: the embryo starts out with a skeleton of pure cartilage that gradually turns almost completely to bone. As adults, we retain only a few vestiges of cartilage—in the nose, the ear, the voice box, the disks between the vertebrae, and at the ends of free-moving bones.

Adam Summers, a biologist at the University of California, Berkeley, is determined to show that this supposed inferiority of cartilaginous fishes is a biomechanical myth. Cartilage is indeed generally weaker than bone but at times can become remarkably stiff and strong. For the past few years, Summers has been studying the cownose ray (*Rhinoptera bonasus*). This three-foot-wide creature, which lives solely on hard-shelled mollusks, is a scourge of oystermen: a school of 3,000 rays can pick an oyster bed clean in an afternoon. A ray eats its prey by grabbing the mollusk in its mouth and crushing the shell with its jaws.

To discover how this fish can be so adept at breaking something so much harder than its own jaws, Summers x-rayed a cownose ray. Its cartilaginous jaws, he found, had a lot of mineral inside them. At first he thought he had picked a diseased individual to study. In humans, cartilage contains hard, calcified deposits only when a person is suffering from a disorder such as scleroderma (an ultimately fatal illness in which the joints and skin stiffen). Yet Summers discovered that ray after ray had the same sort of jaw, with a mineral-rich cartilage unlike any that had been described before.

The mineral, however, is not randomly distributed in the ray’s jaws, nor is it spread evenly. Rather, it is the chief ingredient of hollow struts in both upper and lower jaws, and these struts are concentrated in the areas of the jaws that bear down on prey. Summers cannot yet say how these struts form, but their function is clear. Without adding much weight to a structure, struts allow it to resist bending and buckling. Struts are a favorite tool of engineers, whether they are designing a bridge or a piece of corrugated cardboard. Likewise, struts help a cownose ray’s jaws hold up against the shell of a clam or an oyster.

But Summers suspects that the struts are responsible for only part of the cownose ray’s shell-crushing ability. Species of rays that eat fish or soft-bodied invertebrates have loose ligaments connecting the upper and lower jaws. In these species, the jaws’ left and right sides are separate, which means the ray can bite down with one while opening the other. That freedom gives these rays the flexibility they need to handle squirming prey.

The cownose ray has a different jaw design. To help crush hard prey, it has a solid lower jaw and a solid upper jaw. In addition, ligaments lash this ray’s upper and lower jaws tightly together. Such a design, Summers proposes, would be ideal for a fish that uses its jaws as a nutcracker. Placing a shellfish between them, he says, the cownose ray might contract the muscles on the left side of its mouth. This side would then act like the handles of the nutcracker being squeezed together.
At first, bringing the left side of the jaws together would stretch the right side of the jaws apart. But because the ligaments are so tight, the jaws couldn’t stretch very far, and soon the ligaments would begin acting like the fulcrum at the hinged end of the nutcracker. As the cownose ray continued squeezing the left side of its jaws closer and closer together, it could put more and more pressure on the shellfish, crushing it.

A nutcracker works by amplifying the forces exerted on it. Summers calculates that a cownose ray with prey caught at the center of its jaws would, because of the jaws’ architecture, be able to double the force of its bite. He plans to test his nutcracker model by recording the activity of jaw muscles in live cownose rays as they feast on shellfish. The results of these experiments, he expects, will demonstrate just how a jaw that is more custard than steel can become—with the help of some struts and proper leverage—shell-shatteringly strong.

An excerpt from Carl Zimmer’s new book, Parasite Rex, appears on page 44 of this month’s Natural History.
New Zealand mistletoes that bear strange, sealed flowers depend on savvy native pollinators to thrive.

By Laura A. Sessions

Every year in December, the beginning of the austral summer, the green temperate rainforests in parts of New Zealand come alive with bright-red mistletoe flowers. One of my favorite places to see this natural display of Christmas color is a thirty-acre fragment of southern beech forest on the shore of South Island’s Lake Ohau. This turquoise glacial lake lies in the shadow of the central Southern Alps’ snowy peaks. Nearly every southern beech in this patch of forest is host to one or more large mistletoe plants. Botanists categorize mistletoes as hemiparasites—plants that can make food through photosynthesis after siphoning water and mineral nutrients from a host plant via rootlike structures that penetrate the host’s bark and vascular system. The mistletoes that grow on the Ohau beeches can reach nine feet in both length and width and can virtually envelop a tree, but unlike their European and North American counterparts, they do not damage their hosts. When the mistletoe flowers mature, they drop from the plant and form red piles on the forest floor, like confetti from a holiday party.
A visitor to the Ohau forest who examines these fallen blossoms will notice that many of them have opened upside-down. While the petals of most other flowers are joined at the bottom and fold back from each other at their tips, these mistletoe petals are fused at the top and detached at the base. The stigma, or pollen-receiving structure, stays sealed within the flower tip, hidden from any pollinators that might fertilize the bloom and thus stimulate fruit and seed production, leading to a new generation of mistletoes. Why would a plant produce hundreds of flowers if they remain inaccessible to pollinators? In 1969, referring to these sealed flowers, botanist Job Kuijt declared, “We cannot even guess at the meaning of this bizarre performance.”

Thanks to a research project that began in 1992 and continues today, we can offer more than a guess at the significance of the fallen and unfertilized mistletoe flowers. We now know that these mistletoes have a pollination system unique in New Zealand and that the unpollinated blooms dying on the forest floor represent a breakdown of the system. Led by Dave Kelly and Jenny Ladley, of the University of Canterbury in Christchurch, the project, which I joined in 1996, has gradually been transmogrified into a ten-person field effort. Every December, as other people prepare to celebrate the holidays, we gather our ladders and video cameras, sort through piles of tiny colored wires, mesh bags, batteries, chemicals, and microscope slides, and head out to the field. We now monitor more than 200 plants throughout New Zealand to determine changes in their size, health, and rates of pollination and fruiting. We also take more than 100 hours of video footage each year to record which pollinators visit plants and how they behave.

While mistletoes grow in temperate and tropical regions worldwide, New Zealand is home to eight species that occur nowhere else and one that is also found only on Norfolk Island in the Tasman Sea, between New Zealand and Australia. Our research has focused on two of these species, red mistletoe (*Peraxilla tetrapetala*) and scarlet mistletoe (*P. colensoi*).

In one of their first experiments, Kelly and Ladley attempted to learn more about New Zealand mistletoe reproduction by putting mesh bags over branches bearing unripe buds. The flowers could then be hand-pollinated, and the potential fruit production could be estimated. Or so Kelly and Ladley thought. After several weeks of close monitoring, the buds had ripened but failed
to open. Eventually they began to split from the bottom, as Kuijt had noted, and to fall off the branches. This occurrence and a knowledge of the ways in which certain African and Indian mistletoes achieve pollination gave the researchers clues to what might be going on. On Christmas Eve of 1992, Ladley watched from just a few feet away as a tui, a native honeyeater (a nectar-eating bird), moved deftly among the nearby unbagged flowers on the tree. Using its beak, the bird reached for a bud and gave it a quick twist, which released the four petals. Within a second after the bud sprang apart, pollen was catapulted onto the tui’s head as the bird sipped a pool of nectar.

Until this revelation, no one had known that any New Zealand mistletoes—or any other New Zealand flowers—relied on this unusual pollination mechanism. Flowers that can be popped open in this way by animals are called explosive. Various plant families from different parts of the world have such flowers, many of which are easily tripped by the touch of an insect or even by the wind. But flowers that require forceful opening are rarer and must attract pollinators that know the trick. From the bird’s perspective, explosive twist-top buds unequivocally signal the presence of a sweet fast food (nectar) wrapped in a tamperproof package. The mistletoe also benefits from this setup. Sealed buds protect pollen against rain and mist until a pollinator is available, and once it is, the miniexplosion effectively showers the bird with pollen. The mistletoe usually ceases to produce nectar within the flower once it is opened, thereby encouraging birds to concentrate on opening new flowers rather than revisiting old ones.

In addition to the tui, another New Zealand species of honeyeater, known as the bellbird for its clear, bell-like call, commonly opens mistletoe flowers. Of the 170 species of honeyeaters in Australia and the Pacific Islands, only three—the tui, the bellbird, and the stitchbird (the latter surviving only on offshore islands)—are found in New Zealand. For their mutually beneficial relationship to have evolved, the honeyeaters and the mistletoes with explosive flowers presumably have been coexisting for thousands or perhaps millions of years. Introduced birds, such as blackbirds and finches (which are casual nectar feeders), rarely twist the flowers open. Perhaps these exotic species have not been living long enough with mistletoes in New Zealand to learn the opening maneuver. Occasionally we have seen bellbirds trying unsuccessfully to hasten the opening of the flowers of yellow mistletoe, or *Apleis flavida*, which open on their own. This suggests that explosive opening in red and scarlet mistletoe flowers might have evolved as the birds sought to be the first to reach an untapped nectar source.

Two years after their discovery of the exploding mistletoe flowers, the team found that birds were not the only animals that had learned how to access mistletoe riches. Several species of native solitary bees (*Hylaena agilis* and various *Leioproctus* species) are barely one-fifth the size of a red mistletoe bud, but with persistent gnawing and heaving, they oc-
casionally manage to pry one open with their mandibles. The bees are not interested in nectar; instead, they harvest pollen and haul it back to their nests to feed their larvae. In contrast to the birds’ instant twist-and-sip method, the tiny bees often take more than a minute just to release the petals. On average, they succeed in opening one bud in every four they attempt to spring. But their efforts are generously rewarded. A bee that manages to jimmy open a mistletoe bud gets first access to an untapped store. The New Zealand red mistletoe is the only plant in the world with bird-pollinated explosive flowers that are also opened by insects. This challenges the common notion that plants usually have only one guild of pollinators—for example, either birds or butterflies, but not both.

As is the case with the honeyeaters, only native bees seem to have had time to learn how to unlock the mistletoe blossoms; the insects’ introduced counterparts—exotic honeybees and wasps—have not yet discovered the trick. The native bees may be playing a role that in other parts of the world is likely to be adopted by other types of animals. New Zealand has relatively few pollinators. There are no mammalian pollinators, and only seven bird, one bat, sixteen butterfly, and about forty native solitary bee species serve New Zealand’s flowers. (Australia, in contrast, is home to about 3,000 bee species and 110 bird species that are active pollinators.) Consequently, most New Zealand flowers either attract a range of pollinators (a variety of insects, for example) or are self-fertile (that is, able to produce fruits without pollen from another plant). Red and scarlet mistletoes’ dependence on a few savvy pollinators came as a surprise.

Also unusual is the flower structure of red and scarlet mistletoes, which allows for visits by pollinators of vastly different sizes. A solitary bee weighs only one three-thousandth as much as a bellbird. When a tui or a bellbird pops open a bud, all four petals spring back, and as the bird inserts its beak into the corolla to drink nectar, its head often brushes pollen onto the receptive stigma. If the flower reacted the same way to a bee’s probings, the insect could easily gather pollen from the anthers (the pollen-producing structures) without ever touching the stigma, and pollination would be unlikely. But bees seldom “detonate” flowers the same way birds do. Instead the bee makes a small slit in the end of the bud, creating just enough room to push its way inside. In such cramped quarters, the bee is more likely to touch the stigma—
and pollinate the mistletoe—as it harvests pollen from the anthers. Our experiments show that on average, and despite their size, bees deposit about the same number of pollen grains during a single visit as birds do.

Still, bees are probably not as important to these mistletoes as native honeyeaters are, because the bees enter far fewer flowers. In addition, red and scarlet mistletoes depend on birds for seed dispersal. *Peraxilla* seeds are small and green even when ripe. In order for the seeds contained within the fruit to germinate and to become established on a new host tree branch, the fruit skins must be removed. The birds devour and digest the fruit and its skin, then defecate the seeds, often onto a branch of another tree. The pulpy seed is surrounded by a sticky layer that glues it to the surface on which it lands. Germinating immediately, the seed sends out “rootlets” to tap into the host tree’s water supply.

Because of the mistletoe’s reliance on honeyeaters for both pollination and dispersal (in addition to the honeyeaters, only one other bird, the waxeye, frequently eats the fruit), mistletoe plants are particularly subject to reproductive failure if their avian partners become scarce or disappear, as has happened with other indigenous birds. Plants that maintain less specialized relationships with their pollinators can reproduce with the help of many different insects or various birds; for them, the loss of any one species of pollinator is not so significant. But red and scarlet mistletoe flowers cannot open without the help of specific native bird and bee species, and unopened flowers have only a 5–10 percent chance of forming seeds through self-pollination. Unfertilized flowers end up as mysterious bottom-opened remnants on the forest floor.

At the turn of the last century, botanists reported forests ablaze with the scarlet blooms of native mistletoes, but today few areas of New Zealand support profuse growth. In most places, unpollinated dead blooms littering the ground are more common than flowers twisted open by birds and bees. Our experiments have shown that at several sites in the central Southern Alps of South Island, mistletoe plants produce no more fruits than plants that have been placed inside cages to keep out pollinators. This means that birds and bees are visiting flowers so infrequently—or that the birds are becoming so scarce—that essentially there is no increase at all in pollination over the low rate of self-pollination. (Birds may also be dispersing fewer seeds, although this may be less of a problem than the decline in pollination; ripe fruits can wait six weeks for a bird’s visit, while buds last only six days.) A potential cycle of decline could begin if pollination drops to the point at which these mistletoes become rare and individual birds lose the twisting habit or if, over time, the bird species “forget” how to access flowers.

The decline of New Zealand mistletoes is one of a series of ecological changes stemming from the introduction of land mammals into plant and animal communities that evolved without such creatures. Rats, stoats, ferrets, cats, and possums have decimated native animals that were unaccustomed to mammalian predators. Native birds in particular have drastically declined, and some have been forced to seek refuge on mammal-free offshore islands. One mammal I have studied, the Australian brush-tailed possum, harms mistletoe in a direct way, by devouring it. But another cause of the gradual disappearance of mistletoes throughout New Zealand is the elimination of avian pollinators by mammals. This chain of ecological events may already have doomed a close relative of the red and the scarlet species, the mistletoe known as *Trilepidia adansii*, which has been extinct since the mid-1950s. New Zealand has risen to the challenge, however, and measures are being taken to control exotics and to conserve native species, including honeyeaters and the remaining mistletoes. No longer a mystery, the fallen flowers of Ohau have proved to be the warning sign of a disruption in a long-standing ecological relationship. That partnership must be revived if the newfound pollination phenomenon itself is to survive in New Zealand. ☐
Attack and Counterattack: The Never-Ending Story of Hosts and Parasites

By Carl Zimmer In the Origin of Species, Charles Darwin said little about a particularly powerful evolutionary force that brought him a lot of personal sadness: parasites. His ten children struggled against diseases such as influenza, typhoid, and scarlet fever, and by the time the Origin came out in 1859, three of them had died. Darwin himself suffered for much of his adult life from fatigue, dizzy spells, vomiting, and heart trouble. He once described his health this way: “Good, when young, bad for the past 33 years.” Although no one is sure what made him suffer, some have suggested Chagas’ disease, which is caused by a trypanosome, a parasite that in turn is spread by the beneduxa, a biting insect of South America. The ways to die of Chagas’ are horrible in their variety: your misfiring heart may stop beating, for example, or food may pile up in your colon until you die of blood poisoning. Darwin was bitten by a beneduxa as he was traveling around the world on the HMS Beagle, and many of his symptoms arose only after he returned to England.

Perhaps parasites caused Darwin too much misery for him to recognize their evolutionary importance. But he was hardly alone. Only recently have scientists begun thinking seriously that parasites may be just as important to ecosystems as lions and leopards.

After consuming most of the tongue of a spotted rose snapper, a parasitic isopod (a tiny relative of crabs and lobsters) hooks onto the floor of the fish’s mouth. There it may take over the tongue’s role, helping the fish hold prey—and getting tidbits for itself in the process.
And only now are they realizing that parasites have been a dominant force, perhaps the dominant force, in the evolution of life.

Organisms of all kinds have evolved means to detect, fight, and avoid parasites. *Copadichromis eucinostomus*, for example, a small fish that lives in Lake Malawi in southeastern Africa, is one of many animals in which the females employ some sort of parasite test when selecting a mate. To attract females, the males build bowers out of sand on the lake bottom. Some of the bowers are nothing more than a handful of grains sitting on top of a boulder, while others are big cones several inches high. The males build their bowers near one another, creating dense neighborhoods, and each defends his bower against other males. The female fish spend most of their time feeding on their own, but when ready to mate, they go to the bower neighborhood and inspect the males’ work. If a female chooses to mate with a particular male, she releases an egg and puts it in her mouth. The male then deposits his sperm there too, and the female swims away with the fertilized egg inside her mouth, where it will develop into a baby fish.

The females apparently use the bowers to find out which males do the best job at fighting parasites. Experiments have shown that they prefer males that build big, smooth-shaped bowers and that these males are also the ones with the fewest tapeworms. Perhaps a fish that’s carrying tapeworms has to spend so much time eating that it can’t maintain its bower. The bower thus becomes a medical chart and perhaps a sort of genetic profile.

Parasites also have been instrumental in shaping the social structure of some species. Leaf-cutting ants travel from their nests to trees and hack off bits of leaves, which they grip in their mandibles. Then, forming a parade of green confetti on the forest floor, the ants carry the foliage back home, where they use it to grow gardens of fungi—the ants’ food. Leaf-cutter colonies are divided into big ants, which tote the leaves home, and little ones. The little ants, known as minims, tend the gardens, but they can also be found riding atop the leaf fragments being carried by their larger nestmates. Entomologists were puzzled for a long time over why the minims would waste their time hitching rides like this. Some suggested that they must collect some other kind of food on the tree, maybe sap, and then ride home on the leaves to save energy. In fact, minims are guards. The parasitic flies that attack leaf cutters have a special ap-
Some amphipods, top, parasitized by the larvae of thorny-headed worms (orange) respond by swimming to the surface, where they are likely to be snapped up by a mallard. Bottom: Adult worms complete their life cycle in the duck’s intestine.

Some approach to their hosts; they land on a leaf fragment carried by an ant and then crawl down to lay their eggs in the gap between the ant’s head and thorax. Hitchhiking minims, their mandibles open, patrol the leaf or perch on top of it; when they encounter a fly, they scare it away or even kill it.

No matter what the situation, of course, the best strategy for a potential host is simply not to cross paths with a parasite at all. Consider leaf-rolling caterpillars. These are pretty ordinary insect larvae, with one exception: they fire their droppings like howitzers. As a bit of grass starts to emerge from the caterpillar, it pushes a hinged plate against a ring of blood vessels surrounding the anus. The blood pressure builds up behind the plate, which the caterpillar then releases. The blood slams against the droppings so suddenly that it blasts them three feet a second, in a soaring arc that carries the frass as far as two feet away. What could have driven the evolution of this anal cannon? Parasitic wasps in search of a caterpillar host may be drawn to their prey by the odor of its droppings. High-pressure fecal firing gives the caterpillar a better chance of escaping detection.

However, even if you can blast your frass into the neighboring meadow, even if your mother was an excellent judge of bowers, even if you carry a parasite guard with you through the forest, you may still end up with a parasite inside you. Your immune system, an exquisitely precise system of defense brought about by the evolutionary pressure of parasites, will do its level best to stave off the invasion. But host organisms have evolved other kinds of warfare as well: they can enlist other species to help them; they can medicate themselves; they can even program their unborn offspring for life in a parasite-ridden world.

A plant attacked by caterpillars (which, looked at from this perspective, are parasites themselves) defends itself with its own version of an immune system, creating poisonous chemicals that the caterpillars ingest as they chew. It may also send out cries for help—calling to wasps that parasitize the caterpillars (an apparent case of “the enemy of my enemy is my friend”). When a caterpillar bites into a leaf, the plant responds by making a particular kind of molecule that wafts into the air. The odor is like perfume for parasitic wasps. As they fly around searching for a host, they are lured by the plant’s smell. Following it to the wounded leaf, they find the caterpillar there and inject it with eggs.

To defend themselves against internal parasites, some animals just stop eating—a sheep suffering from a bad case of intestinal worms, for instance, may graze only a third as much as it would otherwise. Such a change clearly doesn’t benefit the parasite, which needs the sheep to eat a lot so that it, too, can eat a lot and make a lot of eggs. Circumstantial evidence suggests that eating less may also somehow boost the sheep’s immune system, making it better able to fight the parasite.

Sometimes parasitized animals change their diet. Some woolly bear caterpillars, for example, normally eat lupines. If attacked by parasitic flies that lay eggs in their bodies, they switch to a diet of poisonous hemlocks. The fly larvae still emerge from the caterpillar, but some chemical in the hemlocks helps the woolly bears stay alive, grow to adulthood, and ultimately metamorphose into Isabella moths. The caterpillars, in other words, have evolved a simple kind of medicine. Chimpanzees also, when infected with flukes and other kinds of worms, seek out plants with medicinal value, swallowing certain kinds of leaves whole and stripping
A snail sheds thousands of tiny larvae of the trematode *Schistosoma mansoni* into the water. The larvae will go on to seek a human host. Burrowing into the skin and settling in veins, they cause the debilitating disease schistosomiasis.

The more parasitic mites a male fruit fly is infested with, the more determined he may be in his efforts to court females.

have left. Once infected with flukes, for instance, some species of snails have only a month or so before the parasites castrate them and turn them into food-gathering slaves. The snails take full advantage of the time, producing a final burst of eggs. If a fluke gets into a sexually immature snail, the mollusk will respond by speeding up the development of its gonads.

Male fruit flies of the Sonoran Desert respond to parasites by escalating their pursuit of females. These tiny insects feed on the rotting flesh of saguaro cacti, where they sometimes encounter mites. Leaping onto the flies, the mites jab them with their needlelike mouths and start to suck up their internal fluids. The consequences can be grave: a heavy infestation of mites can kill a fly in a few days. Biologists have found a big difference between the sexual activities of healthy and mite-infested male fruit flies. Males with parasites spend more time courting females, and the more parasites a male has, the more time he spends at it, in some cases tripling his efforts.

At first it might seem as if the mites speed up their own transmission by putting infected flies in contact with healthy ones. But in fact, these parasites seem to get on flies only when they are feeding on cacti; they never hop from fly to fly during courtship or mating. It appears that the parasites, with no benefit to themselves, have driven the flies to mate more when death is imminent. Why don't flies make the fast-and-furious lovemaking style a permanent one? Sex puts a lot of demands on fruit flies and makes them an easy target for predators. And the risk may not always be worth it; some cacti are covered with mites, but others are mite-free.

Many lizards are also tormented by mites. They can die from an infestation, and survivors are likely to be stunted. When these animals are attacked, they change not their mating behavior but their unborn young. Normally a baby lizard will have a growth spurt in its first year and then grow more
slowly for the rest of its life. A lizard born to mite-ridden parents will instead grow fast for its first two years and perhaps even longer. Lizard mothers apparently can program the future growth of their offspring in response to the presence of parasites. In mite-free times, a young lizard can afford to grow slowly, but when mites are around, it pays to grow quickly so that the little reptile can have a chance of reaching adulthood and producing young of its own.

And if doomed to die, some parasite-infested hosts will do their best, not to protect their own offspring, but to spare their sisters and brothers. Worker bumblebees spend their days flying from flower to flower, collecting nectar and bringing it back to the hive. At night they stay in the hive, kept warm by the heat of thousands of flapping wing muscles. On its travels for nectar, a bumblebee may be attacked by a parasitic fly, which lays an egg in its body. In the warmth of the hive, the parasitic larva’s metabolism runs so quickly that maturation occurs in only ten days. The fly then emerges from its host, ready to infect other members of the hive. Many parasitic flies never get that chance, however, because the infected bee does something strange: it starts spending the night outside the hive. By staying out in the cold, the worker slows down the parasite’s metabolism, often so much that the bee dies a natural death before the fly larva can mature.

As effective as some of these counterattacks may seem, parasites—not surprisingly—can evolve counter-counterattacks. Cow manure fertilizes the grass around it, making it grow lush and tall, but the cows generally stay away from this vegetation. They keep their distance because the manure often carries the eggs of parasites such as lungworms. After hatching, these parasites crawl up nearby blades of grass, where, if all goes well for the parasites, they will be eaten by a grazing cow. Some lungworms pursue a different strategy, however. They bide their time inside the pat of manure until morning light strikes them. Light is their signal to climb up through the manure until they reach the surface, where they begin to hunt around for a species of fungus that also parasites cows—a species that responds to light by growing little spring-loaded packages of spores. When one of the lungworms touches a spore package, it latches on and climbs up to the top. Soon the fungus catapults itself six feet into the air, soaring away from the manure like a puddle jumper, with the lungworm going along for the ride. If the lungworm lands in a patch of grass (and not on another cowpat), its odds of being eaten by a cow are much improved.

Study these arms races long enough, and you start to imagine that hosts and parasites could carry each other into the clouds, each driving the evolution of the other so hard that they become demigods hurling lightning bolts at each other. But the race has its limits, as A. R. Kraaijveld, of England’s Imperial College of Science, Technology and Medicine, demonstrated in some elegant experi-

Like many tapeworms, Anthocephalum dusznyskii is highly specialized, lodging in the gut of only two species of round rays. The scolex, or head, left, of this species adheres to the host’s intestine with rounded attachment structures, each one edged with a row of suckers. Bottom: A parasitic fluke (center, brown) has attached itself to the inside wall of a Portuguese man-of-war’s digestive mechanism. The fluke exploits at least two different types of hosts during its life cycle.
ments with two species of fruit flies (*Drosophila suboscana* and *D. melanogaster*) and the wasp that parasitizes them. Kraaijveld raised the wasps on *D. suboscana* flies and then put a few dozen of the parasites into a chamber with *D. melanogaster*. The wasps parasitized these new hosts, killing nineteen of every twenty flies. But the one in twenty that survived managed to marshal its immune system and kill the wasp larvae. Kraaijveld took these resistant fruit flies and used them to breed the next generation of *D. melanogaster*. Meanwhile, he continued to raise his wasps on the other species, *D. suboscana*. When the next generation of *D. melanogaster* had matured, he transferred some of the wasps into their chamber. The wasps promptly attacked the flies, and once again, Kraaijveld raised the survivors to produce a new generation.

By raising the wasps and flies this way, Kraaijveld was blindfolding one of the boxers in his host-parasite match. With each generation, the *D. melanogaster* flies were able to adapt more and more to the wasps. But the wasps, being raised on another species of fly, had no chance to match the evolution of their *D. melanogaster* hosts. The mismatch let the flies steadily improve in their fight against the wasps. In only five generations, the proportion of flies that could kill the wasp larve rose from one in twenty to twelve in twenty.

Interestingly, in later generations, the resistance remained at 60 percent. Why didn’t it rise to 100 percent, creating a race of perfectly immune flies?

Parasites are unavoidable and often extremely unpleasant. They also turn out to be one of the most important forces of evolution.

Well, fighting wasps is costly. Kraaijveld set wasp-resistant flies in competition for food against regular flies and found that they fared badly. They grew more slowly, died young more often, and, if they survived to adulthood, were smaller. Evolution doesn’t have an infinite arsenal to offer host organisms, and energy spent on one thing is not available for something else. At some point, hosts have to accept one of nature’s absolute truths: parasites are a fact of life.
took off my boots and crouched down at the doorway to enter the smoke-filled hut. The village headman, his outline barely visible, was comfortably settled beside a small fire burning in the center of the room. After motioning me to sit beside him on a pile of deerskins, he placed a teapot on the burning coals. A woman came out of the shadows and carefully handed over a much-dirtied paper packet. Turning to me as if to make sure I watched what he was doing, the headman opened the packet and poured most of the contents into the teapot, then emptied the remainder into my cup. I'd been through this ritual many times during the previous week, but it still fascinated me. He was sharing one of his most precious possessions—and giving me a little extra—to acknowledge the value he placed on my visit. A common condiment throughout the modern world but desperately scarce and highly prized in this remote mountain region, it was the central player in a bartering system that provided the local people's only regular contact with the outside world. The headman was giving me salt.

It was March 1997, and I was accompanying a team of eight scientists and forestry officials on a wildlife survey through the mountainous northern region of Myanmar (formerly Burma). Called "the most forbidding terrain on Earth" by Frank Porters make their way along the bed of the Nam Tamai River, left. In the background are the snow-capped peaks of the southeastern Himalaya. Above: Salt for sale in a Yangon market.

In Myanmar's far north, the body parts of endangered wildlife are bartered for a scarce and highly prized commodity.

By Alan Rabinowitz ~ Photographs by Steve Winter
enclave of Burmese Tibetans (the Rawang are the region’s other principal ethnic group) and the last village one encounters before reaching Myanmar’s tallest peak, Hkakabo Razi.

Long before arriving in Tahawndam, we had passed through a dense subtropical forest—the northernmost range of most Indo-Malayan animals—and had entered the temperate and alpine habitats of the lesser known Sino-Himalayan wildlife. This was the most rugged country I had ever been in. Between valleys and mountain passes, we followed trails that climbed precipitously from 1,500 to more than 10,000 feet. Weather and punishing terrain restricted our movements much beyond Tahawndam, but we had already found three large mammal species not previously known to live in Myanmar: blue sheep, black muntjac (barking deer), and stone marten. Our most exciting find, as we moved north through the transition zone between subtropical and temperate forest habitat, was a deer not quite two feet tall and weighing less than twenty-five pounds. I suspected I was looking at an animal few people, if any, had ever seen outside the region. Further examination of more of these deer—called leaf deer by local hunters—would later confirm my suspicion: this was a species new to science (it is also one of the smallest, and possibly

Kingdon-Ward, a British botanist who collected plants there in the 1930s, northern Myanmar remains one of the most biologically unknown and unspoiled regions in Indochina. The area’s plants originated during the Miocene, presumably became isolated during the turbulent glacial and interglacial period of the Pleistocene, and have remained isolated to this day.

I had first visited the region in 1996 and had gotten as far as the town of Putao, gateway to the rugged terrain where the eastern Himalaya meet up with the Gaoligong Shan and Hengduan Shan ranges that define the border between Myanmar and China. At the town’s market, I had discovered the magnificent horns of a blue sheep while examining wildlife body parts being offered for sale. Blue sheep were known from neighboring Tibet, but this specimen had reportedly been killed north of Putao, in what are locally referred to as the “icy mountains.”

As the Wildlife Conservation Society’s (WCS) Director of Science for Asia, I had arranged with Myanmar’s Department of Forestry to make biological surveys here and to recommend specific areas for protection. Now, in 1997, having walked 250 miles from Putao in the course of nearly a month, we were close to the border with Tibet. The hut where I was drinking tea was in Tahawndam, an
most primitive, members of the Cervidae family).

These important discoveries made me even more concerned about the issue of wildlife protection. Although the people of the region were primarily simple agriculturists, growing staple crops of wheat, corn, and millet, they also hunted. In many village homes, there were skulls mounted on trophy boards—a practice based on the animistic belief that it will bring success on future hunts. Skins, horns, and other animal parts were piled in the corners, waiting to be exchanged for basic necessities when traders came from Myanmar's towns and villages to the south, from neighboring Tibet, or from China's Yunnan Province. At the heart of this trade was salt. The use of salt can be documented as far back as Neolithic times and has long played a pivotal role in human affairs. Settlements have flourished or disappeared because of salt. The historical record indicates that this substance was one of the single most valuable items of commerce in developing civilizations and was also often the currency used both for taxing and rewarding the populace. In China a system of collecting salt as tribute was in place by about 2000 B.C. The word “salary” comes from the Latin salarium, referring to the salt payments given to Roman soldiers.

What makes salt really mysterious, however, is our inability to fully understand our strong desire for this “primordial narcotic” (as one writer described it). Medical research indicates that while we need salt to help regulate the body's internal fluid levels, most of that salt can be obtained from the food we eat (except in purely vegetarian diets). Yet in most societies around the world, people consume at least two to three times more salt than they need. “There is one commodity which all men, of whatever colour, crave,” wrote Kingdon-Ward after meeting Chinese traders in northern Burma more
In northern Myanmar, salt is available mostly in rough, granular form, right. Below: A hunter sells the bill and double-pronged casque of a great hornbill, shot near the town of Putao.

than six decades ago. "It influences their lives. No hardship is too great to be borne, if only the need be thereby satisfied. This commodity is not bread, nor opium either, but common salt; common, that is, almost anywhere but here."

Salt is highly valued in this remote region because there are no natural sources of it. As I finished my tea in the smoky hut and reached for the pot to pour myself another cup, I realized that the desire for this elemental substance, to which I had never before given a moment's thought, was threatening the future survival of some of the world's most unusual and endangered mammals.

Given WCS's mandate from the Myanmarese government to identify areas that could be set aside to protect the country's fauna, I was facing the question of how to curtail the killing of wildlife, a prac-

tice that was also the basis of the barter system between local people and outside traders. The villagers knew their hunting was not sustainable, for they complained about having been able to kill far fewer animals in the past five years and having to devote much more time to the hunt. Yet they readily exchanged these dwindling resources for clothing, tea, and—above all—salt.

I discovered that every village has its hunters, who use mostly the traditional crossbow and poison arrows as weapons. Some also use metal jaw traps and snares brought over from China. When they are not needed for the tending of crops, hunters go off for days or even weeks to stock up on game and rare plants. The items most sought after by traders are certain medicinal herbs that grow at the highest altitudes, the musk glands of male musk deer, and the gallbladders of Himalayan black bears. But every animal part is traded, from serow tongues (consumed to treat headaches) and goral legs (ground into a liniment for joint ailments) to the skins of white-browed gibbons and capped leaf monkeys (made into shoulder bags).

These items are exchanged for white salt, used primarily in tea but also for cooking. "Food doesn't taste good without it," the locals told me again and again. The tribes also barter their kills for a type of red salt from China that they feed to livestock, most of which are gayals (the domestic form of the gaur). For as long as anyone can remember, this has been the system.

In 1996 the government of Myanmar had designated this mountainous northern region a protected area. My purpose now was to convince the government to change the area's status to that of a national park in order to further protect wildlife. Upon returning to the capital, Yangon, I presented officials with a plan—suggested in part by the vil-
lagers themselves. They had agreed to limit their hunting and to monitor the population trends of key game species in exchange for regular shipments of good quality salt and other necessities to be supplied by the park staff. Each headman would be responsible for the actions of individuals in his village. With the incentive of being provided with basic necessities, people would presumably no longer kill animals other than those intended for their own consumption, and the wildlife trade would therefore be curtailed.

The hunger for salt has, in large part, fostered the systematic killing of wildlife—a bad practice both for animal populations and, ultimately, for the villagers who depend on the hunt to acquire a prized commodity. In coming years, we hope that providing salt directly to local people will prove a good practice for both wildlife and people and will help preserve the region’s biological and ethnic diversity, improve the quality of life at a local level, and foster discoveries that enable us to add more pieces to the puzzle of our biological past.

Postscript: In November 1998, Myanmar’s Department of Forestry designated a 1,500-square-mile area Hkakabo Razi National Park—the largest protected area in the country. Early in 2000, Rabinowitz, along with the national park’s new chief, U Thein Aung, returned to the region to talk with local villagers about the park and to bring basic necessities—salt included—in exchange for protecting wildlife.
By Peter M. Kappeler and Alexandra Dill
Illustrations by Deborah Ross

The Lemurs of Kirindy

Female red-fronted lemur (*Eulemur fulvus rufus*)

Near the west-central coast of Madagascar, and a mere hour’s drive from the town of Morondava, is the 25,000-acre Kirindy Forest. Dominated by majestic baobab trees, it is home to the world’s smallest known primate as well as to dozens of amphibian and reptile species and more than sixty species of birds. Every rainy season, Kirindy transforms itself from a tangle of dry branches on which not a single green leaf can be found to an impenetrable emerald wall. Its changeable beauty and the diversity of its inhabitants are enough to captivate any visitor. But the forest’s pull on us lies not so much in its considerable visual charm as in the actions of its eight resident species of lemurs.

Some of Kirindy’s lemurs are strictly nocturnal, others are active only in the daytime, and some are up and about day and night. Different species also exhibit different patterns of activity over the course of a year. In some, both sexes hibernate, while in others, only the female takes time out. For almost a decade, we and other members of the German Primate Center have been working to find out more about this unusual web of daily and yearly activity cycles. Kirindy is indeed a place of pronounced seasonal changes. A short, hot rainy season between December and February is followed by nine months with virtually no rain. At the height of the dry season, nightly temperatures regularly drop below 50°F and sometimes stay just above freezing; during the day, temperatures may rise above 86°F. During the rainy season, temperatures fluctuate between 68° and 104° in the course of twenty-four hours. Most of the forest’s trees respond to the extended dry season by dropping all their leaves to conserve water. Some, such as the three species of baobabs, also store water in their huge trunks. Kirindy’s trees tend to grow extremely slowly and (unlike many tropical trees) have pronounced seasonal cycles of flowering, leafing, and fruiting.

The response of most amphibians and reptiles to the area’s dramatic seasonality is to do much of their hard living—finding a mate, producing eggs, growing, and preparing for the next dry season—during the
Narrow-striped mongoose, or boky-boky (Mungotictis decemlineata)

rainy weeks and to be much less active the rest of the year. For example, five-foot-long Leioheterodon snakes pass the dry months several feet below ground, curled up in a nest of ants, and emerge only after the rains begin. Similarly, many of Kirindy’s birds spend the harsh months in other parts of Madagascar or in Africa or Europe. None of these patterns are surprising. Many birds migrate, and many of the world’s frogs, lizards, and snakes lie low during cooler periods of the year. Some of the lemurs and other mammals of Kirindy, however, are quite another story, a striking exception to the rule that tropical mammals generally do not exhibit strong seasonal variations in activity. Most puzzling among them are several species that hibernate even when the weather is warm.

Verreaux’s sifakas (Propithecus verreauxi verreauxi) are the most prominent inhabitants of Kirindy. These long-legged, seven-pound lemurs, white with dark patches, leap among tree trunks high in the canopy, propelled by their powerful hind legs but continually maintaining an upright posture. Like the vast majority of primates elsewhere in the world, they live in small, cohesive groups of two to eight members and are active exclusively during the day. Sifakas have teeth and guts that are specialized for feeding on leaves, but they adapt their menu opportunistically as different flowers and fruits come into season. These lemurs cope with the long dry season primarily by expending less energy, sometimes halving the distance they travel each day and the time they devote to foraging and other activities. Sifakas’ body temperature falls a few degrees at night, another

The red-tailed sportive lemur saves energy during the dry season by reducing its already low activity level and metabolism.
Red-tailed sportive lemur
(Lepilemur ruficaudatus)
calorie-saving adaptation; when morning comes, they take extended sunbaths high in the trees to bring their temperature back up to normal. Remarkably, the females give birth at this time of year; nursing sifaka mothers produce very dilute milk and thus lose significant amounts of water during lactation. Nevertheless, these animals never descend to the ground to drink, seemingly able to balance their water budget by choosing plants high in liquid content and by occasionally licking dew from leaves and tree trunks in the early morning hours.

Early morning is a time when members of the other group-living lemur species in Kirindy may take a breather from their efforts for a few hours. Red-fronted lemurs (*Eulemur fulvus rufus*), like other members of the genus *Eulemur* and the closely related bamboo, or gentle, lemurs (genus *Hapalemur*), have an unusual circadian rhythm, consisting of several bursts of activity irregularly distributed over the twenty-four-hour cycle. This type of activity pattern, which is termed cathemeral, has been reported outside Madagascar in only one other primate: Azara's night monkey (*Aotus azara*) in South America. (More generally, among the tropical arboreal mammals of Africa, Asia, and South America, only sloths have such an
Verreaux’s sifakas, which never descend to the ground to drink, get part of the water they need by licking dew from leaves and tree trunks.

on-again, off-again lifestyle.) Perhaps the cathecmal cycle of these lemurs represents an evolutionary midpoint in the transition from a nocturnal to a diurnal pattern; night vision requires increased sensitivity to light and generally comes at the expense of color vision and acuity. The transition to cathecmal activity may have been triggered by ecological changes associated with the extinction of large raptors and giant, probably diurnal, lemurs after the onset of human settlement in Madagascar about 2,000 years ago and the resultant hunting and deforestation.

Kirindy’s six other lemur species have strictly nocturnal habits but adapt to the changing seasons in a variety of ways. Coquerel’s dwarf lemur (Mirza coquereli) and the fork-marked dwarf lemur (Phaner furcifer) are active year-round. The leaf-eating red-tailed sportive lemur (Lepilemur ruficaudatus)—like the sifaka—saves energy during the dry season by reducing its already low activity level and metabolic rate (and presumably its body temperature as well, although we have yet to measure this precisely).

Fat-tailed dwarf lemurs (Cheiogaleus medius) take energy savings to an extreme. These five-ounce animals squeeze an entire reproductive cycle into the rainy season and, during this time of plenty, accumulate enough fat reserves to fuel up to eight months of hibernation. Feeding on high-energy fruits and insects, the lemurs convert most of their food into fat, which is primarily stored in the tail, nearly doubling their body mass. At the beginning of the dry season, small groups of males and females retire into hollow trees, their body temperature and metabolic rate drop, and the animals begin hibernation.
The gray mouse lemur (*Microcebus murinus*) can also hibernate for months, but in this species, only adult females do it. Like their fat-tailed cousins, female gray mouse lemurs go through their complete reproductive cycle between late December and early February, acquiring impressive amounts of fat and increasing body mass by more than 40 percent. As the nights begin to get cool, these two-ounce lemurs resort to another remarkable strategy to reduce energy expenditure: night-time torpor. When the temperature falls below a certain point, they enter a tree hole and reduce metabolism, thus lowering body temperature close to the level of the air around them. (Some of our colleagues have recorded body temperatures as low as 48° F in torpid animals.) Huddling together in well-insulated holes further enhances their energy savings. When the ambient temperature rises during the morning, body temperature follows passively up to about 82° F, at which point the metabolism kicks in again and heats the lemurs up to a normal level of about 100° F.

As the dry season progresses, adult females stop leaving the tree hole altogether, remaining inactive for the next four months or more. Males, however, continue venturing out to forage (mainly on gum and the few remaining insects) for at least a few hours almost every night. Why they forgo the substantial energy savings enjoyed by females and expose themselves to owls and other predators every night is something of a mystery to us. However, the mating season begins soon after the females emerge, and we think the males may

Red-fronted lemurs have an unusual circadian rhythm, consisting of several bursts of activity irregularly spread over twenty-four hours.
be taking advantage of these months to establish dominance hierarchies.

The diversity of lifestyles we see in Kirindy's lemurs demonstrates that there is no one way to fit into the forest. Further evidence of the considerable behavioral and physiological flexibility of these primates can be found in other parts of Madagascar as well. Recent observations of gray mouse lemurs at the northern end of the species' geographical range, for example, revealed that neither males nor females hibernate there. In addition, five new species of mouse lemurs inhabiting the west coast of Madagascar—including the smallest living primate, a pygmy mouse lemur discovered at Kirindy—have just been described (these new species will receive their scientific christening in the October issue of the *International Journal of Primatology*). These primates offer scientists an opportunity to study how a group of related mammals respond to a range of environmental conditions—in this case, along the entire length of the world's fourth largest island. The more we can learn about how these animals divvy up the available habitat with closely related species, as well as how they avoid interspecific mating, the more we may be able to understand how Madagascar evolved such a richness of lemurs. Our deepest hope is that habitat destruction on the island will not result in a squandering of this remarkable wealth.
(Continued from page 25)
branching from a single ancestor over a long period of time, then the hierarchical order of the binomial system will capture the topology of organic relationships just as well, because the logic of my system translates pictorially into a tree with a single trunk at the base, which subsequently divides into branches that never coalesce thereafter. I will therefore hedge and win in either case. For my chosen topology might represent either God’s permanent order, preconceived from the first, or the happenstance of historical change and development on an evolutionary tree growing from a single starting point under the constraint of unbroken continuity (although branches may die and fall from the tree as lineages become extinct) and continuous bifurcation without subsequent joining of lineages.”

I emphasize this property of irrevocable branching without subsequent amalgamation because the Linnaean logic of placing small boxes into larger boxes—which just happens to conform to the historical reality of Darwin’s system—establishes just such a map of organic relationships as its primary and inevitable consequence. One can’t, after all, either in Linnaean logic or in the real world, cram big boxes into smaller boxes. Therefore, for example, two species in the same genus can’t reside in different families, and two orders in the same class can’t be placed in different phyla. If lions and tigers rank as two species in the same genus (Panthera), they cannot then be allocated to different families of higher rank (lions to the Felidae and tigers to the Canidae, for example), for the two larger family boxes would then have to fit within the smaller box of the genus Panthera, and both the rules of Linnaean logic and the requirements of Darwinian evolutionary history would be fractured. I can be a monkey’s uncle or a horse’s ass only in a metaphorical

sense, for my species fits into the small box of the genus Homo, which must nest within the larger box of the family Hominidae, and one member of my species can’t opt out of our box to join the Cercopithecidae or the Equidae, thus splitting a coherent lower group into two higher groups. So just watch what you call me, you miserable skunk!

Did Linnaeus therefore just enjoy a little bit of luck in choosing the one logic for a creationist system that would also fit without fuss into a new universe of historical evolution by branching? At least he has demonstrated exemplary survival skills in passing the test of time as taxonomy’s father. But I hesitate to ascribe his remarkable success to pure dumb fortune—for a primary reason that calls upon the key contention of this essay: that taxonomies transcend simple description and always embody particular theories about the causes of order, thus melding preferences of mind with perceptions of nature.

I think that Linnaeus succeeded because, however unconsciously or preconsciously, he made some excellent decisions about both the mental and perceptual aspects of taxonomic systems. On the perceptual side, he must have seen better than any of his colleagues that under the logic of hierarchy and branching, organisms could be arranged into a consistent order that might win general assent without provoking constant bickering among practitioners. Other contemporaries had proposed very different logics of classification but had never found a way to push them through to an unambiguous and consistent system. In the most telling example, Linnaeus’s most famous contemporary and archrival, France’s celebrated naturalist Georges-Louis Leclerc, comte de Buffon (1707–88), had struggled through more than forty volumes of his Histoire naturelle—in my judgment, the greatest encyclopedia of natural science ever written—to develop, without conspicuous success, a nonhierarchical system that joined each species to some others by physiology, to a different group by anatomy, and to a still different set by ecology.

But I would, in addition, like to advance the unfamiliar argument that Linnaeus also succeeded because he

Linnaeus built his system upon a familiar form of logic—a style of reasoning, moreover, that may track the basic operation of our brains.

made a very clever, and probably conscious, choice from the mental side of taxonomic requirements as well. In deciding to erect a hierarchical order based on continuous branching with no subsequent joining of branches, Linnaeus constructed his system according to the most familiar organizing device of Western logic since Aristotle (and arguably of our innate and universal mental preferences as well): successive (and exceptionless) dichotomous branching as a system for making ever finer distinctions. In a logical tree of this form, often called a dichotomous key, one may move in either direction: down the tree, to place a particular basic object into ever larger groups by joining successive pairs, or up the tree, to separate a large category into its component parts by successive twofold division.

One may, for example, interpret the branching diagram presented earlier (see page 24) as a dichotomous key. We can reach dogs by starting with the largest category of all animals, making a twofold division into vertebrates and invertebrates, then splitting the vertebrates into mammals and nonmammals, the mammals into carnivores and noncarnivores, the carnivores into
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Man. If I preferred the hagiographical mode of writing essays, I would stop here with a closing word of praise for Linnaeus's perspicacity in harnessing both the observational and theoretical sides of his mental skill to construct a flexible and enduring taxonomic system that could survive intact under the greatest theoretical transformation in the history of biology.

But he who lives by the sword dies by the sword (as Jesus did not exactly say in a common misquotation that remains potent in truth and meaning despite its inaccuracy in citation). Linnaeus's consistency and wisdom in developing and defending the binomial system of hierarchical classification carried him through to intellectual victory. But like so many originators of grand and innovative systems, he reached too far (whether by overconfidence or overexcitement) and became too committed to his procedure as the one true way for classifying any collection of related objects. (I cannot help recalling my experience with a customs official on a small West Indian island, who recorded my land snails as turtles because his forms permitted only a distinction between warm-blooded and cold-blooded animals and the word “animal” in his personal understanding, designated only vertebrates. Thus, snails became turtles because both are cold-blooded and move with legendary torpor.)

Once Linnaeus had fully developed the binomial system and its supporting logic of a consistently nested hierarchy, he supposed that he had discovered the proper way to classify any group of natural objects, and he therefore began to give binomial species names to several classes of inappropriate phenomena, including rocks and even human diseases. Clearly, he had become enamored with his own device and had lost sight of the key principle that hierarchical embedding by dichotomous branching captures the causal order only within certain kinds of sys-
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- exactly.
tems, particularly those that develop historically by successive branching in unbroken genealogical continuity (with no later amalgamation of branches) from a common ancestor. The fact that Linnaeus tried to apply the binomial system to several groups of objects that, by their own rules of order or development, patently violate the required hierarchical logic indicates that perhaps he never did really grasp the limitations (and therefore the essence) of his system. So perhaps Linnaeus did prevail partly by the luck of organic conformity to his logic rather than by his correct and conscious reasoning about the causes of relationships among plants and animals.

For example, a page from the seventh (1748) edition of Systema Naturae (see page 74) designates binomial species of the genus Quartzum from the classification of rocks and minerals that Linnaeus presented as a third chapter, following his taxonomies for animals and plants. The first “species,” Quartzum aqueum (transparent quartz), includes ordinary glasslike quartz; the second, Quartzum album (white quartz), encompasses less valued, opaquely waterworn quartz pebbles; the third, Quartzum tinctum (colored quartz), gathers together the tinted varieties that mimic more valuable gemstones (Linnaeus calls them false topaz, ruby, and sapphire, for example); and the fourth, Quartzum opacum (opaque quartz), describes the even less useful and less transparent flintstones.

But the nature of quartz, and the basis of relationships among minerals in general, defies the required logic of causality for any system legitimately described in Linnaean binomial terms. The members of Quartzum aqueum, for example, do not hang together as a set of closest historical relatives, all physically derived in continuity from a common ancestor that generated no other offspring. Rather, the specimens of this false species look alike because simple rules of chemistry and physics dictate that transparent quartz will form whenever silicon and oxygen ions come together under certain conditions of temperature, pressure, and composition. The members of this “species” maintain no historical or genealogical coherence. One specimen might have originated half a billion years ago from a cooling magma in Africa, and another just fifty years ago in a bomb crater in Nevada. Minerals must be classified according to their own causes of order—a set of rules distinctly different from the evolutionary and genealogical principles that build the interrelationships among organisms.

Linnaeus clearly overreached in supposing that he had discovered the one true system for all natural objects. In the twelfth and final edition of Systema Naturae (1766), he included a section entitled Imperium Naturae, dedicated to extolling his hierarchical and binomial method as universally valid. God made all things, Linnaeus argues, and must have used a single and universal method, now discovered by his most obedient (and successful) servant. Linnaeus writes: “Omnes res creatae sunt divinae sapientiae et potentiae testes” (“All created things are the witnesses of divine knowledge and power”). Using a common classical metaphor (the thread of Ariadne that led Theseus out of the labyrinth after he had killed the Minotaur), Linnaeus praises himself as the code cracker of this universal order: “Knowledge of nature begins with our understanding of her methods by means of a systematic nomenclature that works like Ariadne’s thread, permitting us to follow nature’s meanders with accuracy and confidence.”

Ironically, however, Linnaeus had succeeded (in a truly ample, albeit not universal, domain of nature) precisely because he had constructed a logic that correctly followed the causes of order in the organic world but that could not (for the same reasons) be extended to cover inorganic objects not built and interrelated by ties of genealogical continuity and evolutionary transformation. The strength of any great system shines most brightly in the light of limits that give sharp and clear definition to the large, but not infinite, domain of its legitimate action. By understanding why Linnaean logic works for organisms and not for rocks, we gain our best insight into the importance of his achievement in devising a system that he applied too widely but that later allowed us to specify the varied nature of disparate causes for nature’s order among her many realms.

On the same theme of power in exceptions, and to make a somewhat ironic point in closing, Linnaeus’s hope that he had discovered a fully universal basis (God’s own rules of creation) for classifying all natural objects has recently suffered another fascinating blow. Science had already denied Linnaeus’s universality more than 200 years ago by validating his procedures only for historically generated genealogical systems (the evolution of organisms) and by rejecting his binomial schemes for rocks or diseases with other theoretical foundations of order. But now one of the most important biological discoveries of our age has also challenged the universal application of Linnaean taxonomy—but this time from the inside (that is, from the world of organisms).

We need not fret for fat, furry, multicellular creatures—the plants, fungi, and animals of our three great macroscopic kingdoms of life. For evolution, in this visible world of complex creatures, does follow the Linnaean topology effectively all the time. That is, the basic structural rule that validates the binomial system works quite satisfactorily at this level, for branches never join once they have separated, and each species therefore becomes a permanently independent lineage, making no further combinations with others after its origin. Evolution cannot make a nifty new species
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of mammal by mixing half a dolphin with half a bat to generate an all-purpose flier and swimmer.

Until a few years ago, we thought that this rule of permanent separation also applied in the simplest world, unicellular bacteria—the true dominators of Earth and rulers of life, in my opinion (see my 1996 book Full House). In other words, we assumed that the bacterial foundation of the tree of life grew in a fully Linnaean manner, just like the multicellular section. (Actually, and to emphasize the importance of the discovery described below, the bacterial domain occupies most of life’s tree, because the three multicellular kingdoms sprout as three terminal twigs on just one of the tree’s three great limbs, the other two being entirely bacterial.)

Apparently we were wrong. By a set of processes collectively called lateral gene transfer (LGT for short), individual genes and short sequences of genes can move from one bacterial species to another. For two reasons, these transfers may challenge Linnaean logic in a serious way. First, LGT does not seem to respect taxonomic separation. That is, genes from genealogically distant bacterial species seem just as likely to enter a host species as do genes from closely related species. Second, the process is apparently not rare enough to permit dismissal as a peculiar exception to the prevailing Linnaean rule of strict branching with no subsequent amalgamation. (If only a percent or two of bacterial genomes originated by import from distant species via LGT, we could view the phenomenon as a fascinating anomaly that does not degrade the primary signal of Linnaean reality. But at least for some species, LGT may be sufficiently common to shine as a primary signal of its own. In the familiar E. coli, for example, 755 of 4,288 genetic units—about 18 percent of the entire genome—have been introduced in at least 234 events of lateral genetic transfer during the last 100 million years.)

Professional evolutionary biologists have been puzzled and excited by these discoveries about LGT. But the word has hardly filtered through to the interested public—an odd situation, given the status of LGT as a challenge to one of our most basic assumptions about the nature and fundamental topology of evolution itself, not to mention the foundation of Linnaean logic as well! Perhaps most of us just don’t care much about invisible bacteria, whereas we would sit up and take notice if we heard that LGT played a major role in the evolution of animals. Or perhaps the issue strikes most people as too abstract to command the same level of attention that we heap and hype upon
Charlie Merrels Lays Up Treasure for the Museum's Future and for His Own Retirement

For most of his working life, Charlie Merrels was an importer of handcrafted products from developing countries. Seeking out traditional products that had sales potential, he worked with local crafts people and local governments to establish cottage industries that enabled their products to be marketed in the USA and Canada.

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such events of minimal theoretical interest as the discovery of a new carnivorous dinosaur larger than *Tyrannosaurus*. But I would not so disrespect the concerns of public understanding. Properly explained, the theoretical challenge of LGT to some truly fundamental views about the nature of evolution and classification should be fascinating to all people interested in science and natural history.

To put the matter baldly, if LGT plays a large enough role in bacterial evolution to overcome the Linnaean signal of conventional branching without subsequent joining, then binomial logic really doesn’t work. An honest diagnosis could not then recommend that we make some minor repairs or apply some small plaster patches, for the Linnaean system would be truly broken by the collapse of its central theoretical prerequisite. The hierarchical basis of Linnaean logic demands that life’s history be built as a tree, without amalgamation of branches once a lineage establishes its independence. But if LGT dominates the composition of bacterial genomes, then trees cannot express the topology of evolutionary relationships, because the pathways of life would then form a meshwork—as bacteria evolve by importing genes from any location on the generalogical net, no matter how evolutionarily distant.

But don’t trust this expert on land snails (in the realm of fat furry things) and diligent essayist on subjects beyond his genuine expertise. Just consider these measured words from a technical article by my close colleague, the leading researcher on the subject, W. Ford Doolittle, of Dalhousie University in Halifax. In the June 25, 1999, issue of *Science* (a special report on evolution from America’s leading journal for professional scientists), Doolittle wrote, in an article entitled “Phylogenetic Classification and the Universal Tree”:

If “lateral gene transfer” can’t be dismissed as trivial in extent or limited to special categories of genes, then no hierarchical universal classification can be taken as natural. Molecular phylogeneticists will have failed to find the “true tree,” not because their methods are inadequate or because they have chosen the wrong genes, but because the history of life cannot properly be represented as a tree.

Do not lament for the spirit of Linnaeus. Yes, his dreams about the discovery of a universal system suffered two sequential blows: first, soon after his death, when scientists recognized that his logic worked only for organisms and not for rocks and the rest of the natural world; and second, as discovered only in the last decade, when Linnaean taxonomy encountered a strong biological challenge from the frequency of lateral gene transfer—the ultimate tree buster—in the substantial domain of bacteria, albeit not in our own world of multicellular life.

As a truly great scientist, Linnaeus understood the central principle that honorable error (through overextension of exciting ideas) comes with the territory, and that theories gain both strength and better definition from principled limitations upon their realm of legitimate operation. Moreover, as the modern founder of the truly noble science of taxonomy, Linnaeus also understood that all classifications must embody passionate human choices about the causes of order—in short, theories that must be subject to continuous revision and correction—and cannot record the accretion of pure and unchanging descriptions of objective nature on the philatelic model.

Thus, taxonomies must express both concepts and percepts—and must therefore teach us as much about ourselves and our mental modes as about the structure of external nature. Surely Linnaeus, of all people, comprehended this fundamental and ineluctable interrelationship of mind and nature, for when he composed, at the very beginning of *Systema Naturae*, his formal description of his newly crowned species, *Homo sapiens*, he linked us (in various editions)—in only one case correctly, as we now know—with three other mammals: monkeys, sloths, and bats. For each of these three, Linnaeus penned a conventional and objective description in terms of hairiness, body size, and the number of fingers and toes. But for *Homo sapiens*, he chose the path of terseness and wrote just the three Latin words of another familiar motto. Not *Natura non facit salutum* this time, but the foremost intellectual challenge of classical wisdom: *Nosce te ipsum*—Know thyself.*

Stephen Jay Gould teaches biology, geology, and the history of science at Harvard University. He is also Frederick P. Rose Honorary Curator in Invertebrates at the American Museum of Natural History.

*I would like to dedicate this essay to Ernst Mayr, the greatest taxonomist of the twentieth (and twenty-first) century, who remains as intellectually active as ever at age ninety-six, and who taught me, through his writing and the human contact of personal friendship, the central principle of our science (and of this essay): that taxonomies are active theories about the causes of natural order, not externally provided stamp albums for housing nature’s obvious facts.*
A Conversation With

John Maynard Smith

By Jonathan Weiner

A classical geneticist and leading theorist in evolutionary biology, John Maynard Smith started out as an engineer and worked as a “stress man” during World War II, calculating the stresses in airplane wings. Since then, he has applied his knowledge of mathematics to some of the greatest problems in evolution—exploring the stress points, the places where the theory threatens to pop its rivets.

Maynard Smith is best known for using game theory to explain the jousting matches that one sees among the males of many species, from sticklebacks to sea lions, from stag beetles to stags. “You’d simply expect them to sort of hit the other chap in the groin as quickly as possible,” he says, “and yet there’s rather little escalated fighting and a great deal of display in settling contests.” It’s almost as if the combatants are cooperating—a paradox the biologist explains by invoking the mathematics of nonzero-sum contests and win-win situations.

At the University of Sussex in England, where he works, Maynard Smith is closely involved with a group of colleagues he calls “The Institute for the Study of Tiny Minds”: neurobiologists working on the behavior of ants, bees, worms, and snails. He also talks daily with colleagues across disciplines who, like him, are trying to apply the theory of natural selection to the design of robots and computers.

JW: How did you get interested in biology? Does science run in your family?

JMS: My father was a poor boy who made good, who became a surgeon. But I can’t remember anything of him; I was only eight when he died, and my mother and her family, with whom I grew up, were really not intellectuals. After my father died, we went to live in the country, in western Britain, and I became obsessed with birds. My Auntie Mary gave me a guide, A Birdbook for the Pocket, which had a picture of each of the British species in it. And oh, the excitement of going through the book: “That’s a robin, that’s a green finch, that’s a blue tit!” But the interesting thing is that I did know them all. The experience has persuaded me ever since that, at least in birds, species are real things. Because any kid would have got the species right. It’s not something that we impose upon nature, it is something that is there to be recognized.

JW: I hear you read a lot of science fiction.

JMS: Yes. Possibly most influential in making me interested in genetics and in evolution was a strange book by a man called Olaf Stapledon, Last and First Men. It’s a history of the next—oh, I don’t know—100 million years of human history. It’s not terribly well written, but the book’s thesis is that there will be a succession of human civilizations that collapse. And it isn’t until human beings deliberately change their own constitution to make themselves less aggressive and more friendly that a stable civilization can be made. Although I no longer believe that the only path to human betterment is to change our genes, I was really persuaded by the argument at the time.
Many years later, I read a collection of short stories by Arthur C. Clarke. In the preface he describes how, as a boy, he read Stapledon’s *Last and First Men* and how this led him into science-fiction writing. And he had taken the book out of the same local public library. Whatever librarian put that book on the counter has got a lot to answer for. Made my hair stand on end when I read that!

*Possible Worlds*, by the biologist J.B.S. Haldane, also impressed me. I was at Eton, where I was not very happy. The school had virtues—it taught me mathematics very well. But it was really anti-intellectual, it was snobbish, it was arrogant; it just wasn’t a pleasant atmosphere. There was one person whom my schoolmasters would speak of with real hatred, and that was J.B.S. Haldane. He was also a socialist, an atheist, a divorcé, and a Marxist. I remember thinking, “Anybody they hate so much can’t be all bad. I must go and find out about him.”

**JW:** By then you knew that you loved biology. What made you shoot off in another direction?

**JMS:** My family supposed that I was going to join my grandfather’s stockbroking business. And I realized at the age of about sixteen, I think, that whatever else I was going to spend my life doing, it wasn’t that. So I announced at Sunday lunch one day, “Look, I’ve decided that I’m not going to become a stockbroker.” And you could have heard a pin drop. My grandfather turned to me and said, “All right, boy, what are you going to do then?” So I said the first thing that came to my head. Literally, on the spot, I said, “I’m going to be an engineer.” And I went to Cambridge to read engineering.

During the war, I worked for a little company called Myles Aircraft. But when the war ended, I went back to college and took a second degree, in biology. I chose University College London because I knew that Haldane was a professor there and I thought it would be interesting to learn from him. And “interesting,” I think, is probably the right word.

**JW:** Not an easy man?

**JMS:** He was fascinated by almost any intellectual problem you would like to bring to him. He was very encouraging to young people. He was, on the other hand, somewhat frightening to be around. He weighed about seventeen stone [240 pounds], and most of it was muscle. He had an extremely short fuse, and he didn’t suffer fools very well. I lived always afraid that he would realize I was really rather stupid. And by his standards I think I was. He never built up a big group around him because of these rather abrasive characteristics. He taught me everything I know. I wept when he died.

**JW:** Your latest book is about recurring patterns in the history of life. How did you come to write such a panoramic book?

**JMS:** Well, it was very much of a joint enterprise with Eörs Szathmáry. We met in 1985 or thereabouts and realized that our minds work together in a very

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**EXCERPT**

**The Language of Life**

The analogy between the genetic code and human language is remarkable. Spoken utterances are composed of a sequence of a rather small number of unit sounds, or phonemes (represented, at least roughly, by the letters of the alphabet). The sequence of these phonemes first specifies different words, and then, through syntax, the meanings of sentences. By this system, the sequence of a small number of kinds of unit can convey an indefinitely large number of meanings. The genetic message is composed of a linear sequence of only four kinds of unit. ... In both systems a linear sequence of a small number of kinds of unit can specify an indefinitely large number of outcomes. ...

We have treated the origin of language as the last of the major transitions. This shows that we are biologists, not historians. Language was indeed the last transition that required biological evolution, in the sense of a change in the genetic message. But there have been two major changes in the way in which information is transmitted since the origin of language. The first was the invention of writing. Without writing, or some equivalent way of storing information, large-scale civilization was impossible, if only because one cannot tax people without some form of permanent record. The latest transition, through which we are living today, is the use of electronic means for storing and transmitting information. We think that the effects of this will be as profound as were those after the origin of the genetic code, or of language, but we are not rash enough to predict what they will be. Will our descendants live most of their lives in a virtual reality? Will some form of symbiosis between genetic and electronic storage evolve? Will electronic devices acquire means of self-replication, and evolve to replace the primitive life-forms that gave them birth? We do not know.

nice way. I mean, he knows all sorts of things I don't know—he really knows molecular biology and chemistry. Eventually we realized that a mathematical model I had made years before, of the evolution of social groups, was extremely similar to one he had developed to try to understand the very early evolution of life. We were really working on the same problem; it was just that one was about animals and the other one was about molecules. You could see enormous parallels between events that happened very early on in the origin of chromosomes and events that happened much later (after 2,000 million years of life's sloshing around doing nothing) in the evolution of eukaryotic cells.

**JW:** You think such different events are fundamentally alike?

**JMS:** These transitions are all concerned with the storage and passage of information. It's fascinating, for instance, to try to model the evolution of the genes together with the evolution of human language—not identical events but at bottom very similar. But by inventing language, we've put ourselves in an unprecedented position. Absolutely. Human beings are enormously influenced by what, for want of a better word, I call myth or ritual. The ability is adaptive, because any individual who lived in a society and could not learn and pick up the cultural beliefs and mores of that society very quickly would be ostracized.

**JW:** One of life's "major transitions," you point out, was when mitochondria—probable descendants of parasites—swam into bigger cells and then got trapped inside and put to work. What about computers and us? Is this the next transition?

**JMS:** We like to think that computers are our slaves. It does seem to be possible that the relationship might be inverted.

Jonathan Weiner's most recent book, Time, Love, Memory: A Great Biologist and His Quest for the Origins of Behavior (Knopf, 1999), is a biography of the molecular biologist Seymour Benzer. It won the National Book Critics Circle Award in 1999.

*By Robert Anderson*

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### Charting the Rocks Below

To anyone unfamiliar with them, geological maps can look like the work of a child who went crazy with Magic Markers, using every possible hue in seemingly random patterns. This is particularly true of "A Tapestry of Time and Terrain," an online map created by the U.S. Geological Survey (USGS) at tapestry.usgs.gov. It combines vivid colors assigned to rocks of different time periods with topographic relief shading to illustrate some of the major geological features of the continental United States.

By clicking on "Rocks of Ages" on the main page, you can check the color-coded geological time scale to see how old the rocks are in your area. You can also select a slice of time—say, the Cretaceous—and a map will display the distribution of rocks from that period only. Click on "Description of Features" and you can zoom in on one of forty-eight points on the map to get a closer look and a brief description of the local geology.

Number twenty-six, for example, shows the Los Angeles area and describes how the relative westward movement of Earth's crust north of the Garlock Fault interferes with the movement of tectonic plates along the San Andreas Fault—a wrench in the works that threw up the mountains upon which my house rides. The map gives a nice tour of the nation's geology, but it left me wanting to zoom in much closer and to examine more than the forty-eight points offered.

If this Web site piques your curiosity and you want to learn more about the rocks that underlie your locality, the USGS also offers the National Geologic Map Database—a searchable catalog of both paper and digital maps (ngmdb.usgs.gov/). You can select from different kinds of maps and a host of other resources. Andrew Alden, About.com's geology guide, has also gathered geological maps of most states at geology.about.com/education/geology/msub24.htm.

Robert Anderson is a freelance science writer based in Los Angeles.
BOOKSHELF

Extinct Humans, by Ian Tattersall and Jeffrey H. Schwartz (Nevaumont/Westview Press, 2000; $50)
In a new look at the fossil record of human evolution (augmented by numerous photographs), two anthropologists show convincing evidence for the existence of fifteen kinds of humans and near-humans that once walked the earth—many of them, surprisingly, at the same time and in the same places.

Voodoo Science: The Road From Foolishness to Fraud, by Robert L. Park (Oxford University Press, 2000; $25)
Physicist Park debunks some foolish and fraudulent scientific claims, such as magnetic deficiency syndrome, cold fusion, and free energy. (Also check out Park’s weekly electronic newsletter at www.aps.org/WN/.)

LEAP, by Terry Tempest Williams (Pantheon Books, 2000; $25)
Williams, a passionate advocate for the natural world, takes the reader on an improbable and lyrical pilgrimage through the landscape of Hieronymus Bosch’s enigmatic painting The Garden of Delights. As she contemplates the fifteenth-century triptych, she reflects on nature, contemporary life, and her Mormon upbringing.

Bananas: An American History, by Virginia Scott Jenkins (Smithsonian Institution Press, 2000; $16.95)
One of our country’s most popular and inexpensive fruits—the banana—comes from a herbaceous plant (not a tree) that can grow to a height of thirty feet, is endemic to the rainforests of Southeast Asia, and may have been cultivated as early as 1000 B.C.

Virtual Tibet: Searching for Shangri-La From the Himalayas to Hollywood, by Orville Schell (Metropolitan/Holt, 2000; $26)
Schell, a China expert and dean of the Graduate School of Journalism at the University of California, Berkeley, recounts the tangled history of Western encounters with Tibet. He is particularly vivid on the subject of Hollywood’s skewed portrait of a country that is occupied by China and whose leader, the Dalai Lama, is in exile.

The Muse of History and the Science of Culture, by Robert L. Carneiro (Kluwer/Plenum, 2000; $37.50)
American Museum of Natural History anthropologist Carneiro, in a thoughtful and thought-provoking treatise on the nature of history (from “great man” and racial theories to theological, philosophical, and anthropological views), proposes some scientific “laws” of cultural development.

Why do we sing, write poetry, tell jokes, believe in fairness, and invent fantastic myths? According to evolutionary psychologist Miller, our capacities for art, morality, language, and creativity evolved by sexual selection—that is, because of competition for sexual partners.

The Emperor of Nature: Charles-Lucien Bonaparte and His World, by Patricia Tyson Stroud (University of Pennsylvania Press, 2000; $34.95)
Napoleon’s nephew, ornithologist Charles-Lucien Bonaparte, came to the United States in 1823 at the age of twenty. During his five-year sojourn, he became closely associated with the Philadelphia group of naturalists that included William Bartram, Thomas Say, and John James Audubon.

The books in “Natural Selections” can usually be purchased in the Museum Shop, (212) 769-5150, or via the Museum’s Web site, www.amnh.org.

PHOTOGRAPHY

Hoopla!

On the island of Sicily, near the active interface of Eurasian and African tectonic plates, one of the world’s most continuously active volcanoes—Mount Etna—rumbles and spews. Historians have chronicled its intermittent paroxysms since Pindar and Aeschylus wrote about a spectacular explosion there in 475 B.C. Over the past five years, four summit craters have produced spectacular lava fountains and powerful explosions. Since 1997, Swiss geography teacher Jürg Alean, Italian astronomer Marco Fulle, and Italian seismologist Roberto Carniel have been among those monitoring the mountain. Last February, they observed several hoops of steam being ejected from the crater known as Bocca Nuova. Alean photographed this ring, he says, as it “gently drifted overhead and past the Sun, which was tinted orange by aerosols in the plume of expelled steam and gases.” In recent months, the steam rings—estimated at 600 feet across, sailing as high as 3,000 feet above the ground, and lasting up to ten minutes—have become almost a daily occurrence. Alean speculates that they may be formed by “rapid gas pulses emitted through narrow vents into the atmosphere,” like the artificial smoke rings that once emanated from a famous billboard in New York City’s Times Square. Produced by pulses of steam forced through a large round pipe, the ephemeral rings exited a gigantic cigarette smoker’s mouth, then wafted dreamily above the congested streets.—Richard Milner

Photographs by Jürg Alean
The Matsés Inventory

In northeastern Peru, Museum mammalogists tap local knowledge to catalog the fauna of the rainforest.  

By Henry S. F. Cooper Jr.

Tropical rainforests are now disappearing, according to some estimates, at the rate of 65,000 square miles a year—the equivalent of Washington State. “There is a growing idea that we don’t know what’s in these vanishing areas,” said Robert S. Voss—an associate curator in the Museum’s mammalogy department, when I visited him in his loftlike white office on the fifth floor. Over the past decade, Voss—a lean, animated man in his mid-forties who talks very fast—has been taking inventory of the mammals at the eastern and western extremities of Amazonia, which is home to the world’s largest extant rainforest. The farther west one goes, the more diverse the mammalian fauna becomes, and the reason may be that the soils of Peruvian Amazonia, which were created by alluvium from the Andes, are richer than the leached-out pre-Cambrian soils along the Atlantic seaboard.

Voss, whose specialty is rats, started his inventory in the early 1990s at the low end of the diversity gradient, in a stretch of pristine forest near Paracou, a field station in French Guiana. Because the country is an overseas department of France and because a European Space Agency rocket-launching base is located there, it is wealthier than many of its neighbors and hence there is less pressure to cut down its forests. Nancy B. Simmons, Voss’s wife, who is also an associate curator in the mammalogy department and who specializes in bats, was a coinvestigator throughout the project. (The two are known around the Museum as “Rats and Bats.”)

In the course of thirty-six weeks’ work between 1991 and 1994, Voss and Simmons, using a variety of traps and nets inside a circle of rainforest about four miles in diameter, found 142 species of mammals—more than had ever been found in any comparable habitat and approximately three times the number of mammal species in temperate-zone woodlands in, say, New York or Connecticut. More than half—78 species—were bats, including ghost bats, fishing bats, giant false vampire bats, mammal- and bird-feeding vampire bats, nectar-feeding bats, fruit bats, sucker-winged bats, and freetailed bats. The list also included mouse opossums, water opossums, two- and three-toed sloths, giant armadillos, silky anteaters, marmosets, howler monkeys, jaguars, kinkajous, coati-mundis, tapir, peccaries, brocket deer, pygmy squirrels, water rats, climbing rats, agoutis, prehensile-tailed porcupines, and many smaller rodents.

In 1998 Voss shifted his research to the high-diversity end of Amazonia, west of the Ucayali River, one of the Amazon’s main tributaries. One of the most remote rainforests anywhere, the region is home to the Matsés Indians, whom Voss first heard about from an Ohio State University undergraduate, David Fleck. In the mid-1990s Fleck had encountered a group of Matsés...
read a paper coauthored by Voss about conducting rainforest inventories, Fleck asked him for help.

"We put together a couple of crates of equipment, sent them off, and then forgot about David," Voss says. "It wasn't until a year later that we began getting crates of specimens—fabulous material, just incredible stuff. Most people don't have the opportunity to collect things like this any more. But David was working with the Indians, and most important, he came back speaking Matsés."

In 1998 Voss joined Fleck at Nuevo San Juan, where the two men collaborated with their Matsés hosts in surveying the local mammalian fauna. In the course of just one season, Voss identified 150 mammal species, and he suspects that number will grow to 200. The list includes about as many bats as were found at Paracou (although they constitute less than 50 percent of the total because of the abundance of other species). From the start, the Matsés made major contributions to the effort. Bats, for example, had one name, quesban, so Fleck would say, "Tell me about quesban; is there just one kind?" And the Matsés would reply, "Oh, no! There's the black quesban with the bright white stripes that roosts between the buttresses of large trees in primary forest, and then there's the smaller, browner quesban with slightly less bright white stripes that lives higher up in the trees, and then there's the sort of green quesban with white stripes you can barely see and that roosts on the inclined trunks of trees that hang out over the river."

As Voss says, "It turns out they recognize thirty or forty different types of bats. What David found was that recognition of biological diversity precedes the cultural processes that result in naming." Indeed, the methods by which Matsés learn about natural history are now the subject of Fleck's doctoral work: at Rice University, he has switched from zoology to linguistics. And just as he was once adopted by the Matsés, he has now been adopted by the Museum as a field associate in the anthropology department.

Creating an inventory of mammals, however, involves more than simply counting species; it also entails finding them. In this respect as well, the Matsés are critical to Voss's studies, because they know the habits of the mammals they hunt. Certain bats sleep inside termite nests, but Voss could never find such a roost until a young Indian boy named Moisés directed him to a crevice in one of the large termite nests commonly located on tree trunks throughout the forest. When Voss put his hand inside, sure enough, the nest was full of bats. Moisés was given a machete as thanks. Other Matsés children began bringing him bats, rodents, and other animals, for which he rewarded them with fishhooks or flashlights.

When Voss was unable to return to Peru in 1999 because of writing responsibilities and other Museum duties, he and Fleck recruited the Matsés to act as research assistants. Joachín Rojas, Moisés's father, was given a pencil and notebook and hired to locate and describe bat roosts. Voss showed me the notebook, which was filled with pages of neat handwriting, all in Matsés, interspersed with competent illustrations of a number of different roosts. (In the late 1960s, a group of missionaries known as the Wycliffe Bible Translators taught the Indians how to write in their own language using the Roman alphabet. The missionaries translated the Bible into Matsés and also established schools for the children.)

Fleck has also been recording the Matsés. Voss played me an interview with a hunter that included the man's evocative imitations of the calls of titi monkeys. "The Indians know where the animals live," says Voss. "They know how many young they have, they know when the young are born, and they know what foods are eaten at what times of the year. They know what the principal predators are, what sounds woolly monkeys make when they get up in the morning, how they call to one another throughout the day, whether the group stays together or disperses into smaller
groups, how they reunite in the evening, and how roost trees are chosen. The tapes just go on and on and on.” (To hear excerpts from the interviews, go to www.naturalhistory.com).

As part of his doctoral research, Fleck is transcribing these interviews. He is also compiling the natural history information contained in them for a classroom text in Matsés, a field guide to sixty or seventy mammals. Voss believes the book will help preserve not just the animals but the language (the only other book in Matsés is the translated Bible). Above all, though, the project is an attempt to repay the Matsés by preserving their trove of ethnobiological knowledge in their own language for future generations.

Henry S. F. Cooper Jr., a former staff writer for the New Yorker, has been visiting the Museum since he was four years old. He has contributed articles to Natural History on the Museum’s newest fossil hall and the redesigned planetarium.

Events

SEPTEMBER 22 AND 23
9:00 A.M. to 5:00 P.M. Scientists James Watson (Cold Spring Harbor Laboratory), Harold Varmus (Memorial Sloan-Kettering Cancer Center), and Stephen Jay Gould (Harvard University and New York University) are among the speakers at a two-day conference, “Sequencing the Human Genome: New Frontiers in Science and Technology.” The conference is free, but reservations are required. For more information, go to www.amnh.org/welcome/specials/genomics/.

SEPTEMBER 25
7:30 P.M. As part of the “Distinguished Authors in Astronomy” series, astronomer Mitch Begelman, of the University of Colorado, gives a talk about black holes, drawing on his new book, Turn Right at Orion: Travels Through the Cosmos (Perseus, 2000).

The Web site for AustraliaQuest is launched at www.classroom.com. AustraliaQuest is the fifth online expedition sponsored by Classroom Connect in partnership with the Museum. This interactive journey allows students to join a scientific expedition for a five-week exploration of the island continent’s geography, natural history, and, in particular, its aboriginal culture. Millions of children have participated in previous Quest expeditions.

DURING SEPTEMBER
Musings is a free quarterly Web newsletter about Museum exhibitions and classroom resources for science educators. Produced by the Museum’s National Center for Science Literacy, Education, and Technology, it is available at www.amnh.org/learn/musings. To be included on the mailing list, e-mail musings@amnh.org.

Museum naturalists lead three series of eight walks each in Central Park (on Tuesdays, Wednesdays, and Thursdays) to observe the fall migration of birds during September and October. Learn how to use field marks, habitat, behavior, and song to identify birds. For details and a complete schedule, call (212) 769-5200.

In addition to Dolphins (a film about these marine mammals in the wild, with a soundtrack by Sting), the Museum’s IMAX is also presenting To Be an Astronaut, featuring a NASA team of astronauts on their extensive prelaunch in-flight training sessions.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100. Visit the Museum’s Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are available online.
By Meredith F. Small  I may be a card-carrying academic with a Ph.D. in anthropology, but I like trashy TV shows as much as the next person. And that’s why I tuned into the CBS hit *Survivor* one Wednesday night this summer. I knew the premise—sixteen people stranded on a tropical island for thirty-nine days, periodically forced to vote someone off until just one survivor remained to claim the million-dollar prize. And so I sat down with some friends for a night of popcorn and laughs. Still, I couldn’t keep from analyzing the contestants’ behavior. They were doing what we primates do best—making alliances, strategizing, and gossiping about one another.

Though supposedly posing a test of survival skills, the desert-island situation was rather contrived. Two teams “comfortable in the forest.” And one woman gained respect because she could throw a spear. Even the crotchety old man was tolerated because he was fit, straightforward, and a hard worker. What seemed to count was knowledge and ability in the current context. (The physician, on the other hand, was generally disliked.)

And there was a predictable subsistence pattern: the women went into the forest to dig up cassava roots while the men went fishing. As is commonly the case, the gathering was productive, but the hunting effort proved disappointing. In one scene, the women lambasted the men for wasting their time lounging on rafts when there was real food to be found in the woods. Buckling under, the men sauntered off to gather, grousing all the way, and came back with only one pitiful root. It reminded me of the division of labor found in the typical hunting-and-gathering group: women walk miles and haul home loads of nuts or roots to provide most of the calories; men pursue the more glamorous, and more elusive, gazelle.

I was also reminded of how quickly tribal loyalty develops. The two teams were separated on the island and met only during the staged competitions. Yet each team was more than willing to make disparaging remarks about the other, belittling the abilities of individual members while at the same time praising their own weakest members. What we had here, I thought, was the beginning of an ugly kind of nationalism. Of course, given the survivor-takes-all premise, this was a highly charged situation involving ambitious contestants. But I think these people were behaving as good primates always do—using their smarts to quickly master their social situation.

During the show, when I unglued myself from the tube and focused on the group of friends watching it with me, I noticed that they, too, were making instantaneous personal judgments about the contestants. They yelled comments at the TV, made pronouncements on who should be voted off and who should stay, reveled in every bit of gossip. And that’s the secret of *Survivor*’s success. Underneath it all, we are just a bunch of apes who want to know what our fellows are up to, always eager to be part of the action.

Meredith F. Small is a professor of anthropology at Cornell University in Ithaca, New York.
EXPLORE THE WORLD

**DECEMBER 2000**

Family Adventure in the Land of Pharaohs and Prophets: Egypt, Israel, Jordan, and the Red Sea
Aboard the Callisto
$1,995 – $5,195

**JANUARY 2001**

Exploring Antarctica & The Falkland Islands: Aboard the Hanseatic
January 14 – 29, 2001
$7,975 – $15,475

The Galapagos Islands: Aboard the Isabela II
January 14 – 24, 2001
$4,995

Cuba: Image and Reality Aboard the Panorama
January 18 – 28, 2001
$5,595 – $6,495

Heaven & Earth: Around the World Private Jet Expedition to Celebrate the Rose Center for Earth and Space: Tikal, Cuzco, Machu Picchu, Easter Island, Samaq, Ayers Rock, Borobudur, Angkor Wat, Taj Mahal, Luxor, Petra, and Norway’s Northern Lights
January 19 – February 10, 2001
$32,950

Indochina Unveiled: Vietnam, Cambodia, and Laos
January 26 – February 11, 2001
$6,290

**FEBRUARY 2001**

Bhutan & Northern India: Aboard the Royal Orient
January 29 – February 15, 2001
$7,950

Timbuktu and the Rivers of West Africa: Mali, Senegal, and the Gambian Aboard the Halcyon
February 4 – 17, 2001
$5,595 – $6,495

Mexico: Mayan Ruins and Exquisite Haciendas
February 9 – 22, 2001
$5,690

Big Cats of the Serengeti: Biodiversity and the Role of Carnivores in Ecosystems
February 19 – March 4, 2001
$8,490

Inside Saudi Arabia
February 22 – March 8, 2001
$7,850

The Amazon: Discovering its Natural Wonders Aboard La Amatista
February 24 – March 4, 2001
$3,195

**MARCH 2001**

The Lost Islands of Tahiti: Exploring French Polynesia Aboard the Paul Gauguin
March 1 – 11, 2001
$4,930 – $9,760

Belize & Tikal: Rainforests, Reefs, and Ruins
March 9 – 18, 2001
$3,590

The Amazon: Discovering its Natural Wonders Aboard La Amatista
$3,195

Indian Ocean Odyssey: South Africa, Madagascar, and the Seychelles Aboard the Hanseatic
March 17 – April 4, 2001
$9,975 – $17,475

Exploring Southeast Asia Aboard the Eastern & Oriental Express: Thailand, Malaysia, Cambodia, Singapore, and Hong Kong
March 18 – April 1, 2001
$6,690 – $7,490

**APRIL 2001**

Egypt and the Nile: Aboard the M.S. Nile Sovereign
April 22 – May 6, 2001
$5,780

Sicily: Crossroads of Mediterranean Civilizations Aboard the Halcyon
April 25 – May 5, 2001
$5,295 – $6,195

**MAY 2001**

Springtime in Japan: Exploring Gardens, Temples, and Traditional Culture Aboard the Clipper Odyssey
May 7 – 21, 2001
$7,990 – $11,690

Classical Greece & The Elgin Marbles
May 9 – 19, 2001
$5,490

Historic Cities of the Sea: Sicily, Malta, Tunisia, and Spain Aboard the Celeia II
May 9 – 20, 2001
$6,695 – $12,595

Africa’s Wilderness by Rovos Rail: South Africa, Zimbabwe, Botswana, and Namibia
May 16 – 30, 2001
$8,495

**JUNE 2001**

Madagascar: Witnessing the Total Solar Eclipse
June 9 – 23, 2001
$8,990

Fire & Ice: The Kuril Islands and Kamchatka Peninsula Aboard the Clipper Odyssey
June 18 – 30, 2001
$6,490 – $10,690

China for Families: Beijing, Xi’an, Yangtze River, Shanghai
June 19 – July 3, 2001
$4,980 – $5,620

North America’s Great Lakes: From Toronto to Chicago Aboard Le Levant
June 24 – July 2, 2001
$3,890 – $5,390

National Parks of the West Private Jet Expedition: Mt. Rushmore, Grand Teton, Yellowstone, Grand Canyon, Glacier National Park, Zion, Bryce Canyon, and Mesa Verde
June 30 – July 11, 2001
$13,950

Wildlife of the Galapagos Islands: A Family Adventure Aboard the Santa Cruz
June 30 – July 10, 2001
$3,490 – $4,110

**AMERICAN MUSEUM OF NATURAL HISTORY/DISCOVERY TOURS**

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## ON A DISCOVERY TOUR

### 2001 Programs

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<td>July 7 – 13, 2001</td>
<td>€1,350 – €2,600</td>
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<td>Inside Iceland</td>
<td>July 9 – 18, 2001</td>
<td>€4,275</td>
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<td>Exploring the Natural Wonders of Ireland: A Family Program**</td>
<td>July 11 – 19, 2001</td>
<td>€1,970 – €2,990</td>
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<td>Voyage to the North Pole: Aboard the Yamal</td>
<td>July 18 – August 1, 2001</td>
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<td>August 2 – 14, 2001</td>
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<td>Family Alaska Expedition: Aboard the Wilderness Adventurer</td>
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<td>Exploring Atlantic Canada: Bay of Fundy and Nova Scotia</td>
<td>August 7 – 14, 2001</td>
<td>€2,045</td>
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<td>Undiscovered Greece: Hidden Islands, Villages, and Ancient Sites Aboard the Callisto</td>
<td>August 16 – 25, 2001</td>
<td>€3,995 – €5,295</td>
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<td>The Outer Islands of Britain, Ireland, and Scotland: Aboard the Song of Flower</td>
<td>August 22 – September 2, 2001</td>
<td>€5,975 – €11,475</td>
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<td>China &amp; The Yangtze River</td>
<td>August 27 – September 13, 2001</td>
<td>€6,790 – €7,390</td>
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<td>The Elbe River: A Journey from Prague to Berlin Aboard the Katharina</td>
<td>August 29 – September 11, 2001</td>
<td>€5,790 – €6,390</td>
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<th>Program Description</th>
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<td>September 4 – 23, 2001</td>
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<td>The Ancient Silk Road: A Journey Through China and Central Asia</td>
<td>September 21 – October 14, 2001</td>
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<td>October 1 – 21, 2001</td>
<td>€9,880</td>
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<td>Exploring Egypt &amp; Jordan by Private Plane</td>
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<td>€5,990</td>
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<td>Ethiopia: The Heart of African Civilization</td>
<td>October 3 – 17, 2001</td>
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<td>Papua New Guinea: Journey to the Last Unknown</td>
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<td>October 27 – November 7, 2001</td>
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- **Festivals of India**: Aboard the Palace on Wheels  
  November 2 – 18, 2001  
  Price TBA

- **Patagonia**: Torres Del Paine and Tierra Del Fuego Aboard the Terra Australis  
  November 5 – 16, 2001  
  €4,975 – €6,975

- **Arabian Gulf Voyage**: Dubai, Qatar, Bahrain, Kuwait, Saudi Arabia, Khasab, and Muscat Aboard the Song of Flower  
  November 7 – 20, 2001  
  Price TBA

**December 2001**

- **Nepal**: A Himalayan Family Adventure  
  December 19, 2001 – January 2, 2002  
  €5,990 – €6,490**

**January 2002**

- **South Pole Expedition**:  
  January, 2002  
  €38,950

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The miracles of science
Crying Out Loud

Natural historians—whether field biologists, medical doctors, neuropsychologists, anthropologists, paleontologists, or mathematically-minded theorists—have a tendency to ask annoying (because difficult) questions about things the rest of us take for granted. Take the unremarkable fact that human infants have very loud cries. There’s nothing to say about the phenomenon that isn’t obvious, right?

But to people who habitually think about behavior in the light of natural selection, the very noisiness of babies’ crying—like the noisy begging of a brood of nestlings—is a bit of a conundrum. Why would any helpless, immature organism do something that seems so likely to attract predators and squander precious energy? Doesn’t it stand to reason that the neonates of all species—including our own—should be neither seen nor heard?

Well, yes—and no. In “The Uses of Crying and Begging” (page 62), Bryant Furlow takes a look at “parent-solicitation displays” (scientific jargon for baby-to-parent communication) and presents new evidence that the attention-grabbing traits of the newborn and newly hatched may have evolved for reasons that are not entirely self-evident.—Ellen Goldensohn

PS. Some readers have written to us wondering what happened to “Universe,” Neil de Grasse Tyson’s popular column on astrophysics. Tyson, director of the planetarium in the new Rose Center for Earth and Space at the American Museum of Natural History, has just finished a half-year sabbatical away from our pages. He returns with “Doubling Time,” a humorous meditation on the information revolution (page 84).

AMERICAN MUSEUM OF NATURAL HISTORY
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Ellen V. Futter President

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Can Scientists Make This Mummy Talk?

DEsert Mummies of PERU

Sunday, October 8, 9 pm e/p
Old Wounds
As a surgeon interested in the history of wound care, I very much enjoyed Stephen Jay Gould’s essay “The Jew and the Jew Stone” (6/00), in which he discusses Johann Schröder’s seventeenth-century recipe for weapon salve. About ten years ago, I treated an elderly woman who had lacerated her arm while preparing a meal. As I dressed her wound, she informed me of how she had initiated her treatment at home by anointing the offending knife with oil, wrapping it in a clean linen napkin, and placing the knife in a drawer. She explained that she had learned to do this when she was a young girl living in rural Ireland.

The origins of weapon salve are obscure. Sir James George Frazier, in The Golden Bough, describes sympathetic magic as the root of the salve. The magic inhered in the ability of an object that had come in contact with a body to affect that body from afar. Therefore, treating a sword with weapon salve was the equivalent of treating the wound. My patient’s self-treatment was still common in England in the early twentieth century.

Alan Sori, M.D.
Paterson, New Jersey

Medium Message
Thank you for the lovely illustrations and the explanation of the symbolism of the Chinese scroll described in “Fascination of Nature,” by Roderick Whitfield (7–8/00). But what material was used to make the scroll, and what medium was used to paint it?

Jeremiah B. Lighter
New York, New York

Roderrick Whitfield
replies: The painting surface is specially woven silk treated with alum to hold both ink and colors, which are generally mineral pigments. The scroll is then mounted, along with additional sheets of paper (for a title and calligraphy to be added later by connoisseurs), and the whole is held together by a thin backing of mulberry bark.

Armadillo Masochism
It certainly sounds as though Robb White (“Endpaper,” 7–8/00) is a glutton for punishment when it comes to armadillos. At the very least, reason should have warned him that the “peculiar movement of the anus” might well have foreshadowed a movement of another kind. As if leaning down “for a closer look” wasn’t enough the first time, he relates that he was still at it some years later, trying to write a number on the back of another specimen and suffering a busted lip and two loosened teeth in this encounter.

Robert and Mary Rubalsky
Queens, New York

Panama Coronation
I read “The Crown of Montecristi” by Tom Miller (6/00) just as my older summer hats were in need of replacement. The article left me torn between the thought that buying a true Panama hat from Ecuador made me an exploiter of poverty-stricken adults and children and the thought that I was keeping a craft and a tradition alive.

When I visited my favorite hat shop, I looked at a shantung and a cheap Panama hat but decided that my head would look and feel better when crowned by a true Montecristi.

Arthur Tenenholtz
New York, New York

Natural History’s e-mail address is nhmag@amnh.org.
appropriately complex
Archaeologists Thomas H. McGovern and Sophia Perdikaris ("The Vikings' Silent Saga," page 50) have both done work on Scandinavian settlements in the North Atlantic—McGovern in the Shetland Islands, Iceland, and Greenland, and Perdikaris mainly in the Lofoten and Vesterålen island groups in northern Norway. McGovern is a professor of anthropology at Hunter College, of the City University of New York (CUNY), and coordinator of the North Atlantic Biocultural Organisation. Perdikaris is an assistant professor of anthropology and archaeology at CUNY's Brooklyn College. She is also director of the Brooklyn College Zooarchaeology Laboratory and of CUNY's Northern Science and Education Center.

For his doctoral dissertation, at Lehigh University in Pennsylvania, Rogelio Macías-Ordóñez ("Touchy Harvestmen," page 58) wanted to choose an animal species that would lend itself to research on mating strategies. Noticing a pair of striped harvestmen mating, he wondered whether this common daddy longlegs might be a good candidate. "I found close to nothing in the literature on the mating systems of this group," he says, "and for so common an animal that's not a good sign: it usually means that it is too hard to study. Surprisingly, the years have passed and no special problem has emerged. I guess I was lucky to find an empty niche." Macías-Ordóñez is now an associate research scientist in the department of ecology and animal behavior at the Instituto de Ecología in Xalapa, Veracruz, Mexico.

Bryant Furlow ("The Uses of Crying and Begging," page 62) traces his interest in biology to a childhood spent on a farm in Oregon, where he devoted no small amount of time to collecting rats and shrews and assorted other small creatures. Later, at the University of New Mexico, from which he graduated summa cum laude, he did a study of human infant cries that became the basis of his senior thesis. Furlow now lives in California and is a regular contributor to the British weekly New Scientist. His fascination with life's early stages continues unabated. Most recently his attention has been captured by the effect of prenatal stress on child development and adult behavior. Furlow still spends a lot of time in the field—but now he's collecting insects with his wife, Tara Armijo-Prewitt, an entomology graduate student at the University of California, Davis.

Richard Fortey ("Crystal Eyes," page 68) brings us his great enthusiasm for ancient fossil trilobites in a chapter he has adapted from his new book Trilobite! Eyewitness to Evolution (Knopf, November 2000). The volume is something of a bridge between his other writings—learned and popular. On the one hand, he is at work as "trilobite coordinator" for the upcoming tome Treatise of Invertebrate Paleontology, and on the other hand, he confesses, he "must be one of the few paleontologists to have written two humorous books pseudonymously." A Merit Researcher at the Natural History Museum in London and visiting professor of paleobiology at Oxford University, Fortey, like many other paleontologists, collected fossils as a child, in his case, trilobites in Wales. But he adds, "I am also a passionate amateur mycologist. If I hadn't done trilobites, I'd have done mushrooms."

John Cancalosi ("The Natural Moment," page 94) took this month's featured photograph of the bearded vulture in the Spanish Pyrenees. Cancalosi (pictured here with his son, Nicholas) thought a sheep carcass would be a windfall for scavenging vultures, but the birds were slow to descend: "I worked in conjunction with a biologist over several weeks, most of which I spent staring into space, perched on a rather uncomfortable board in a cold blind." Then one week, several birds investigated the spread, and he photographed them (with a Nikon F-5 camera) from about forty yards away. Cancalosi has a master's degree in zoology and left a teaching job eleven years ago to become a full-time photographer. A worldwide traveler, he spent a year living, and eating, in Spain, where he finally acquired a taste for olives.
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The Wetlands That Almost Disappeared.

In southern Louisiana, a vital wildlife breeding ground was endangered. Freshwater wetlands were vanishing. Leveeing along the Mississippi River had reduced the influx of fresh water and silt. But then, people working nearby partnered with the Fish and Wildlife Service to carve channels into the levees. Hundreds of acres in the Delta National Wildlife Refuge were restored. And so was nature’s glorious nursery.

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People Do.
Singing in the Brain

Hummingbirds don’t just hum—they sing. And they learn the tunes from one another.

By Annette Heist

The fact that humans learn to talk by listening to and imitating other people seems obvious. If speech were built in, as breathing and swallowing are, we would all speak the same language, free of dialect, and life might be a lot simpler (think foreign travel or peace negotiations). While children pick up language with enviable ease, the process of vocal learning is actually quite complex, and most linguists agree that there is a critical time when it should occur. But given the proper teachers and timing, most humans can learn to produce a seemingly infinite number of sounds and sound combinations.

Such is not the case with most animals. In fact, only whales, dolphins, bats, and some birds are known to have the ability to learn vocalizations. Separate a kitten from its mother or other tutor, and its mew will be basically the same as that of its littermates—a pattern that holds true for the howl of a wolf, the grunt of a gorilla, and the whinny of a horse.

Vocal learning has been repeatedly demonstrated in two bird orders, Passeriformes (specifically the oscine songbirds) and Psittaciformes (parrots), and is believed to occur in a third, the Trochiliformes (hummingbirds). By comparing brain structures in these three bird orders, which are widely separated from one another on the avian family tree, Rockefeller University biologist Claudio Mello and his colleague Erich Jarvis, of Duke University, have shown that the same areas that control song learning and production in songbirds and parrots are also present in hummingbirds, a finding that strengthens the case for vocal learning in the latter.

Most people are surprised to learn that hummingbirds even have songs. “The songs aren’t particularly loud and you sort of have to know what to listen for,” explains Mello. “They are higher pitched than those of songbirds, but the songs are amazingly rich, and in some species they can be quite complex.”

In the 1950s biologists began to investigate the processes by which birds imitate the sounds they hear and incorporate them into songs. Appropriately enough, that work began with songbirds, a suborder that includes almost half the nearly 8,500 living species of birds. W. H. Thorpe, of the University of Cambridge, was the first to demonstrate learning in birds by performing what is now considered to be a classic experiment, involving the isolation of male chaffinches (European songbirds) in soundproof chambers equipped with speakers. Young chaffinches that heard recorded chaffinch songs were able to imitate these songs, while birds deprived of the recordings developed abnormally simple songs.

Isolation experiments are exceedingly difficult to do with hummingbirds, however. Because of their extraordinarily fast metabolism, baby hummers must be fed every ten minutes around the clock. But in 1990, this type of experiment was conducted on one species of trochilid, the Anna’s hummingbird (Calypte anna). The late Luis Felipe Baptista, of the California Academy of Sciences, and Karl Schumann, at the Zoologisches Forschungsinstitut in Bonn, Germany, found that a male Anna’s hummingbird raised in isolation produced a much simpler
song than did wild males. The song was also very different from that of three males hand-raised together. The outcomes suggested that the males were imitating each other's vocalizations—evidence that hummingbirds learn their songs. Other research showed that the nearest neighbors of hermit hummingbirds (Phaethornis longuemareus) sing more similar songs than nonneighbors of the same species; and the songs of green hermit hummingbirds (P. guy) living in Costa Rica are different from those of the same species living in Trinidad.

In the 1970s and 1980s, Fernando Nottebohm, of Rockefeller University, and several colleagues set about mapping the parts of the brain involved in the singing process. The researchers identified six anatomically distinct areas—clusters of cells called nuclei—in the forebrain of songbirds. These nuclei are organized into two distinct paths: the posterior pathway, which controls song production, and the anterior pathway, which controls song learning. Together these pathways form a song control system that must be intact if birds are to sing the songs they've learned.

Forebrain nuclei similar in structure and location have also been found in the budgerigar (an Australian parakeet). No such nuclei have been found in the birds most closely related to songbirds, the suboscines (woodcreepers, ovenbirds, antbirds), or in other nonlearners of songs such as pigeons and doves (order Columbiformes) and chickens, turkeys, and quails (order Galliformes).

And before Mello and Jarvis, no one had bothered to look for these nuclei in hummingbirds.

Working with songbirds in the 1990s, bird researchers added a novel tool to their toolbox, a gene called ZENK, that would make the search for nuclei in hummingbirds much easier. Nottebohm, Mello, and Jarvis noticed that the number of activated ZENK genes in certain areas of the brain was very low when the songbirds were quiet. When the birds sang or heard songs, however, ZENK activity increased. By measuring the levels of activated ZENK in specific locations, the researchers were able to see the previously identified nuclei "in action." ZENK gave the researchers a window into the brain, enabling them to see how certain behaviors set into motion the molecular activity of cells in specific brain areas.

The ZENK gene soon led the researchers to discover another nucleus in the songbird vocal system, bringing the total to seven. With ZENK they were also able to define more clearly the roles of the anterior and posterior pathways. The anterior pathway (which, they knew, needed to be intact for learning to occur) showed signs of activity only when the birds heard songs by members of their own species. And after they had heard the song a number of times, the ZENK response began to fade. "With ZENK," says Jarvis "we now had a technique that essentially lit up the learning center."

Jarvis and Mello went on to look at budgerigars' brains. "The brains were much more similar to songbirds' brains than people thought," says Jarvis. "We found many of the same structures, and their placement in the brain was identical." One question remained: Did hummingbirds, too, have the brain structures and pathways necessary for learning?

To answer that question, Mello and his colleagues have made several trips to his native Brazil, to an area with one of the world's highest densities and spe-
cies diversity of hummingbirds. The researchers set up a hummingbird feeder on the veranda of the Museu de Biologia Mello Leitão, a small museum and biological research station on the outskirts of the town of Santa Teresa, nestled high in the Atlantic tropical forest of Brazil’s east coast. Part of the research involved learning to identify individual birds—no easy feat.

For the uninitiated, it is difficult to tell apart the thirty or so species of *beija-flores* (Portuguese for “flower-kissers,” the creatures we call hummingbirds) that live in this swath of forest, and it is mind-numbing to try following the activity of individual birds. They move so fast that keeping your eye on one is like trying to follow a single bee in a swarm. Banding—the field technique commonly used for telling birds apart—doesn’t work: hummingbirds’ legs are so tiny that there is little space for a band, and the birds weigh so little that attaching a band could significantly affect their ability to fly.

“After a couple of days, you start to see individual variation, a messy feather here, or a slightly darker color,” says Linda Wilbrecht, a graduate student at Rockefeller. Working at Mello’s field site in Brazil, Wilbrecht and her fellow graduate student Sidarta Ribeiro observed the behavior of individuals of two species, sombre hummingbirds (*Aphantochroa cirrhochloris*) and rufous-breasted hermits (*Glaucis hirsuta*). Wilbrecht and Ribeiro followed birds that were doing one of three things: singing in territorial defense, listening to recorded songs of conspecific birds, or perching quietly. These species were chosen, in part, because their songs are very different. *G. hirsuta*’s is complex, while *A. cirrhochloris*’s is fairly simple. A complex song is itself evidence that a bird learned its song: the innate vocalizations of birds (those produced by pigeons, for example) tend to be simple, with few syllables and a narrow range of notes. Because of the differences between the two species, Jarvis and Mello reasoned, one might be a learner and the other not—a possibility that would make their results quite intriguing.

Back at Rockefeller University, the researchers hoped to learn whether the behavior they had observed in the field translated into observable differences in the ZENK expression within the birds’ brains. In the laboratory, the researchers confirmed that seven nuclei are active in singing hummingbirds, and that these structures are strikingly similar to the seven forebrain structures involved in vocal learning and production in songbirds and parrots. It also turned out that *Aphantochroa*’s song is not so simple after all. While these birds do sing relatively few notes, each note is in itself more like a chord—more complex than notes in a *Glaucis* song. As for their brains, there is little difference in their structure. For the first time scientists can say definitively that hummingbirds have the necessary brain circuitry for vocal learning.

And what of the evolutionary path that brought hummingbirds to this point? Of the twenty-three bird orders, the three in which song learning occurs are very distantly related; on the avian family tree they are separated by several orders in which learning doesn’t occur. This suggests two possible scenarios: First, all the birds shared a common ancestor that had the necessary brain structures, but only three orders retained them, developing into learners, while the intervening orders did not. But that would mean that some birds with the structures necessary to learn, and maybe even the ability to learn, have lost them over time. To Jarvis, this seems an unlikely scenario. The second possibility is that the three orders independently evolved the same learning structures in their brains. “Maybe complex behaviors can evolve more than once. What we’re saying is that there is an overarching factor that says if vocal learning is going to occur, then Mother Nature is only going to let it happen this way,” Jarvis says.

The next step is to use ZENK to look at the brains of the intervening orders to see if birds that don’t learn songs share the same brain structures and pathways with their educated (or educable) cousins. The researchers will start with doves, and if the learning structures aren’t found, the second hypothesis becomes even more likely. Jarvis doesn’t think learning structures will be found in the other birds, “but if in a million years pigeons develop learning, I say I can predict where in their brains those structures will be.”

Annette Heist is a producer of National Public Radio’s Science Friday.
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IN SUM

WHY DO BIRDS DIVORCE? In most of Europe, blue tits (Parus caerulescens), relatives of North American chickadees, form strong, persistent pair bonds that last through many breeding seasons. But blue tit females studied on the Mediterranean island of Corsica abandon a previous mate 59 percent of the time.

What causes such a high rate of “divorce” among these Corsican blue tits?

According to ornithologist Jacques Blondel and colleagues at France’s National Center for Scientific Research, the divorce rate is determined by large variations in the quality of breeding sites on the island.

While males cling to the old homestead, many females simply move to habitats where vegetation is denser, caterpillars (their staple food) are more abundant, and parasites are less profuse. So when a Corsican female leaves her mate, she does so to find a better home in a nicer neighborhood with better dining opportunities. (“High Divorce Rates in Corsican Blue Tits: How to Choose a Better Option in a Harsh Environment,” Oikos 89, 2000)

FIDDLE WITH THE TRUTH Males of an Afro-Asian species of fiddler crab (Uca annulipes) have one oversize claw that they use for both flirting and fighting. In the presence of a female, a male waves the claw in a fast, frantic display. During territorial contests with other males, the crabs use claw length to assess an opponent’s fighting ability.

When they lose these claws (through injury or predation), male fiddler crabs soon grow new ones that look similar to the originals but are much lighter, flimsier, and of little use in fights. Such males, according to animal behaviorist Patricia R Y. Backwell, of the Smithsonian Tropical Research Institute in Balboa, Panama, nevertheless manage to intimidate rival males and to attract females. (“Dishonest Signaling in a Fiddler Crab,” Proceedings of the Royal Society of London B 267, 2000)

NEW HOMINID TROVE At Drimolen, a cave site discovered less than a decade ago in the Krugersdorp district of South Africa by André W. Keyser, of the University of the Witwatersrand, researchers have reported finding seventy-nine new fossils of hominids (the group that includes humans and our closest extinct relatives).

Estimated at 1.5 to 2 million years old, the Drimolen fossils are mostly teeth that belonged to Paranthropus robustus australopithecine. In addition, Keyser and Ron J. Clarke have pieced together an australopithecine skull and jaw from Drimolen—the most complete yet found.

On the basis of fossils found at the nearby Swartkrans and Kromdraai sites some seventy years ago, paleoanthropologists had speculated that two hominid species—P. robustus and P. crassidens—had once lived there but had become extinct long before the first humans appeared on the scene. The new evidence suggests that the area was inhabited by a single population of a robust australopithecine species whose dental features varied widely.

In another study, Keyser and colleagues confirmed that Drimolen is the second site in South Africa where Paranthropus and Homo remains have been found together, strengthening the evidence that “man-apes” did indeed coexist with early humans there for hundreds of thousands of years. (“The Drimolen Skull: The Most Complete Australopithecine Cranium and Mandible to Date” and “Drimolen: a New Hominid-Bearing Site in Gauteng, South Africa,” South African Journal of Science 96, April 2000)

ALTRUISTIC MEERKATS Altruism, according to evolutionary biologist W. D. Hamilton, sometimes evolves among social species if the altruistic individuals share a large number of genes with the individuals they are helping. Evidence to support Hamilton’s kin-selection model has been found for various social insects as well as for hyenas, kingfishers, and mole rats—all of which show a high degree of relatedness between the helpers and the broods they assist in rearing. Mammalogist Tim H. Clutton-Brock, of the University of Cambridge, and colleagues recently tested the hypothesis on a population of meerkats (Suricata suricatta), a desert-adapted mongoose that lives in southern Africa.

Most meerkat young are born to a single dominant female. After she gives birth, one or two helpers remain in her burrow each day to “baby-sit” while the rest of the group members leave to forage. Baby-sitters usually spend up to three weeks caring for the litter, an exertion that results in considerable weight loss.

Clutton-Brock’s team studied fifteen groups of meerkats in the Kalahari Desert to see if the meerkats that gave the most help were in fact those whose genes were most like those of the infants they nurtured. The results, however, were negative. In their analysis of 114 helpers—most of known pedigree—the researchers found “no indication that the large differences in contributions to baby-sitting that exist among helpers are related to differences in their kinship to the litter they were caring for.” (“Individual Contributions to Baby-sitting in a Cooperative Mongoose, Suricata suricatta,” Proceedings of the Royal Society of London B 267, 2000)—Richard Milner
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It’s a sure sign of fall in Worcester County when lone kestrels appear on the horizon and the sky fills with Canada and snow geese. Over 350 species of birds have been recorded in Worcester County, including pelicans and pewees, kingbirds and cuckoos, herons, harriers, and eagles. Along the coast, you can visit Assateague to observe innumerable migratory species, including peregrine falcons, merlins, and enormous flocks of tree swallows. Just offshore, northern gannets pass by the hundreds.

One of the best places in Worcester County for fall birding is the Pocomoke Sound, a mostly tidal marsh with a few acres of forest. In this area, ducks, wading...
birds, and shorebirds are awaiting your visit. Herons, egrets, and ducks can all be seen in the marsh, searching for food, or just playing. Ospreys, once declining in numbers in Maryland, have fully recovered and now nest on channel markers, which are visible from the shore. And from April to September, you can catch a glimpse of a barn owl on the marsh.

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Birding Hot Spots

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One of the treats of making the Alabama Gulf Coast your birding destination is the Alabama Coastal Birding Trail, where some of the most popular birding sites in the state are located. The trail is separated into six loops that can each take a half-day or more to complete. A 51-page booklet that introduces the trail, complete with maps, photographs, and directions, can be obtained from 800-745-SAND.

In October, watch the Hummer Bird Study Group at Fort Morgan as they record height, weight, health, and species of the many birds traveling south for the winter. This group welcomes the public to visit their site and observe the birds as they are each given a physical and then released to continue the journey south. For more information call 334-968-7511.

One of the best loops for fall birders is the Dauphin Island – Bayou La Batre Loop, home of the Dauphin Island Audubon Bird Sanctuary. The sanctuary consists of 164 acres of maritime forest, marshes, and dunes, including a lake, a swamp, and a beach, located at the eastern end of Dauphin Island, a 14-mile-long barrier island off the Alabama Gulf Coast. The sanctuary is the largest segment of protected forest on the island and, in the fall, the final feeding and resting place for neo-tropical birds on their return flight to Central and South America.
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LITTLE ST. SIMONS ISLAND IS REGARDED as one of the best locations to spot shorebirds on the Georgia Coast. The island’s constant growth creates large areas of intertidal flats and sandbars that make attractive feeding areas for shorebirds. Although birds may be seen at any time, the tide plays an important role in determining their location and behavior. The optimum time for shorebirding is high tide, when the birds are pushed onto the upper reaches of the sandbars and beaches.

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For more information on Dauphin Island,
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Outer Islands of
Britain & Ireland

Orkney Islands, Shetland Islands,
Outer Hebrides — Isles of Lewis and Harris,
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Seeds of Fortune

How does a fir tree cross a desert? By winning a lottery.

By Peter J. Marchand

The place is Wind Whistle in southeastern Utah, just a stone’s throw from Canyonlands National Park. Tucked into the deep shadow of a north-facing cliff grow three Douglas fir trees, the largest more than two feet in diameter and nearly a hundred feet tall. The trees might not have attracted my attention but for one thing: Wind Whistle is in sagebrush desert, and these firs are a long way from their nearest kin. While the site obviously suits the trees, their presence here tells much about the sweepstakes character of long-distance seed dispersal, one of the great gambles in the life of a plant.

Seed dispersal is no less important to the success of a plant than are its germination, growth, and flowering. It is the sole means by which plants track shifting resources in an ever changing landscape. And autumn is the best time to view plants’ strategies for getting around. A walk through the woods and tall meadows at this time of year reveals an abundance of architectural innovations for spreading seeds: the fluttering samaras of ashes and maples; the winged nutlets of birches, alders, and conifers; the sticky coating of mistletoe; the sweet berries of heaths; the wind-borne plumes of asters and milkweed; the explosive pods of jewelweed; the clinging spikes of beggar-ticks; the minute, dustlike seeds of bellflowers and orchids; and on and on. It’s a display of extraordinary beauty and purpose, but despite their elaborate structures and their adaptations to specific agents of transport, seeds are often ill fated. Long-distance dispersal, it turns out, is much like a lottery.

Though I can see where my Douglas firs might have come from— the hazy blue slopes of the La Sal Mountains rise sharply from the plateau on the distant horizon— getting seeds from there to here would have presented a problem. The valley between is broad, about twenty-five miles across, and the seed of a Douglas fir is not well equipped to travel that distance. It is winged enough to be carried beyond the shadow of its parent tree, but experimental evidence suggests that seeds are often ill fated. Long-distance dispersal, it turns out, is much like a lottery.

A black noddie tern, studded with Pisonia seeds, walks on an island near Australia’s Great Barrier Reef. Such migratory seabirds are capable of carrying seeds long distances.
successful in at least one of these places. A good way for a plant to get itself transported by an animal is to barter a nutritional reward, such as the juicy pulp of a fruit, in exchange for a lift—an evolutionary tactic that works for a great number of plant families. In most cases, however, this mode of transport seldom carries seeds very far. Except during migratory flight, the combination of an animal's limited foraging range and the usual rate of passage for food moving through its gut generally results in a seed's being defecated within a few hundred feet of where it was consumed. (Surprisingly, some carnivores provide an exception. Bears, coyotes, and pine martens, for example, frequently ingest berries when available and then move the seeds considerable distances by virtue of their large territories. Food-caching specialists, such as jays and nutcrackers, may also transport seeds a few miles, where they are often buried and not recovered.) For most plants, then, the best bet may be to sidestep the expense of nutritional enticement and just attach their seeds directly to an animal. Although propagules such as the familiar burdock and beggar-tick must still await a chance encounter with a passing animal, once affixed, the chingling seeds may be carried, undiscovered, quite far by a bird or large mammal, especially a long-distance migrant, before finally being groomed off.

Dispersal by attachment is not always a matter of design, however. While a number of seeds possess hooks, barbs, or viscid substances for a quick stick, many small seeds without special anatomical adaptations can get caught up in fur, feathers, and feet. In *Origin of Species*, Charles Darwin recounts having been sent a specimen of a red-legged partridge with considerable dried mud on its feet. He removed the mud, moistened it, placed it under a bell jar, and subsequently germinated no fewer than eighty-two seeds. The most telling tale, though, comes from Macquarie Island, some 600 miles out to sea between New Zealand and Antarctica. All of the thirty-five terrestrial plant species on Macquarie are animal dispersed, mostly via adhesive propagules. The floras of the Cocos, Galápagos, and Hawaiian Islands, too, are mostly the result of animal dispersal, although ocean drift has contributed significantly to seed arrival, with wind only a minor player.

Pondering again the origin of the three marooned Douglas firs, I recalled once seeing, on a crisp fall day, a flock of Cassin's finches dismembering ripe subalpine fir cones while a steady rain of seeds fluttered to the ground. It was not hard to imagine one of those little packets of life, encased in its own papery sail, flying on the wings of a bird to distant soil. But though the colonization of a faraway place is a momentous development for a plant species, it is also a rare outcome of seed dispersal.

The successful establishment of a single plant, let alone a plant population, in a new neighborhood is a game of formidable odds—a matter of chance events played out on a field of ever changing boundaries and conditions. Yet, as those three tall trees attest, in the seed dispersal sweepstakes, as elsewhere, small odds occasionally turn up big winners.

Remnants of a dense oak forest survive in Texas, Oklahoma, and Kansas.

By Richard V. Francaviglia

Most people heading for Lake Mineral Wells State Park, thirty miles west of Dallas/Fort Worth, Texas, are drawn by the prospect of boating, swimming, or rock climbing. Ask one of them what “Cross Timbers” means and you’re likely to get a blank stare. But a century ago, almost everyone in the area would have used that term to describe the kind of scrubby oak forest found on the east side of Lake Mineral Wells. A forested archipelago awash in a sea of prairie, the area known as the Cross Timbers once ranged from north-central Texas well into Oklahoma and as far north as southeastern Kansas. Dominated by post oak and blackjack oak, the forests followed the lay of the land, doing best in sandy soil and in the rugged sandstone uplands. Prairie grasses, on the other hand, flourished in soils derived from limestone.

The earliest historical references to the Cross Timbers come from eighteenth-century Spanish explorers, who called it the *monte grande* (great forest), a designation they based on Indian names for the conspicuous landmark. The English term “Cross Timbers” (occasionally “Cross Timber”) was in use by the 1820s, but its origin is uncertain. Some people say it arose because the forests crossed the great rivers of the region—the Brazos, Red, Washita, Canadian, and Arkansas. Others believe the reason was that the settlers had to cross through the timbered lands on their way west. Then again, post oaks are also known as cross oaks, so the name may simply derive from one of the region’s principal trees.

Early observers, such as naturalist Thomas Nuttall (1786–1859), noted the connection between the forest’s vegetation and its geology. Climate, too, has been an important influence. The Cross Timbers straddle an intermediate zone between the humid eastern part of the continent and the semiarid lands to the west, forming an outpost of eastern moist forest within the western prairies.

About 11,000 years ago, near the end of the Ice Age, the wetter, cooler climate here supported a forest comprising mainly spruce and other conifers. As the area dried out, the forest composition changed, and fires—which suppress woody vegetation—fostered the spread of grassland. Fires do occur naturally, but the people who
began to occupy the area as the climate became warmer and drier may also have played a role: hunters may have deliberately set fires to drive their prey and for other purposes, such as to encourage the growth of vegetation attractive to game.

The Cross Timbers occupied about 30,000 square miles when farmers and ranchers began to arrive in the early nineteenth century. While some of their activities, notably fire prevention and cattle grazing, promoted the growth of trees, the farming of cotton and other crops tended to work against preservation of the forests. Nonetheless, substantial portions of the Cross Timbers were left alone: as the settlers soon realized, the prairie lands were much better suited for cultivation. In addition, the post oaks and blackjack oaks made poor structural lumber—in part because they grew neither tall nor straight. As a result, they were spared the wholesale cutting that removed much of the hardwood forest in the East.

Perhaps as much as 15 percent of the original Cross Timbers survives, mostly as haphazard patches of woodlots and scrub forest scattered amid the pastures, fields, and small communities. Nearly all of it is in private hands, but the forests can still be enjoyed in a number of public places, including the 3,000-acre Lake Mineral Wells State Park, whose lake was created during the 1930s through dam construction. Here the forest occupies a ridge east of the lake—a rugged, marginal location that was never heavily used. Some of this park’s venerable post oaks may be more than 250 years old (although usually less than thirty feet tall and not more than two feet in diameter). Another good site to visit is Keystone State Park, which encompasses Keystone Lake near Tulsa, Oklahoma.

Back in 1831, while traveling through what is now Oklahoma, statesman-writer Washington Irving encountered the Cross Timbers. So tough was the going that he described the vegetation as “forests of cast iron.” Yet today large portions of the Cross Timbers have almost vanished, not only from the land but from public consciousness. Historians and ecologists, however, have begun to urge preservation of its remnants, which provide habitat for animals, protect the soil from erosion, replenish the underlying aquifer, and also contribute to our understanding of humankind’s complex relationship to nature. As private landowners come to realize that their patches of scrubby-looking forest represent a cultural heritage and a natural resource, they too may join the cause.

Richard V. Francaviglia is a professor of history at the University of Texas at Arlington, where he also directs the Center for Greater Southwestern Studies and the History of Cartography. His latest book is The Cast Iron Forest: A Natural and Cultural History of the North American Cross Timbers (University of Texas Press, 2000).

For visitor information, contact: Lake Mineral Wells State Park 100 Park Road 71 Mineral Wells, Texas 76067 (940) 328-1171 www.tpwd.state.tx.us park/lakemine/ lakemine.htm

**HABITATS**

**Cross Timbers forest** is dominated by post oak (*Quercus stellata*) and blackjack oak (*Q. marilandica*), but other trees abound, including live oak, black hickory, cedar elm, hackberry, and eastern red cedar. Along with sassafras and other bushes, the understory is often thick with vines and brambles, including catbrier, Virginia creeper, poison ivy, and raccoon grape.

**Prairie openings** contain an array of grasses, including big bluestem, Indian grass, side-oats grama, buffalo grass, and silver bluestem.

**Forest edge** habitat, especially on drier sites, often features yucca and numerous kinds of prickly pear cacti. Mesquite, though native to the area, has become more common in the last century, in part as a result of grazing.

**Streamside** vegetation is found along watercourses that have not been inundated owing to dam construction. The willows, white oaks, cottonwoods, and pecans that grow here are normally much taller than the oaks of the Cross Timbers forest.
Rings Around the Planets

Saturn’s most prominent feature is no longer a singular phenomenon.

By Richard Panek

Color-enhanced photograph of Saturn’s rings taken by the Voyager 2 spacecraft.

Saturn is the ringed planet, right? Wrong. A little over twenty years ago, it was demoted to a far less privileged position in the solar system: a ringed planet. To be precise, it is merely one of four—or possibly more—such celestial objects.

Saturn’s seemingly distinctive look has been an object of astronomical fascination since July 1610, when Galileo first observed the planet’s “triple-bodied” appearance through a telescope and tried (although unsuccessfully) to explain it (see “The Sharp-Eyed Lynx Outfoxed by Nature,” Natural History, May 1998). It wasn’t until 1659 that the Dutch astronomer Christiaan Huygens, working with better equipment and more favorable viewing conditions, finally announced a solution to the puzzle: “a thin, flat ring, nowhere touching.”

Thin, flat rings, actually, as French-Italian astronomer Jean-Dominique Cassini determined in 1675. (Thereafter, the space between the inner and outer rings was called the Cassini Division.) Having figured out that Saturn actually had rings, astronomers next asked themselves: Why rings, of all things? Specifically, are the rings of Saturn solid, or are they . . . something else?

Definitely something else, said French theoretician Pierre-Simon Laplace, who in 1785 proved mathematically that the rotation rates of solid rings would violate Kepler’s third law of planetary motion. As to what that something else might be, Laplace had a suggestion: not two rings but millions of rings, all rotating at varying rates. In 1856 the British astronomer James Clerk Maxwell refined that hypothesis, arriving at an interpretation more in keeping with the satellite pattern elsewhere evident in the solar system: not millions of rings but millions of moonlets. Indeed, American astronomer James E. Keeler validated this interpretation in 1895 through spectroscopic observation.

There the matter of planetary rings more or less rested until March 10, 1977. On that day, two groups of astronomers observed the disappearance (occultation) of a ninth-magnitude star behind Uranus. One group of astronomers, aboard an airborne observatory, noticed several spikes on the data plot just before the star vanished from view, indicating some sort of irregularity in the immediate vicinity of the planet. On a hunch, the researchers radioed the ground-based team and urged them to continue gathering data when the star reemerged from behind Uranus. Sure enough, the second group of astronomers found an identical set of spikes at the same distance from the planet. The only possible explanation was rings.

Suddenly Saturn’s centuries-old reign as the ringed planet was over. Then, visits of the Voyager 1 spacecraft to Jupiter in 1979 and of Voyager 2 to Neptune in 1989 revealed that they too had ring systems. Some astronomers have even hypothesized the presence of very thin rings around Mars as well (they’re looking). Apparently rings are...
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a common feature among planets—a realization that has only complicated astronomers’ efforts to study what rings are, where they came from, and how they work.

The rings of Saturn and Uranus appear to consist primarily of ice particles, ranging in size from mote to iceberg, while Jupiter’s seem to be rock. Neptune’s rings, however, remain a mystery. The particles that comprise the rings of these four planets might be relics from the formation of the solar system or remnants of moons that broke apart after venturing too close to the planet, or maybe of moons that suffered from violent collisions. Whatever their source, these particles have settled over the eons into a central plane, apparently stabilized by the host planet’s gravitational field.

Still, mathematicians have shown that gravity alone can’t explain why millions of particles would maintain a ring shape over time. One further possible explanation has met with great success: bodies called “shepherd moons” may gravitationally corral the particles. Predicted in 1979, they’ve since been photographed around Saturn and Uranus. But even after more extensive and precise surveys of these shepherds have been conducted, the mechanics of rings will probably remain, as one planetary specialist recently told a meeting of the American Astronomical Society, “hideously complicated.”

Despite the discoveries of the past two decades, Saturn does retain its distinction as the only planet whose rings are visible through telescopes available to the backyard astronomer. By the end of October, the planet will be nearer to Earth than at any time since February 1977. Coincidentally, the planet’s tilt will leave the rings more “open” to view than they have been in nine years. Check the eastern sky about two hours after nightfall. One look through even a modest telescope and you’ll see for yourself that even though this ringed planet may no longer be singular, it remains no less spectacular.

Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens (Penguin, 1999).

THE SKY IN OCTOBER

Mercury reaches its greatest elongation east of the Sun (25.5°) on October 6, but the acute angle made by the ecliptic and the western horizon at this time of year causes the planet to be swallowed in the bright evening twilight for most of the month. You may get a glimpse of it during the first week of October as a zero-magnitude “star” sitting about 6° below and to the right of Venus. It arrives at inferior conjunction with the Sun on October 29.

Venus sets from one and a half to two hours after sunset this month and hence will finally be visible against a completely dark sky. On the evening of October 27, Venus passes 3° north of the first-magnitude red star Antares. At magnitude −4.0, the planet appears over 100 times more dazzling than the star. The two-day-old waxing crescent Moon approaches Venus on the evening of October 29.

Mars is now rising two and a half to three hours before the Sun. By month’s end it lies 213 million miles from Earth and thus remains unusually dim—at a magnitude of 1.8 throughout the month. On the morning of the 24th, you’ll find the waning crescent Moon sitting just below and to the left of Mars.

Jupiter is visible as a brilliant starlike object (magnitude −2.7), rising on October 1 in the east-northeast about three hours after sunset. By month’s end, it can be seen high in the southern sky between midnight and dawn. On the night of October 16–17, the waning gibbous Moon forms a triangle with the planet and the reddish first-magnitude star Aldebaran. On October 21, Jupiter passes 5° north of the star, completing the second in a series of three conjunctions.

Saturn rises a couple of hours after sundown on the 1st, but by the 31st, it emerges from the horizon shortly after sunset. Through most of this month, you’ll see it as a very bright, −0.1 magnitude, yellowish-white “star” high in the southern sky between midnight and dawn. Telescopes trained on Saturn reveal its great, glimmering icy ring system. A waning gibbous Moon passes close to this ringed planet on the night of October 15–16.

The Moon is at first quarter on October 5 at 6:59 A.M. The full Moon appears on October 13 at 4:53 A.M. Last quarter is on October 20 at 3:59 A.M., and new Moon is on October 27 at 3:58 A.M.

Comet LINEAR—in case you were looking for it—broke into several smaller pieces at the end of July and disintegrated throughout the month of August.

Daylight Saving Time officially ends on October 29 at 2:00 A.M. local time, when clocks should be set back one hour to 1:00 A.M.

Unless otherwise noted, all times are given in Eastern Daylight Time.
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High and Dry

If a tree grows too tall, it may end up with broken water pipes.

Story by Carl Zimmer ~ Illustration by Sally J. Bensusen

Trees are wooden giants, towering over us puny animals. For a tree, height is often the secret to success, allowing it to get out of the shade of neighboring trees and soak up sunlight. Yet after a few decades, most trees stop ascending. Why, ecologists and botanists would like to know, are trees as tall as they are and no taller?

The question of tree size isn’t purely academic. As we pump billions of tons of carbon dioxide into the atmosphere, Earth’s climate and organisms will respond in ways we’re unable to predict with certainty. One of the unknowns is how the extra CO₂ (a crucial ingredient in photosynthesis) will affect plant growth. Will it stimulate growth and thus cause plants to draw in even more of the gas—perhaps enough to help reduce global warming? A crucial part of the equation may be just how tall trees can grow.

During photosynthesis, a tree uses the energy of the sunlight hitting its leaves to combine water, carbon dioxide, and assorted minerals in the production of carbohydrates. Water is also needed to transport nutrients, control temperature, and maintain healthy tissues. This precious liquid has to be absorbed through the tree’s roots and then carried up the trunk and branches through a system of narrow tubes known as the xylem.

Each leaf is covered with stomata, tiny pores through which CO₂ enters and water evaporates. Molecules of liquid water tend to stick together, and as water evaporates from a leaf, the remaining water “pulls” on the water below it, creating an upward movement that extends all the way down through the tree to the soil. As water moves into the leaf and out into the air, tension develops in the xylem, pulling in more water from the roots.

Although a single stoma can create only a minuscule tug on the water inside a tree, all of the stomata on all of a tree’s leaves can create a huge force capable of hauling about a hundred gallons of water a day up a large tree. And the most elegant feature of this design is that the tree doesn’t have to put any effort into its hydraulic delivery system; evaporation (prompted by solar energy) does the work instead.

But this tremendous feat of natural engineering is not risk free. Drier air sucks the water out of a tree with greater force. As evaporation pulls a column of water upward, the liquid’s molecular cohesion puts up some resistance, causing the water to stretch like a rubber band. If the force pulling up the water column is considerable, the column may snap like a rubber band as well. The result is a gap in the column, taking the form of a bubble.

Although botanists know little about this kind of bubble (it’s hard to study what goes on inside a tree trunk), they’re pretty sure it’s a problem for a tree. Unless the break is repaired, the tree will no longer be able to draw water up from the roots. Scientists are investigating this process but don’t yet understand it fully.

Having studied the sucking action of trees, biologists Barbara Bond, of Oregon State University, and Michael Ryan, with the U.S. Forest Service, believe (as do many other scientists) that prevention is part of the tree’s solution. Trees, they suggest, have developed adaptations that keep water columns from snapping. When the tension that develops as water escapes stomata exceeds a certain level, some of the leaves’ pores will simply close up, decreasing the pull of evaporation.

The risk of rupture is greater for big trees than for small ones, according to Bond and Ryan, because the columns in the big trees are longer and thus offer greater “hydraulic resistance.” (In physics, the resistance of an object increases as its length increases.) This resistance, added to the extra gravitational force acting on the water contained in tall trees, means that these taller trees require more pulling power to draw up water.

Bond and Ryan have found circumstantial evidence of this risk by watching how stomata on both short and tall trees behave. In the morning, as the air is warmed by the rising sun, its relative humidity drops, increasing the force exerted by evaporation on the leaves of trees. Eventually, trees of all sizes will close their stomata, but tall
Water enters a tree through fine roots and root hairs, travels upward through the xylem, and evaporates through tiny pores, or stomata, in the leaves (needles, in a conifer). If dry air draws water out of a tree with too much force, this water-delivery system may suddenly fail. To prevent such a disaster, trees close their stomata.

trees close theirs earlier in the day than shorter ones.

Although tall trees may gain some protection by shutting down their pores, they do have to pay a price. Closed stomata cannot draw in air. Without CO₂, photosynthesis comes to a halt, and without photosynthesis, the tree stops growing. Exactly where this trade-off occurs in the growth of a tree depends on its physiology and its environment. Bond and Ryan think it’s no coincidence, for example, that the world’s tallest living trees, the redwoods, are bathed in fog coming off the Pacific Ocean. In the moist air, they propose, these trees don’t lose water as quickly, so they can keep their pores open longer and perform more photosynthesis. But even for fog-shrouded redwoods, there is a limit. Sooner or later, every tree has to give up its quest for height in order not to die of thirst.

*Science writer Carl Zimmer’s latest book, Parasite Rex, was just published by the Free Press.*
Syphilis and the Shepherd of Atlantis

The most “poetic” statement about the dreaded plague is not an early physician’s hexameter but the modern map of the pathogen’s genome.

By Stephen Jay Gould

We usually manage to confine our appetite for mutual recrimination to merely petty or mildly amusing taunts. Among English speakers, unannounced departures (especially with bills left unpaid) or military absences without permission go by the epithet of “taking French leave.” But a Frenchman calls the same, presumably universal, human tendency filer à l’anglaise, or “taking English leave.” I learned, during an undergraduate year in England, that the condoms I had bought (for no realized purpose, alas) were “French letters” to my fellow students. In France that summer, my fellow students of another nation called the same item a chapeau anglais, or “English hat.”

But this form of pettiness can escalate to danger. Names and symbols inflame us, and wars have been fought over flags and soccer matches. Thus, when syphilis first began to ravage Europe in the 1480s or 1490s (the distinction, as we shall see, becomes crucial), a debate erupted about naming rights for this novel plague—that is, the right to name the disease for your enemies. The first major outbreak had occurred in Naples in the mid-1490s, so the plague became, for some, the Italian or the Neapolitan disease. According to one popular theory (still under debate, in fact), syphilis had arrived from the New World, brought back by Columbus’s sailors, who had pursued the usual activities in novel places—hence “the Spanish disease.”

The plague had been sufficiently acute a bit northeast of Columbus’s site of return—hence “the German disease.” In the most popular moniker of all, for this nation maintained an impressive supply of enemies, syphilis became “the French disease” (morbus Gallicus in medical treatises, then usually published in Latin), with blame cast upon the troops of the young French king, Charles VIII, who had conquered Naples, where the disease first reached epidemic proportions, in 1495. Supporters of this theory then blamed the spread through the rest of Europe on the activities of Charles’s large corps of mercenary soldiers, who, upon demobilization, fanned out to their homes all over the continent.

I first encountered this debate in a succinct summary written by Ludovico Moscardo, who described potential herbal remedies in the catalog of his museum, published in 1672: “Ne sapendo, a chi dar la colpa, li spagnuoli lo chiamorono mal Francese, li Francesi male Napolitano, e li Tedeschi, mal Spagnuolo” (not knowing whom to blame, the Spaniards call it the French disease, the French the Neapolitan disease, and the Germans the Spanish disease). Mos-
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cardo then added that other people attribute the origins of syphilis to bad airs generated by a conjunction of the three most distant planets—Mars, Jupiter, and Saturn—in the night sky.

How, then, did the new plague receive its modern name of syphilis, and what does “syphilis” mean, anyway? The peculiar and fascinating tale of the naming of syphilis can help us to understand two key principles of scholarship that may seem contradictory at first but that must be amalgamated into a coherent picture if we hope to appreciate both the theories of our forebears and the power of science to overcome past error: first, that the apparently foolish concepts of early scientists made sense in their times and can therefore teach us to respect their struggles; and second, that these older beliefs were truly erroneous and that science both progresses, in any meaningful sense of the term, and holds immense promise for human benefit through correction of error and discovery of genuine natural truths.

“Syphilis,” the proper name of a fictional shepherd, entered our language in a long poem composed in 1,300 verses of elegant Latin hexameter and published in 1530 by the greatest physician of his generation (and my second favorite character of the time, after Leonardo da Vinci)—a gentleman from Verona (also the home of Romeo and Juliet), Girolamo Fracastoro (1478–1553). Fracastoro dabbled in astronomy (he became friends with Copernicus when both studied medicine at Padua), made some crucial geological observations about the nature of fossils, wrote dense philosophical treatises and long classical poems, and held high status as the most celebrated physician of his time (in his role as papal doctor, for example, he supervised the transfer of the Council of Trent to Bologna in 1547, both to honor his holiness’s political preferences and to avoid a threatened epidemic). In short, a Renaissance man of the Renaissance itself.

My inspiration for this essay flowed from the stark contrast between Fracastoro’s christening of syphilis in 1530 and the style and substance of a 1998 paper on the genome of the bacterium that truly causes syphilis. Fracastoro could not resolve the origins of syphilis and didn’t even recognize its venereal mode of transmission. So he wrote a poem and devised a myth, naming syphilis to honor a fictional shepherd of his own invention. In greatest contrast, the sober paper published by thirty-three coauthors in Science magazine (July 17, 1998) resolves the 1,138,006 base pairs—arranged in a sequence of 1,041 genes—in the genome of Treponema pallidum, the undoubted biological cause of syphilis.

Fracastoro’s shepherd may have ended an acrimonious debate by donating his neutral name, but Fracastoro himself, as a Veronese patriot, made his own allegiances clear in the full title of his epic poem: Syphilis sive morbus Gallicus (Syphilis, or the French disease).

To epitomize some horrendous complexities of local politics: Verona had long been controlled by the more powerful neighboring city of Venice. Italy did not yet exist as a nation, and the separate kingdom of Naples maintained no formal ties to Venice. But commonalities of language and interest led the citizens of Verona to side with Naples against the invading French forces of Charles VIII, while general French designs on Italian territory prompted nearly a half century of war and strong Italian enmity, especially following Charles’s temporary occupation of Naples.

Meanwhile, Maximilian I, the Hapsburg Holy Roman Emperor (who ruled an Austrian-dominated confederation in western and central Europe, despite the name), added Spain to his extensive holdings by marrying both a son and a daughter to Spanish rulers. He also allied himself with the Pope, Venice, and Spain to drive Charles VIII out of Italy. A decade later, given the shifting alliances of realpolitik, Maximilian had made peace with France and even sought its aid to wage war on Venice. His successful campaign split Venetian holdings, and Maximilian occupied Fracastoro’s city of Verona from 1509 until 1517, when control reverted to Venice by treaty.

Fracastoro had fled the territory to escape Maximilian’s war with Venice. But he returned in 1509 and began to prosper both immediately and mightily, so I assume that his allegiances lay with Maximilian. But to shorten the tale and come to the relevant point, Maximilian (at least most of the time) controlled Spain and regarded France as his major enemy. Fracastoro, as a Veronese patriot and supporter of
Maximilian, also despised the French presence and pretensions. Fracastoro's interest therefore lay with absolving Spain for the European spread of syphilis by denying the popular theory that Columbus's men had inadvertently imported "the Spanish disease" with their other spoils from the New World. Hence, for Fracastoro, his newly christened syphilis would be called morbus Gallicus.

I can't boast nearly enough Latin to appreciate Fracastoro's literary nuances, but experts then and now have heaped praise upon his Virgilian style. Joseph Scaliger, perhaps the greatest scholar of the generation after Fracastoro's, lauded the work as "a divine poem," and Geoffrey Etough, the major translator of our time, writes that "even Fracastoro's rivals acclaimed him second only to Virgil." In this essay, I will use Nahum Tate's English version of 1686, the first complete translation ever made into any other language and a highly influential work in its own right (despite the clunkiness of Tate's heroic couplets in utterly unrelieved iambic pentameter). This version remained a standard source for English readers for more than two centuries. Tate, one of England's least celebrated poets laureate (or is it poet laureates, or even poets laureates?), wrote the libretto for Henry Purcell's short operatic jewel Dido and Aeneas. A few devout choristers may also know his texts for "While Shepherds Watched" or "As Pants the Hart." We shall pass by his once-popular adaptation of King Lear, with its happy ending in Cordelia's marriage to Edgar.

Syphilis sine morbus Gallicus includes three parts, each with its own form and purpose. Part 1 discusses origins and causes, while parts 2 and 3 narrate myths in closely parallel structure, designed to illustrate the two most popular (though, in retrospect, not particularly effective) cures. Fracastoro begins by defending his choice of morbus Gallicus as a name for the disease:
To Naples first it came
From France, and justly took
from France his name
Companion from the war . . .

He then considers the theory of New World transmission on Spanish ships and admits the tragic irony, if true:

If then by Traffick thence this plague was brought
How dearly dearly was that Traffick bought!

But Spanish shipping cannot be blamed, Fracastoro holds, because the disease appeared too quickly and in too many places, including areas that never received products from the New World, to validate a single point of origin:

To whom all Indian Traffick is unknown
Nor could th'infection from the Western Clime
Seize distant nations at the self same time.

Spain must therefore be absolved:

Nor can th'infection first be charged on Spain
That sought new worlds beyond the Western main.
Since from Pyrene's foot, to Italy
It shed its bane on France,
while Spain was free.

From whence 'tis plain this Pest must be assign'd
To some more powerful cause and hard to find.

The remainder of part 1 presents Fracastoro's general view of nature as complex and puzzling but intelligible—thence exemplifying Renaissance humanism, an attitude that tried to break through the strictures of Scholastic logical analysis to recover the presumed wisdom of classical times (“renascence” means “rebirth”) but that did not yet include the belief in the primacy of empirical documentation that would characterize the rise of modern science more than a century later. Fracastoro tells us that we must not view syphilis as divine retribution for human malfae-
sance (a popular theory at the time)—a plague that must be corrected but cannot, as a departure from nature's usual course, be comprehended.

Rather, syphilis originated by natural causes that can, in principle, be understood. But nature is far more complex and unattuned to human sensibilities than we had been willing to admit, and explanation will not come easily—for nature works in strange ways and at scales far from our easy perception. For example, Fracastoro argues, syphilis probably had no simple point of origin followed by later spread (thus absolving Spain once again). Its particles of contagion (whatever they may be) must be carried by air but may remain latent for centuries before breaking out. Thus, the plague of any moment may emerge for reasons set long before. Moreover, certain potent causes—planetary conjunctions, for example, that may send poisonous emanations to Earth—remain far from our potential observation or understanding. In any case, and on a note of hope, Fracastoro depicts plagues as comprehensible phenomena of complex nature. And just as they ravage us with sudden and unanticipated fury, the fostering conditions will change in time, and our distress shall lift:

Since nature's then so liable to change
Why should we think this late contagion strange?
The offices of nature to define
And to each cause a true effect assign
Must be a task both hard and doubtful too.

Part 2 continues the central theme of natural causation and potential alleviation, but in a very different manner. Following the traditions of Latin epic poetry, Fracastoro now constructs a myth to illustrate both the dangers of human hubris and the power of salvation through knowledge. He begins by giving the usual sage advice about alleviation via good living: lots of vigorous exercise, healthy and frugal diet, and no sex. (This regimen, addressed to males alone, proscribes sex only as a drain upon bodily energy, not as a source of infection—for Fracastoro did not yet understand the venereal transmission of syphilis.) But cure also requires pharmacological aid. Fracastoro upheld the traditional Galenic theory of humors and regarded all disease, including syphilis, as an imbalance among essential components that must be corrected by such measures as bleeding, sweating, and purging:

At first approach of Spring,
I would advise,
Or ev'n in Autumn months if strength suffice,
To bleed your patient in the regal vein,
And by degrees th'infected current drain.

Part 2 then extols the virtues of mercury as a cure in this context. Mercury can, in fact, retard the spread of

(Please turn to page 74)
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The Knuckle-Walking Wounded

In Uganda, chimpanzees are sometimes caught in poachers’ snares.

By Martin N. Muller

Climbing a steep trail in Kibale Forest National Park, I stopped briefly to listen for chimpanzees. The forest was quiet, save for the squabbling of red colobus monkeys in the valley below. Occasionally the tumult was punctuated by the shrill cry of East Africa’s ubiquitous red-chested cuckoo: *Wip wip weeoo,* “it will rain.” Clear skies contradicted the bird’s gloomy forecast as I continued up the slope toward a huge fruiting *Mimusops* tree, where there was evidence the apes had been feeding.

I discovered three of them eating the immature fruits in the tree’s spreading crown. With my binoculars, I identified middle-aged Kabarole and her twelve-year-old son, Kakama. The third individual was harder to distinguish, although she was clearly a juvenile female. “Do we have a female that has a wire snare on her right hand?” I asked Christopher Katongole, one of the Ugandan field assistants from Kibale. “No. The snare must be new,” replied Christopher, “and it’s wrapped around all four of her fingers below the knuckles.” I could also see where the thick, multistranded wire had cut her right hand, creating an open, raw wound. Suddenly she turned, and we saw that her left hand was missing at the wrist. It was Nectar.

I had come to this 300-square-mile equatorial forest in southwestern Uganda to conduct research for my doctoral dissertation on the behavior of wild chimpanzees. When I first arrived in January 1996, Nectar was a precocious and independent seven-year-old whose elfin countenance belied a rather sober disposition. Her mother, Finger, had given birth days before my arrival, so Nectar had a baby brother, Pollen, to occupy her attention. Nectar herself, however, was disabled. Nine months earlier, a poacher’s snare had caught her left hand, and although she tore free from the wooden pole to which the snare was anchored, the loop of wire remained firmly embedded in her wrist. For three months, it worked its way deeper and deeper into the flesh, causing her hand to swell, rot, and eventually fall off. A human sustaining such a ghastly wound would probably have died without medical intervention. Wild chimpanzees, though, are amazingly tough, and Nectar was tougher than most. She survived the ordeal and learned to cope with her handicap. Her stump couldn’t bear much weight, but she was able to limp through the forest on three limbs. She fed and groomed herself with her unimpaired right hand. If her right arm itched, she scratched it by rubbing against a tree.

Now, two years later, Nectar had stumbled into another snare, and the wire had already started to cut into the fingers of her right hand. As we headed back to camp with the grim news, I wondered whether she would lose this
hand too—and, without it, whether she had much chance of surviving. It seemed unlikely. To feed, she was obliged to pull branches toward her with her stump and to pluck fruit with her lips. She couldn’t use her hands to walk, so she shuffled awkwardly on two legs. It was harrowing to watch her negotiate the canopy while wobbling like a drunken tightrope walker. Removing the snare, however, would require shooting Nectar with a tranquilizer dart, a complicated and risky procedure.

Wild animals are protected throughout Uganda—not just in the national parks. So all hunting is, in fact, poaching. Most of the poachers in Kibale are subsistence farmers who cultivate maize, cassava, millet, bananas, and plantains in the fertile hills just north of the equator and east of the Ruwenzori Mountains. Few are dependent on bushmeat to feed their families, and they set snares only for bushpigs, bushbucks, and duikers. Unfortunately, the snares are just as likely to catch humans, elephants, or chimpanzees. To humans wandering in the park, snares are mere irritants (albeit alarming ones) to be untangled from one’s boot. To elephants, the other end is bowed down to a shallow, camouflaged pit, where it is connected to a loop of wire or nylon rope. When an animal steps on the camouflage, its foot lands in the pit, triggering the release of the bent pole, which causes the snare to tighten around the foot. Humans who unwittingly step into a snare are sometimes wrenched off their feet; most animals panic, pulling the wire tighter as they try to escape. Poachers may wait ten days or more before checking their traps; in the meantime some animals die.

Chimpanzees are tremendously strong and, if ensnared, generally tear the loop of wire from the pole or rip the pole from the ground. In 1996 a male chimpanzee we called Big Brown (the former alpha male in our study
group) carried a six-foot pole tucked under his arm for more than fifteen days before it separated from the wire, which to this day binds two of his fingers together. Such wires commonly stay put for months or years, invariably causing pain and regularly producing amputees like Nectar.

Since Harvard University anthropologist Richard W. Wrangham began studying Kibale's chimpanzees in 1987, he has found many of them suffering from serious snare injuries. Easygoing Yogi has lost all but two of his fingers; Kabarole, lacking her right hand, uses her stump as a club in moments of pique; aging Stocky, another former alpha male, now hopelessly craven, hobbles cautiously on a mangled hand; shy Stump is missing her right hand, and her son, Twig, his left. Another chimpanzee to join the ranks of the walking wounded was the lusty young Nile. In April 1998 I noticed a rope snare wrapped around the fingers of her left hand. One month later the snare was gone, but so were two of her fingers, and a third dangled from a thin strip of ragged rotted flesh.

The news of Nectar's misfortune was a blow to all of us involved in the Kibale Chimpanzee Project, a study focusing on the Kanyawara community of fifty or so chimpanzees. If we failed to act, Nectar's hand might wither and fall off, making it difficult if not impossible for her to walk, climb, and feed. We could hope that only one or two fingers would fall off with the snare and some functioning digits would remain. But if we darted her with a tranquilizer, we risked losing her in the dense undergrowth before the tranquilizing agent immobilized her—or she might panic, climb into the crown of a tree, and, after the drug had put her to sleep, plummet to the ground. Also, since chimpanzees are rarely alone, the others might attack us to protect their unconscious companion. But in the end, the decision was to try to remove the snare.

An antipoaching patrol in Kibale Forest National Park

The Snare Patrol

By Richard W. Wrangham

The deliberate hunting of chimpanzees is unknown in Uganda, but snares are set for antelope, pigs, and other small animals. Chimpanzees, which travel in small groups and congregate in fruiting groves, normally recognize these traps and walk around them. But sometimes, perhaps distracted by play or other social interactions, a chimpanzee will be caught. Each year, some 3.7 percent of the chimps living within the group called the Kanyawara community in Kibale Forest National Park are ensnared. Many suffer permanent damage. Of fifty-nine adult Kanyawara chimpanzees observed between 1988 and 1999, four had lost a hand, and another twelve had noticeable wounds, ranging from lost knuckles to bent wrists and crippled feet. Several others, with no signs of aging or illness, had disappeared.

In 1997, under the auspices of the Uganda Wildlife Authority, researcher Samuel Mugume, of Makerere University, conducted a study of the park. He estimated that at least 15,000 snares had been set throughout Kibale. In an effort to discourage hunters in the park from setting them altogether, four rangers (funded by the Columbus Zoo in Ohio and the Jane Goodall Institute) now patrol Kibale, receiving a bonus of thirty-three cents for each snare they collect. Since September 1997, they have removed about 2,300 snares. We hope that these efforts lead to similar programs in other parts of Uganda.

Richard W. Wrangham is a professor of biological anthropology at Harvard University and since 1987 has directed the Kibale Chimpanzee Project.

Samuel Mugume, shown here with confiscated snares, has been leading the effort to eliminate the snares in Kibale.
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The next morning, Nectar arrived at the *Minusops* tree soon after we did. With her were the adolescent male Kakama and a small group of females that included Nectar's mother, Finger. A typical chimpanzee day starts at first light, when individuals leave their nests into a dense thicket, forcing us to call off our attempt. The following day, the group had disappeared.

A month later, we came upon Nectar and two-year-old Pollen feeding by themselves in a large fig tree. Where was Finger? Pollen usually did not stray far from his mother, and Nectar was hovering close by as if anxious to keep her brother out of danger. Eventually the siblings led us into a dense thicket where Finger lay dying. She had developed a severe respiratory infection: her labored breathing was clearly audible. Pollen clung to Finger's side and buried his face in her arms.

She died that afternoon. During the night we returned, hoping to spirit Finger away while Pollen slept, but we found him still clinging to her. As our flashlights shone across his face, he looked up with a lifeless, vacant expression. Only the next morning, when he had joined Nectar to feed in the fig tree, were we able to remove his mother's corpse.

Nectar immediately adopted her baby brother, allowing him to sleep in her night nests and grooming him earnestly, if ineffectively, by rubbing her stump through his hair. When possible, she carried him, but the snare made it difficult for her to walk on her own, let alone with an infant. At times, she received help from other chimpanzees. Rosa, a self-assured female of Nectar's age, and Light Brown, a strikingly tall and good-natured male, occasionally pitched in to carry Pollen when the group traveled long distances. For the most part, though, Nectar had to care for her brother alone. Pollen was at least still climbing into the fig tree to feed. Increasingly, however, he was becoming listless and withdrawn, refusing invitations to play and grooming himself disconsolately.

With Finger gone, a major obstacle to darting Nectar had been removed, and we decided to try again. But Nectar, now responsible for her brother's safety, refused to let us approach. If we moved too close, she screamed with agitation and then melted into the undergrowth with Pollen in tow. The fig tree finally ran out of fruit, and they disappeared. We had no idea where to look for them. When Nectar turned up with a group of adult males three weeks later, Pollen was not with her. It would have been remarkable for a two-year-old chimpanzee to survive in the wild without his mother, but we couldn't help thinking that Nectar, so tough and independent, might have been able to save her little brother if she'd had just one good hand.

After Pollen disappeared, Nectar formed a special friendship with the amiable, two-fingered Yogi. The pair could often be seen traveling, resting, and grooming together, perhaps because their similar injuries caused them to lag behind the other chimpanzees. With adult males in attendance, we were reluctant to organize another darting attempt, so the snare stayed on Nectar's hand. A few weeks later she vanished, and she has not been seen since. It makes me sad thinking about her; I know that snare rarely kill quickly.

Martin N. Muller spent more than two years in East Africa completing his Ph.D. dissertation, "Endocrine Aspects of Aggression and Dominance in Wild Chimpanzees," for the University of Southern California's Department of Anthropology. He has a postdoctoral position at Harvard University.
The Vikings’ Silent Stroke

What went wrong with the Scandinavians?
The turf buildings of an eighteenth-century farmstead are preserved as Iceland's Glaumbaer Museum.

Westward expansion?

By Thomas H. McGovern and Sophia Perdikaris
early in the ninth century, adventurous Scandinavians migrated to the northern British Isles (the Shetlands and Orkneys), around Britain to the Hebrides and into the Irish Sea, and still farther west to the apparently uninhabited Faeroe Islands. By A.D. 874 Scandinavian settlers, no doubt accompanied by substantial contingents of native British Islanders, were colonizing Iceland, and in about 985, Iceland-born Erik “the Red” Thorvaldson began the settlement of Greenland, recruiting mostly other Icelanders to join him as colonists. At the turn of the millennium, as recounted in Icelandic sagas first written down 300 years later, Erik’s sons explored parts of the Canadian Arctic and the coasts of “Vinland”—probably Newfoundland and adjacent Labrador. Any doubts that the Scandinavians did indeed reach the New World were laid to rest during the 1960s, with the discovery and excavation of L’Anse aux Meadows, a site in Newfoundland that dates to about 1000.

This westward expansion across the North Atlantic took nearly two centuries to complete, with each new colony, especially in its vulnerable early years, greatly dependent upon the preceding ones for settlers, livestock, and supplies. The enterprise hinged on the Scandinavians’ excellent ships and their skill in navigating across large bodies of water, a seafaring advantage that also enabled them to plunder European shores (in addition to their westward push, Scandinavians—including Norwegians, Swedes, Danes, and Finns—penetrated south as far as the Mediterranean and east as far as the Caspian Sea). As raiders they were known as the Vikings, a term that is now loosely applied to all Scandinavian peoples of the Viking Age (ca. 800–1100) and also, sometimes, of the Middle Ages (ca. 1100–1500). The impetus for migration came from overpopulation at home as well as from increased conflict between minor aristocrats, conflict that was fueled by the new, plundered wealth.

But the chain of communities connecting mainland Scandinavia with the New World did not long survive. Archaeologists who have examined L’Anse aux Meadows in Newfoundland tell us that this settlement lasted just a few decades, perhaps only a few years. Subjected, after 1300, to increasingly cool summers and greater amounts of sea ice, the Greenland colony, numbering between 3,000 and 5,000 souls, fell on hard times and died out by about 1450. Icelandic settlements succeeded in surviving these same hard times and still worse ones that followed—including periodic volcanic eruptions and, in the first half of the eighteenth century, famine and smallpox. Still, nearly a quarter of the island’s population of 45,000 to 55,000 perished. In northwestern Europe, dismal living conditions were created by the development of commercial fishing, a harshly exploitative industry.

Where did these bright, ambitious, hard-working settlers go wrong? For an answer, we need to look beyond the Icelandic sagas and other written records—a precious but finite resource—and incorporate the testimony of pollen, soils, insect remains, human and animal bones, charcoal fragments, ice cores, and volcanic ash layers. The silent sagas contained in this archaeological, paleo-environmental, and climatic evidence—assembled by many researchers during the past two decades—tell us that part of the problem may have been the settlers’ attempt to transplant a way of life that had worked in Scandinavia but ultimately proved unsuitable to the more marginal environments and less stable climates of Iceland, Greenland, and northern North America.

Animal bones and other materials collected from archaeological sites show that in their homelands, wealthy Scandinavians had large farmsteads with dairy cattle (also a source of meat), pigs, sheep and goats (exploited for wool or hair, as well as milk and meat), and horses (used for transport). The ideal farmstead had ample pastures, fields of barley—cultivated more to make beer than bread—and was located near sealing beaches, bird cliffs (providing meat, eggs, and eiderdown), and an inshore fishery that could be exploited year-round. Fishermen used hooks and long hand lines and usually carried out their trade from rocks or on boats that did not venture over the horizon. Archaeological finds in the Orkneys show that early
Vikings successfully exported this comfortable lifestyle, based on an abundance of local resources.

At first, the settlers of southern Iceland replicated this pastoral ideal quite closely, but by the eleventh or early twelfth century, they, along with their pigs and goats, must have used up much of the forest. This may be the main reason that pigs, which need woodlands to thrive, dropped out of the archaeological record at this time, as did goats, which probably were not as efficient as sheep at turning grass into milk. The relative numbers of cattle also decline in favor of sheep, probably because cows require better quality pasture. The old expectations and practices did not die so easily, however. When Erik the Red and his contemporaries settled Greenland, they sought to establish, wherever possible, not only the modified eleventh-century Icelandic farmstead but the original Scandinavian farmstead, rich in pigs and cattle. This simply did not work over the long term.

The vegetation of the North Atlantic, dominated by Old World plants all the way from Norway to western Greenland, probably gave the early settlers a false impression that the environment was uniform throughout the region. Viking farmers arriving in Iceland from northern Norway or the Shetlands would have been encouraged by the sight of pastures with sedges and grasses and dwarf woodlands of birch and willow resembling those at home. But the colonists from Scandinavia and the British Isles had crossed critical environmental thresholds when they went from islands warmed by the North Atlantic Drift (the northern extension of the Gulf Stream) to Iceland and Greenland, where these warm waters met cold currents from the north. The colder winters and shorter growing season made the

Sheep that spent the summer in mountain pastures are herded across volcanic sands to lowland farms near Iceland's northern coast. The island's earliest Scandinavian settlers also imported cattle, pigs, and goats in an attempt to replicate the Scandinavian farmstead.
green fields they encountered more fragile. While Scandinavian pastures and woods could sustain large concentrations of cattle and pigs, these same animals helped denude the landscapes of Iceland and Greenland within a few generations. In addition, the more variable climate was in a deceptively mild mood when the Vikings first arrived; subsequently, it not only fluctuated but followed an overall cooling trend that seems not to have reversed itself until the early twentieth century.

The concealed environmental differences extended to the soils, which form at a far slower rate in both Iceland and Greenland because of the slower rate of plant growth and decomposition there. In Iceland the impact of Viking farmsteads on the land can be dated by analyzing layers of volcanic ash in soils, sediments, and ice caps. Rapid erosion occurred at many elevations after the initial settlement, probably as vegetation was consumed by livestock, turf stripped for house construction, and trees cut down for timber and fuel. Once compromised, the volcanic soil was vulnerable to wind erosion. The situation stabilized for a while, but between 1450 and 1750 additional waves of erosion started in the upland areas and moved downward.

The early Icelandic settlers apparently farmed a great deal of the island, since Viking Age archaeological sites are found at higher elevations and farther inland than any currently occupied farms. In 1998 Icelandic archaeologist Órri Vésteinsson discovered one such site, Sveigakot, in northern Iceland near Lake Mývatn, at the edge of what today, because of erosion, is a great desert of black sand and rock. Volcanic ash, carbon 14, and artifacts all date this site to the tenth century. Vésteinsson’s team has excavated substantial numbers of cattle, goat, and sheep bones and a generous collection of pig bones (which become very rare after 1000 in both Iceland and Greenland). Excavation also has turned up pieces of flattened birch bark (perhaps roof shingles) and large amounts of wood charcoal and iron smelting slag, all suggestive of forest resources long ago expended.

All in all, the early settlers—who probably anticipated that the climate would remain warm and that the grasses and trees would regrow at a rate comparable to that in Scandinavia—appear to have rapidly consumed what environmental historian William Cronon has called their “natural capital”—soils and vegetation that had built up over millennia. By the time they realized that soils and weather were less forgiving in the new land, severe and often irreversible damage had been done, and similar natural resources were lost to...
later generations. To compensate, the colonists turned increasingly to the sea.

Scandinavians had always hunted seabirds, seals, and occasionally whales, but preserved fish, especially cod and related species, was their main North Atlantic marine product. They used two principal methods of preservation. Stockfish consisted of fish that were beheaded, gutted, and air-dried at temperatures just around freezing, while for klippfish, the fish were beheaded, split open, and dried, sometimes—if the air was insufficiently cold—with salt.

Even before the ninth century, stockfish was produced in substantial amounts in northern Norway, especially around the cod spawning grounds off the Lofoten and Vesterålen Islands. Since the product had a shelf life of more than two years with no refrigeration, it was a resource that could be counted on even when the harvest failed or dairy supplies ran short. During the Viking Age, stockfish was traded to people in the south for barley and to the Saami reindeer herders in the north for furs. It could be taken along on boat voyages as a convenient, nutritious meal and was consumed on land in years when the harvest was poor or the sea uncooperative. In the hands of the Viking chieftains vying for royal authority, stockfish was not only a source of wealth but a means of ensuring status. When exchanged for barley, it permitted the brewing of the beer that made guests and dignitaries happy, secured alliances, and sanctified religious festivals.

Viking colonization of the North Atlantic may have contributed to the preserved fish trade. Sites in the Orkneys, Shetlands, and northern Scotland are particularly rich in cod and other deep-sea fishes. In Iceland preserved saltwater fish bones have been found on tenth-century inland sites such as Sveigakot. In Greenland, however, the principal marine food sources were seals and seabirds rather than fish, while walrus ivory and hide seem to have served as overseas trade goods.

By 1100, at the end of the Viking Age, Norway had been unified under one king and the nation had been Christianized through its contact with Britain. Norwegian fisheries came under the direct control of the state and local bishops, and stockfish became a major source of royal and ecclesiastical revenue. Traded all over Europe, stockfish was no longer a subsistence foodstuff and item of barter, delivered personally by a fisherman to a local strongman, but an internationally exchanged commodity, a product of standardized size, value, and quality that could be bought and sold in distant countinghouses by men who would never see the fishermen or the fish. Archaeologically, this transformation can be discerned in the fish bones found at sites in Norway and Iceland; fewer fish species are represented (because of the concentration on cod fishing), and the estimated lengths for these fish fall mostly in the range suitable for stockfish (overly large fish would start to rot before they were fully preserved, while small fish would end up hard as rocks). Headless fish turn up on inland Norwegian and Icelandic sites dating to the Viking Age, but the numbers of such fish increase during the thirteenth and fourteenth centuries, especially in the new urban settlements that provided commercial markets for all sorts of commodities.

In the process of making merchants and lords wealthy, this early globalization spawned the north-
west European fishing villages now looked upon as "traditional" settlements. Unlike the earlier farmsteads organized around a broader array of resources, these villages were founded only to provide access to fishing grounds, often on barren points or other areas with poor agricultural potential. These centers were provisioned partly by the few local farms that were still functioning but increasingly with foods imported in exchange for fish. (The discovery of Polish grain beetles at the site of Langeses, in the Lofoten Islands, shows how far Baltic grain was transported.) With commercialization, fishermen added more hooks to longer lines, and several times a day, without benefit of a reel, had to haul in as much as 300 to 500 feet of hemp, with several cod attached per yard. Most of the year-round and seasonal occupants of these new settlements were desperately poor, caught up in debt passed from one generation to the next. A great many fishermen perished at sea, especially during the brutal winter season.

This second, commercial wave of European expansion did not reach Greenland before the colony met its end. Large-scale fishing seems to have developed in Iceland during the fourteenth century, but true fishing villages did not emerge there until full-scale commercialization of fishing was imposed in the eighteenth century by Denmark, which controlled the colony. Wherever commercialization penetrated, however, its effects were similar. It brought connections to a wider world, to manufactured goods, bread, beer, and brandy—but at the price of oppressive working conditions.

By the time Columbus set sail, Greenland was dead, Iceland was struggling to survive climate change and a drawn-down natural capital of soil and vegetation, and the northern isles of Britain had been captured by the Scottish crown. Industrial fishing was sending the northern Norwegians into debt—and into early graves—and Scandinavia was dominated by Danish elites, whose cultural aspirations were influenced by the free towns of northern Germany. The North Atlantic had become a very different place from the open frontier full of possibilities that Erik the Red and his contemporaries knew—in large part owing to the unintended consequences of choices made by the early Vikings themselves.
Touchy Harvestmen

For a striped daddy longlegs, when it's time to mate, the only option is a blind date.

Story by Rogelio Macías-Orduñez
Photography by Joe Warfel

Imagine you are deaf and nearly blind and can hardly smell anything, but you have eight legs, each forty or fifty feet long. These legs are what enable you to assess your environment, detect rivals and predators, find mates, and procure food. That is the tactile perspective of most daddy longlegs, also known as harvestmen. As the British arachnologist Theodore H. Savory once stated, “The study of harvestmen is a study of legs.”

Making up the order Opiliones (which together with spiders, scorpions, mites, and other groups form the arthropod class Arachnida), daddy longlegs are creatures that people commonly encounter, both indoors and out. About 7,000 species of harvestmen have been described, and many more remain to be identified. Relatively little is known, however, about how they lead their lives. During the past seven years, I have been trying to understand the mating strategies of one of the most
share the same habitat but be active at different times of day, when the humidity and temperature fit their particular demands. Adult striped harvestmen, like adults of some other species, appear for only a few weeks during the year and then die. As is true for most species in temperate zones, they are active in late summer and early fall—hence the name “harvestman.”

The population I study, in an old quarry on the campus of Lehigh University in eastern Pennsylvania, is most active between mid-September and mid-October. During this period, males station themselves on the moss-covered, football- to beachball-size rocks on the ground, frequently remaining on these territories for days at a time. As females wander amid the surrounding leaf litter, they climb over the rocks and find the waiting males. Not until they actually come into contact

abundant species in the eastern United States, the striped harvestman (*Leiothrix rutilata*). This species can easily be recognized by the characteristic blackish stripe on its back. The females range from yellow to light brown, while the males—which are smaller and have more elongated bodies—usually are tinged reddish orange (perhaps a warning to predators that they taste bad).

Each species of daddy longlegs has its preferred environmental conditions. Several species may do a male and a female detect each other’s presence. Exactly how an individual recognizes that it has encountered a member of the opposite sex is not yet known. Characteristic anatomy and behavior may be detected through touch. The animals may also have taste or short-range odor receptors on their legs that play a role.

If a male detects a female, he pounces on her, attempts to grasp her from the front with short appendages known as pedipalps, and tries to copulate.
While other male arachnids use their pedipalps to insert sperm into the female, male daddy longlegs have true intromittent genitalia. In both sexes, the genitals are located just below the mouth, so the position for copulation is halfway between face-to-face and belly-to-belly. I've observed that females usually resist the advance and wrestle with the insistent male. It is hard for a female to escape a male's grasp, but the male needs her cooperation; mating is impossible if she does not lift up her front end.

Larger males copulate more, perhaps because they are better able to subdue reluctant females. Another possibility is that females assess male size through such wrestling matches, choosing to copulate only with larger males. In other animal species in which males have mating territories, females can generally assess and compare males before entering their domains, but a striped “harvestwoman” cannot know whether a male is nearby—much less choose one—before she touches him.

After mating, the female usually remains on the rock and lays her eggs there. She repeatedly inserts her ovipositor under the moss cover, searching for crevices in the rock where her eggs can safely spend the winter. The male follows her while she does this, keeping contact with at least one leg. He fends off any male that approaches the female. (Similar behavior, common among other species in which fertilization occurs inside the female, helps the male assure paternity.) If the male loses leg contact with the female, he walks in circles until he locates her. He is apparently unable to distinguish his recent mate from other females laying eggs, however, and will guard the first female he finds in his search.

When the female leaves the rock, the resident male remains behind, waiting for more females to arrive. Since soon afterward the first female may copulate with another male on another rock, the obvious question is, Which male's sperm will fertilize which of the female's eggs, and how is this regulated? Unfortunately, we don't yet know whether it is a matter of anatomy, physiology, behavior, or even direct competition between the sperm themselves.

Rocks are good mating territories not only because gravid females prefer them as places to lay eggs but also because these sites enable males to comfortably grasp a female and attempt to copulate. A male that encounters a female on leaf litter also will try to copulate, but if females want to avoid the advance, they typically succeed. Males can rarely achieve the balance and support there that they would get on the flat, hard surface of a rock.

When two males encounter (that is, touch) each other on a rock, they generally start fighting, but the newcomer can usually be counted on to retreat. Sometimes, given their lack of long-range perception, two males occupy and patrol the same rock without detecting each other. If two such established residents finally do touch, neither is inclined to withdraw, and the contender possessing more legs usually wins.

Most adults in the population I study are missing at least one leg, and some lack as many as four. Unlike other arachnids, daddy longlegs do not grow back missing legs. The ones they lose most frequently are from the second pair, which are much longer than the others and are used not for support but for detecting obstacles, rocks, and other harvestmen. The legs are lost mainly in struggles to escape the grasp of predators and because of problems during molting. Fights between males and sexual encounters (although energetic) rarely result in lost legs.

Although copulation and egg laying take place on the rocks, at any given time most of my striped harvestman population will be occupied elsewhere. Rocks offer scant shelter, and on rainy days, males climb a tree or retreat under a leaf. And rocks usually harbor little food, which must be searched out in the leaf litter. While some species may be better at hunting than others, most harvestmen scavenge dead plants and animals, only occasionally catching relatively easy prey, such as small caterpillars. The females I observe have larger home ranges than males do and are constantly wandering in search of food required for egg development.

**Order Opiliones**
To striped harvestmen, ground litter is a complex and unstable three-dimensional surface, and their progress over it seems difficult and slow. At their scale, the litter is constantly changing, with autumn leaves falling and drifting and the occasional squirrel walking through the accumulation and altering the topography. Therefore, harvestmen probably do not have the ability to memorize paths on the litter leading to and from a particular rock.

A harvestman uses its long, second pair of legs to sense its surroundings.

Males are more abundant than females at the beginning of the mating season, but they start to die sooner. The first frosts—which in eastern Pennsylvania normally occur during early November—finish off all the adults. Laid by the thousands, the eggs remain under the moss layers inside the rock crevices until the next spring, when they hatch. The offspring grow throughout the summer, and the new generation is ready to gather on the rocks and reproduce as autumn again approaches.
From a hatchling magpie’s first tentative squawk to a newborn baby’s cry, the care-soliciting signals of dependent offspring are the first form of communication in many species. They are also among the most ostentatious forms of communication around. Writhing broods of songbirds, necks outstretched and beaks agape, confront parents at the nest. Chinstrap penguin siblings chase their parents through crowded rookeries for a meal. Robin chicks, jockeying for preferred feeding locations in the nest, get into shoving matches. Even before hatching, when heat and not food is the resource chicks crave, embryonic white pelicans vocalize in the egg. Nor are these displays limited to birds and mammals. Tadpoles of the poisonous frog *Dendrobates pumilio* perform vigorous swim displays when their mothers check on them, and mother frogs often respond by leaving behind unfertilized eggs as food. Even insect larvae try to get adult attention; immature burying beetles gesticulate at their parents to earn a helping of regurgitated, rotten meat.

Indeed, most offspring displays seem much more extravagant than one would think necessary to elicit attention from parents already eager to protect and feed their own. Surely natural selection designed maternal brains to be responsive. The excited squeals of hungry piglets and the bleats of insistent lambs seem better designed for pestering reluctant mothers than for conveying a simple message of need. Why hasn’t evolution programmed human babies to seek parental favor with pleasant sounds and gestures—a nudge, for example, or a hushed whimper?

Back in 1974, Harvard biologist Robert Trivers (now at Rutgers University) supplied part of the answer. Trivers challenged the idea that the interests of a caretaking parent and its helpless young are essentially harmonious. He pointed out that because the offspring of almost all vertebrates share only half their genes with each parent, the stage is set for conflict. In Darwinian terms, he reasoned, each
Throughout the animal kingdom, helpless offspring have ways of demanding attention that parents can’t ignore. But all the yelling and screaming and peeping and bleating may communicate much more than mere hunger and thirst.
Favoritism: American coots, right, tend to give more food to the chick with the brightest red splotch on its forehead.

Barn swallow chicks, above, were found in one study to be better fed by parents if they had more red-orange pigment on the inside of their beaks.

That this difference has a lot to do with predators is supported by a series of imaginative experiments by ecologist David Haskell, now at the University of the South in Sewanee, Tennessee. Haskell placed clay eggs and miniature walkie-talkies in artificial nests. He then broadcast recorded begging calls of a tree-nesting species (the black-throated blue warbler) from ground-nesting ovenbird abodes and vice versa. Later, he counted rodent tooth imprints on the clay eggs. Playing the louder calls on the ground increased visits by predators there, he found, but playing the relatively soft begging calls of ovenbirds from tree nests did not. Haskell got similar results with the begging calls of cardinals, bluebirds, and catbirds. (Some researchers have suggested that the attracting of predators could actually be the point of begging. Were this the case, solicitation displays—particularly vocalizations—should be designed to maximize the risk of attracting a predator, forcing parents to immediately feed the young in order to quiet them. Haskell’s work effectively refutes this argument.)

Besides attracting predators, begging displays also take a toll on an animal’s store of energy. John McCarty, at the University of Florida in Gainesville, measured oxygen consumption in chicks and found that when they begged, their metabolic rates increased—in starlings by 8 percent over resting rates and in tree swallows by 42 percent. According to Dutch zoologists Simon Verhulst and Popko Wiersma, only between a tenth and a third of the energy a chick successfully extracts from food is available for growth, so expending just 10 percent of its total energy on begging displays could reduce a chick’s growth budget by as much as half.

Perhaps the energy costs associated with begging have acted, over the evolutionary long run, to minimize offspring’s exaggerations of their nutritional needs, so that even the healthier ones are not begging for more than they really need. Formalizing this idea in 1991 with the mathematical tools of game theory, H. Charles J. Godfray, of Imperial College in London, found that the escalations of the conflict between parents and offspring may be resolved in just such a truce. So long as the costs of increased begging mount more quickly than the benefits of extra food, Godfray showed, exaggerating need will not pay off, and offspring will beg only as much as their real needs dictate. Even though the cost of begging does not in itself always outstrip the benefits of parental feedings, a chick is
less able to turn the extra food into usable energy as its gut becomes full. The benefits of additional begging therefore decline, while the cost in calories stays the same. Since his game-theory model predicted that offspring would increase their begging rate only as their need increased, Godfray assumed that parents would distribute food among siblings according to need.

In laboratory studies of budgerigars, or “budgies” (the small Australian parakeets that make such good pets), Judy Stamps, of the University of California, Davis, found that mother budgies with access to unlimited food supplies feed their smallest, youngest offspring more than they feed the older, larger chicks. But in the natural world, food may be sharply limited, and because in many species of birds (including budgies) eggs hatch on successive days, the first chicks to emerge have an advantage over their siblings in size. According to zoologist Alex Kacelnik and several colleagues at the University of Oxford, the parent birds in two asynchronously hatching species (starlings and yellow-headed blackbirds) favor larger chicks even when needier, younger chicks beg more.

Experiments on three species of primates—vervets, macaques, and humans—also demonstrated that parents play favorites, to the benefit of healthier offspring. The more the offspring cried, the less the mother responded. In her study of maternal investment in human twins, for example, psychologist Janet Mann, of Georgetown University, found that when one twin is healthy and the other sick, the unhealthy twin has to cry longer for maternal attention and feeding than its sibling does. Clearly, the squeaky wheel does not always get the grease.

Nor does a cost-benefit analysis explain everything about offspring displays. Among American coots, for example, chicks hatch already sporting a red head splotch, and when feeding their broods, parents consistently favor offspring with the reddest

**Does each offspring in a brood beg for more than its fair share?**

**And do parents distribute to each according to its need?**

Irrational exuberance? A white pelican tries to disengage a chick from its throat after feeding.
Conspicuous attention-getting displays by young animals may be advertisements of good health, not expressions of need.

adornment. Unlike active begging, the red spot "costs" a chick no more when it's full than when it's hungry, so what could explain the existence of this silent solicitation mechanism?

One neglected possibility is that such signals, as well as ostentatious and costly displays, have evolved not as simple expressions of need but because they reveal an offspring's vigor or its weakness. That is, showy signals—whether the speed of a baby chinchirrup, the redness of a head splotch, or the loudness of a songbird's call—may actually announce to a parent that a particular offspring is healthy and worth investing in. Baldly put, if food and parental energy are limited, it may not pay for an animal parent to invest equally in all the young if some of the brood (or litter) have little chance of surviving to reproductive age. Therefore, many researchers expect to see just the sort of discriminat ng parental investment reported by Mann—behavior that favors more vigorous offspring over their less healthy sibs. And one way parents could "force" offspring to reveal how healthy they are compared with their siblings would be to refuse to invest, at least initially, until the young have performed some costly task.

For myriad reasons, some offspring are more likely than others to live to adulthood and pass along their parents' genes. An offspring's reproductive value depends both on intrinsic qualities, such as immunological health and developmental soundness, and on extrinsic factors, such as food supply. Even the healthiest offspring is unlikely to survive some environmental disasters, for example. And during dangerously lean times, a parent's best strategy for getting its genes into succeeding generations may be to "disinvest" in current offspring and to use whatever food and water are available to ensure its own survival and own future reproduction. Conversely, during a year of bumper crops, mothers and fathers may invest in even their frailest-looking daughter or son. (This presents something of a problem for studying parental investment in the lab, because captive animals are typically very well fed and do not have to partition limited food supplies among their young.)

When Spanish zoologist Javier Bustamante, of Spain's Estación Biológica de Doñana, and his fellow researchers studied chinstrap penguin feeding chases on Deception Island, off Antarctica's northern tip, they speculated that the chases were probably won by the hungrier sib, because it would be more motivated than the less hungry chick to catch up with the parents. But siblings do not always share equivalent good health, and as Bustamante's team was quick to admit, the hungrier chick may also be the weaker one, unable to catch up. Any differences in overall vigor would quickly affect the outcome of the race, with the weaker and thus needier offspring losing chase after chase and being favored with fewer and fewer feedings by parents. In such cases, greater speed does not advertise greater need.

Instead, such food chases may function primarily to reveal the vigor of an offspring to its parents. The more fleet-footed of two chinstrap penguin sibs is the fitter; being the bolder signaler, it is recognized by the parent as being more likely to survive. In fact, some displays do reveal the young's chances of growing up healthy. One well-studied solicitation signal is the cry of the human infant. A baby's vocalizations are the product of complex, integrated processes involving the brain, heart, lungs, and vocal tract, so the way they sound may reveal the health of those systems.

Indeed, some pediatricians recognize that a change in the quality of an infant's cry can be a powerful indicator of serious illness. In the first year of life, the healthy human infant cries at a fundamental frequency (the rate at which the glottis opens and closes, perceived by listeners as the pitch) between 300 and 600 Hz—in other words, somewhere near the A that symphony orchestras tune up
Infants suffering from hypoxia, metabolic diseases (such as diabetes), serious bacterial or viral infections, brain damage, malnutrition, and various chromosomal aberrations produce cries that exceed 600 Hz—the upper limit of the normal range. The pitch (as well as the variability of that pitch) of a newborn’s cry also predicts subsequent cognitive development. At age five, children whose cries at age one had shown lower and less variable pitch scored significantly higher on standardized intelligence tests than those whose cries had been high-pitched and variable. In one experiment, recorded cries with fundamental frequencies exceeding 610 Hz were rated by adult listeners as “aversive,” “grating,” and “irritating.” And in a series of field studies, developmental psychologist Ann Frodi, now of Linköping University in Sweden, found that unhealthy cries are connected with parental neglect or even abuse—behaviors that resemble other animals’ strategies of parental disinvestment.

Another offspring solicitation signal that reveals health—specifically immunologic health—is the red gape of barn swallow nestlings. Earlier this year, a team of zoologists led by Nicola Saino, of the University of Milan in Italy, reported that the carotenoid pigments that lend chicks’ mouths their bright red color are also key immune-system stimulants. When the team injected barn swallow chicks with foreign antigens, the color of the chicks’ gapes dulled as their bodies drew upon all available carotenoids to mount an immune defense. Injecting other immunostimulants in experimentally infected chicks brightened their gapes. Taken together, these experiments demonstrate that gape color is a reliable advertisement of immune status, so chicks unable to mount a vigorous response to infection advertise that fact every time they beg. Parent barn swallow in the Italian study favored nestlings with the brightest gapes—in other words, with superior health.

If the explanation of begging displays as advertisements of health is correct, then offspring signals are yet another example—like flamboyant courtship behavior or escalations of aggressive displays in territorial disputes—of signalers advertising their health and vigor to a discerning audience. The next time your newborn wakes you in the wee hours of the morning, try to remember this: she’s just reminding you she’s worth the effort.
Five hundred million years ago, trilobites looked...

*Huntonia*, above, which lived on the seafloor about 400 million years ago, could gaze forward and to the side.

the world through clear calcite glasses.

By Richard Fortey

One of the most difficult jobs I ever attempted was to count the number of lenses in a fossil trilobite eye. I had been fascinated by these long-extinct arthropods as a child and have since spent years studying them as a paleontologist. For the task at hand, I took several photographs from different angles of the eye (which was about the size of a grain of rice) and then made enormous prints that allowed me to see the individual lenses (which were microscopic). Eventually I hit upon the notion of pricking each counted lens on the photograph with a pin so that it wasn't counted twice. But when I moved on to the next photo, I would be unsure of the last lens I'd counted and how the tiny hexagons linked up from one picture to the other. Was the last lens the one with the little scratch, or that one a mite larger than its neighbor? The work was undeniably suitable for an obsessive with insomnia, but it was worth it. For trilobites have the first really well-preserved visual systems in the fossil record. Furthermore, their eyes are unique in that they are made of the mineral calcite. The trilobites have many living, if remote, arthropod relatives—and trilobites have been extinct for 250 million years—but no other has chosen the trilobite way to see the world.

Calcite is one of the most abundant minerals. The white cliffs of Dover are calcite; so are the bluffs along the Mississippi River. Surely one could expect no surprises from a substance so common and so familiar. But calcite has some unusual properties. Because of its natural inpurities it has long provided builders with colorful stone and decorative slabs. The purest examples of calcite, however, are transparent, with perfect crystal form and clarity. The chemical composition, CaCO₃, is simple as minerals go. As the crystal grows, the constituent atoms stack together in a lopsided way and do not allow other, stray atoms to intrude to cloud the crystal's mineral exactitude. The clearest calcite crystal, transparent as a toddler's motives, is Iceland spar. Look into a crystal of Iceland spar and you can see the secret of the trilobite's vision. While most other arthropods have lenses made of relatively soft, unmineralized cuticle, similar to that of the rest of their exoskeleton, trilobites used the transparency
of clear calcite as a means of transmitting light. The trilobite eye is in continuity with the rest of its shelly suite armor. It sits on top of the animal's cheek, an en suite eyeglass, tough as a clamshell.

Clear calcite is optically complex. If you break a large piece of crystalline calcite, you are left with a regular, six-sided chunk of the mineral—a rhomb—which treats light in a peculiar way. If a beam of light is shone at the sides of the rhomb, the beam splits in two, a phenomenon known as double refraction. The course of the two rays is determined, as is the shape of the rhomb, by the stacking of the individual atoms. There is one direction, and one direction only, in which light does not indulge in this optical split: when a ray of light approaches along what is termed the c axis of the crystal, it is afforded free passage. Like a VIP at an international airport, this privileged ray passes straight through. If a crystal is elongated in parallel to the c axis, into the shape of a long prism, light entering from most angles will be split and the dual rays will in turn be deflected to reach the edge of the prism and will not be "seen" by a receptor cell located at the base of the prism. But light shining along the prism's long axis will still pass unrefracted. This is how most trilobite eyes are constructed. We know that the first trilobites already had a well-developed visual system. Indeed, the large eyes found in the genus Fallotaspis, from Morocco, prove that sophisticated vision goes back at least 540 million years to the Cambrian period.

Recent laboratory work has led to the discovery of the pervasive influence of genes that control the sequence of development of the various organs as animals grow from embryo to adult. These are genes so deeply embedded in the body plans of organisms that the memory of their origin is lost far back in Precambrian history. We can never, ever, directly sample the genetic code of the trilobite, but we can be sure that its development was under the control of the same kinds of genes we recognize in living animals. Development inexorably follows a blueprint originally drawn up in the most ancient times. It is rather wonderful to imagine this distant manifesto at work on the growing trilobite, directing the brain to be enclosed within the head and, of course, issuing instructions for the growth and development of eyes.

For eyes are part of this ancient list of instructions. It seems that the making of an eye is the same impulse in fish or fly or man. Eyes are under the control of a gene called Pax6. The end product may be very different, but the instruction "Make eyes" may be common to all animals. The deep language of the genes is an Esperanto of biological design that can be understood by all creatures that have light-sensitive organs. Trilobites offer visible evidence of the halfway point in optical history. We can feel a bond with the trilobite that would not have been apparent when nineteenth-century investigators first gazed upon the animal's stony eyes. "Look into my eyes," the trilobite now seems to say, "and you will see the vestiges of your own history."

Trilobites are the only animals known to have used the optical properties of pure calcite to form clear visual images. When light enters a calcite crystal from most directions, it is refracted and creates a double image, above left. But when it enters along a particular axis, as it did in the calcite eyes of trilobites, the eye sees a single image, above right.

The number of lenses in a trilobite eye varies, according to the species, from one to several thousand.
The number of lenses in a trilobite eye varies, according to the species, from a mere one to several thousand, as in the ones I attempted to count. This eye was of the compound type and, just like a fly’s eye, was a honeycomb of hexagons. In most trilobite lenses, the c axis is exactly at right angles to the surface of the lens. If you can see the whole surface of an individual lens, then the chances are that the lens can “see” you. So you could deduce a trilobite’s field of view by summing up the angles of orientation of all the individual lenses. Thirty years ago, Euan Clarkson, of the University of Edinburgh, investigated the field of view of trilobite eyes for the first time. What he did was to mount several species of trilobites in a way that allowed him greater accuracy in measuring the c axis of each of hundreds of hexagonal lenses. Then he plotted the spread of directions of these axes to see what the trilobites saw.

Clarkson found that the trilobite eyes he examined looked sideways, forward, and often a little backward. Like searchlights sweeping over the ground and low bushes but not up to the sky, the trilobites’ eyes could be cast over the area surrounding the animal, but not upward or directly downward. Most trilobites lived on and around the seafloor, and this was the world they wished to appraise, a world on the sediment where, day or night, most of the events affecting their lives took place. Densely lensed eyes of trilobite type are particularly good at detecting movement. Another animal approaching across the sediment surface will trigger one lens after another as its image impinges on different parts of the field of view. If the change is alarming, the trilobite may be stimulated to take evasive action: perhaps to roll up into a ball or to swim away as fast as possible.

The trilobite eye grew in harmony with the animal. As in all arthropods, the eye surface had to be molted along with the rest of the hard exoskeleton. In trilobites, as the new skeleton hardened after each molt, more lenses were added and new crystals generated from a zone at the top of the eye. The animals were not able to see as we see but rather appreciated the world in a thousand fragments of light, as if the brain were a pointillist with a palette of prisms. The eyes may have permitted comprehension of the world in the same fashion as the similar compound eyes of living arthropods. Apposition eyes do not form complete images of their surroundings (some other arthropod eyes have lenses arranged in such a way that they are able to collaborate and produce a single, complex image).

But there is another kind of trilobite eye. One of the commonest trilobites in the Devonian rocks of New York, Ohio, Ontario, Germany, and Morocco is the compact animal called Phacops. Its large, crescent-shaped eyes stand prominently atop the cheeks. Instead of lenses so minute that they require a microscope to be seen properly, Phacops’s lenses can be recognized by our unaided eyes as tiny, perfectly formed balls, which line up quite conspicuously in rows. These eyes seem to have been turned out by a machine, neat as billiard balls arranged in a box. When sectioned, the eyes reveal their secrets. First, the lenses are indeed nearly spherical, or perhaps slightly drop-shaped, with a disquieting resemblance to glass eyes. Second, there is usually a little “wall” between adjacent lenses, a kind of baffle that stopped light from one lens overlapping that of the next. Often the lenses are slightly sunken, and the areas between them swollen. Clearly a very sophisticated structure (even more so than the hexagonal-lensed trilobite eye), Phacops’s crystal eye is a sports coupe in the age of the boneshaker.

In 1972 Kenneth M. Towe, of the Smithsonian Institution in Washington, D.C., demonstrated the efficiency of the Phacops kind of trilobite eyes—by taking photographs through them. The fat, biconvex lenses of the phacopid eye were designed to
bring bright beams to a focus. If you hold a clear glass marble up to the light and peer through it, you can get some idea of the process; you will see an upside-down world, all bent and distorted. But in Towe's photos, the trilobite images seem to be much clearer than that. How could this be? The problem with light traveling through a convex lens to a focus is that different rays travel different distances through the lens according to their trajectory. This means that the rays are bent to different degrees. The result is a fuzzy focus. Euan Clarkson and University of Chicago physicist Riccardo Levi-Setti discovered that something strange had happened to the calcite in the lower part of each Phacops lens: magnesium atoms were present in just the right quantity to correct the spherical aberration. For every bend to the left, there was a compensating bend to the right. This corrective layer made a bowl within the lens; the trilobite had thus manufactured what modern opticians term a doublet. The animals with these eyes may have seen more complete images of an object than their hexagonal-lensed fellows. All this 400-million years ago.

The trilobite whose lenses I started counting had the hexagonal lens design and was a particularly goggle-eyed species, with peepers puffed up like little bladders. The eyes bulged out on either side of the head in the manner of those slightly grotesque ornamental goldfish that have such a thyroidal look. I named this shrimp-sized animal Opipeteur, having recruited the help of a classicist friend to find out the Greek for “one who gazes.” The lenses of Opipeteur's eyes were tiny, but unlike those in the crescent-shaped eyes of most trilobites that lived on the seafloor, Opipeteur's lenses faced in all directions, even downward. This trilobite must have been a free swimmer rather than a bottom dweller. Ancient oceans could have swarmed with trilobites, just as krill throng in modern-day seas. These elongated trilobites were the remote ecological equivalents of shrimp, moving through the water column or even on the surface.

A number of different trilobites proved to have this free-swimming design. Fossils of one, the Cyclops-eyed Pricyclops, are common in dark Ordovician mudstones 400 million years old. These sediments were originally deposited in relatively deep water, to which these swimmers were apparently confined. Could one somehow test the difference in life habits between shallow- and deep-dwelling trilobites by examining their eyes? Tim McCormick, now at the University of Glasgow, and I, following techniques used to determine how light intensity influences the eyes of living arthropods, were able to insinuate ourselves into the daily lives of our fossil trilobites by making a series of careful measurements on eye construction. We were able to show that Pricyclops had eyes constructed in the same fashion as crustaceans that still live in the deeper part of the water column in oceans today. So it seems that trilobites were indeed able to swim at various depths.

Blind, totally eyeless trilobites have given us another indication of the range of trilobite habits and habitats. My colleague Bob Owens and I collected trilobite fossils in some localities in Wales where ten or more blind or nearly blind species lived together. They must have crawled about the seafloor in a dark world. Bottom dwellers lost their eyes not because they were degenerate but because, like living crustaceans that inhabit caves, these species simply did not need eyes in their specialized environment. Yet other trilobites in the same Welsh rocks were huge-eyed swimmers. It did not take us long to deduce that the swimmers had swum well above the lightless seafloor on which the blind animals dwelled, and had joined their sightless fellows only when they drifted to the seafloor in death and, fortunately for us, were fossilized.

"Look into my eyes," the trilobite seems to say, "and you will see the vestiges of your own history."
the syphilis spirochete, but Fracastoro interpreted its benefits only in terms of humoral rebalancing and the purging of poisons—for mercury plasters induced sweating, while ingestion encouraged copious spitting. The treatment, he admitted, may be unpleasant in the extreme, but ever so preferable to the dementia, paralysis, and death imposed by syphilis in the final stages of worst cases:

Nor let the foulness of the
course displease.
Obscene indeed, but less than
your disease.

The mass of humors now
dissolved within,
To purge themselves by spittle
shall begin,
Till you with wonder at your feet
shall see,
A tide of filth, and bless
the remedy.

Finally, Fracastoro spins his myth
about human hubris, repentance, and
the discovery of mercury. A hunter
named Ilceus kills one of Diana’s sacred
deer. Apollo, Diana’s twin brother, be-
comes royally infuriated and inflicts
the pox of syphilis upon poor Ilceus.
But the contrite hunter prays mightily
and sincerely for relief; and the goddess
Callirhoe, feeling pity, carries Ilceus
underground, far from the reach of the
sun god’s continuing wrath. There in
the realms of mineralogy, Ilceus dis-
covers the curative power of mercury.

Fracastoro wrote these first two
parts in the early 1510s and apparently
intended to publish them by them-
selves. But by the 1520s, a new (and
ultimately ineffective) “wonder cure”
had emerged, and Fracastoro therefore
added a third part to describe the new
remedy in the mythic form previously
applied to mercury—the same basic
plot, but this time with a shepherd
named Syphilis in place of the hunter
Ilceus. And thus, with thanks to read-
ers for their patience, we finally come
to Fracastoro’s reason and motives for
naming syphilis. (An excellent article
by R. A. Anselment supplied these de-
tails of Fracastoro’s composition: “Fra-
castoro’s Syphilis: Nahum Tate and the
Realms of Apollo,” Bulletin of the John
Rylands University Library of Manchester
73, 1991.)

Fracastoro’s derivation of the
name has never been fully re-
solved, but most scholars regard
Syphilis (often spelled Syphilus)
as a medieval form of Sipylus, a son of
Niobe in Ovid’s Metamorphoses—
a classical source that would have
appealed both to Fracastoro’s Renais-
sance concern for ancient wisdom and to his
abiding interest in natural change.

In part 3 of Fracastoro’s epic,
the sailors of a noble leader (un-
named, but presumably Colum-
bus) find great riches in a new
world but incur the wrath of the
sun god by kil-
ling his sacred
parrots (just as Il-
ceus had angered the same personage
by slaying Diana’s deer). Apollo
promises horrible retribution in the
form of a foul disease. But just as the
sailors fall to their knees to beg the sun
god’s forgiveness, a group of natives ar-
ries—“a race with human shape, but
black as jet,” in Tate’s translation. They,
too, suffer from syphilis and have come
to the parrots’ grove to perform an an-
annual rite that recalls the origin of their
misfortune and also permits them to
use the curative powers of local botany.

These people, we learn, are the de-
graded descendants of the race that in-
habited the lost isle of Atlantis. They
had already suffered enough in losing

Fumigating a ward of syphilis patients with mercury vapors,
Leipzig, 1689
Syphilus his name.
A thousand heifers in these vales he fed,
A thousand ewes to those fair rivers led.

This drought our Syphilus beheld with pain,
Nor could the sufferings of his flock sustain.
But to the noonday sun with upcast eyes,
In rage threw these reproaching blasphemies.

Syphilus cursed the sun, destroyed Apollo’s altars, and then decided to start a new religion based on direct worship of his local king, Alcithous. The king, in turn, heartily approved this new arrangement:

Th’aspiring prince with godlike rites o’erjoyed,
Commands all altars else to be destroyed,
Proclaims himself in earth’s low sphere to be
The only and sufficient deity.

Apollo becomes even angrier than before (for Ilceus alone had inspired his wrath in part 2), and he now inflicts the disease upon everyone—but first upon Syphilus, who thus gains eternal notoriety as name bearer:

Th’all-seeing sun no longer could sustain
These practices, but with enraged disdain
Darts forth such pestilent malignant beams,
As shed infection on air, earth and streams;
From whence this malady its birth received,
And first th’offending Syphilus was grieved.

He first wore buboes dreadful to the sight,
First felt strange pains and sleepless passed the night;
From him the malady received its name,
The neighboring shepherds caught the spreading flame:
At last in city and in court 'twas known,
And seized t'ambitious monarch on his throne.

A shepherd or two could be spared, but the suffering of kings demands surcease. The high priest therefore suggests a human sacrifice to assuage the wrath of Apollo (now given his Greek name of Phoebus), and guess whom they choose? But fortunately, the goddess Juno decides to spare the unfortunate shepherd and to make a substitution, in obvious parallel to the Biblical tale of Abraham and Isaac:

On Syphilus the dreadful lot did fall,
Who now was placed before the altar bound
His head with sacrificial garlands crowned,
His throat laid open to the lifted knife,
But interceding Juno spared his life,
Commands them in his stead a heifer slay,
For Phoebus's rage was now removed away.

Ever since then, these natives, the former inhabitants of Atlantis, perform an annual rite of sacrifice to memorialize the hubris of Syphilus and the salvation of the people by repentance. The natives still suffer from syphilis, but their annual rites of sacrifice please Juno, who in return allows a wondrous cure, the guaiacum tree, to grow on their isle alone. The Spanish sailors, now also infected with the disease, learn about the new cure and bring guaiacum back to Europe.

Thus, the imprecation heaped upon Spain by calling syphilis the Spanish disease becomes doubly unfair. Not only should the Spaniards be absolved for importation (because the disease struck Europe all at once, and from a latent contagion that originated well before any ships reached the New World), but the same Spanish sailors, encountering a longer history of infection and treatment in the New World, had discovered a truly beneficial remedy.

Many people know about the former use of mercury in treating syphilis, for the substance had some benefit and the remedy endured for centuries. But the guaiacum cure has faded to a historical footnote because, in a word, this magical New World potion flopped completely. (By 1530, the year of Fracastoro's publication, Paracelsus himself had branded guaiacum as useless.) But Fracastoro devised his myth of Syphilus during the short period of euphoria about the power of the new nostrum. The treatment failed, but the name stuck.

The syphilis organism's new genome map—1,041 genes made of 1,138,006 base pairs—is beautiful in its gloriously complex factuality.

We should not be surprised to learn that Fracastoro's attraction to guaiacum owed as much to politics as to scientific hope. The powerful Fugger family, the great German bankers, had lent vast sums to Maximilian's grandson Charles V in his successful bid to swing election as Holy Roman Emperor over his (and Fracastoro's) archenemy, Francis I of France. As partial repayment for Charles's debt, the Fuggers received a royal monopoly for importing guaiacum to Europe. (The Hapsburg Charles V also controlled Spain and, consequently, all shipping to and from Hispaniola, where the guaiacum tree grew.) In fact, the Fuggers built a chain of hospitals for the treatment of syphilis with guaiacum. Fracastoro's allegiances, for reasons previously discussed, lay with Charles V and the Spanish connection, so his tale of the shepherd Syphilus and the discovery of guaiacum suited his larger concerns as well. (Guaiacum, also known as *lignum vitae* or *lignum sanctum* ["wood of life" or "holy wood"], has some medicinal worth, although not for treating syphilis. As an extremely hard wood, of the quality of ebony, guaiacum also has value in building and decoration.)

Fracastoro did proceed beyond his politically motivated poetry to learn more about syphilis. In the later work that secured his enduring fame (but largely for the wrong reason)—his *De Contagione et Contagiosis Morbis et Curatione* (On Contagion and Contagious Diseases and Their Cure) of 1546—Fracastoro finally recognized the veneereal nature of syphilis, writing that infection occurs "verum non ex omni contactu, neque prompte, sed tum solum, quum duo corpora contactu mutuo plurimum incauissent, quod praecipue in coitu eveniebat" (truly not from all contact, nor easily, but only when two bodies join in most intense mutual contact, as primarily occurs in coitus). Fracastoro also recognized that infected mothers can pass the disease to their children, either at birth or through sucking.

Treating himself diplomatically and in the third person, Fracastoro admitted and excused the follies of his previous poem, written "*quum innocue essemus*" (when we were younger). In this later prose work, Fracastoro accurately describes both the modes of transmission and the three temporal stages of symptoms—the small, untroublesome (and often overlooked) genital sore of the primary stage; the secondary stage of lesions and aches, occurring several
months later; and the dreaded tertiary stage, developing months to years later
and leading to death by destruction of
the heart or brain (called paresis, or
paralysis accompanied by dementia) in
the worst cases.

In the hagiographical tradition still
all too common in textbook accounts
of the history of science, Fracastoro has
been called the father of the germ theo-
ry of disease for his sensitive and ac-
curate characterization, in this work,
of three styles of contagion: by direct
contact (as for syphilis), by transmis-
sion from contaminated objects, and at
a distance through transport by air.
Fracastoro discusses particles of con-
tagion called semina (seeds), but this
term, taken from ancient Greek medi-
cine, carries no connotation of an or-
ganic nature or origin. Fracastoro does
offer many speculations about the na-
ture of contagious semina, but he nev-
er mentions microorganisms, a hypothe-
sis that could scarcely be imagined
more than fifty years before the inven-
tion of the microscope.

In fact, Fracastoro continues to
argue that the infecting semina of
syphilis may arise from poisonous em-
unations sparked by planetary con-
junctions. He even invokes a linguistic
parallel between transmission of
syphilis by sexual contact (coitus) and
the production of bad seeds by plan-
etary overlap in the sky, for he describes
the astronomical phenomenon with
the same word, as “coitu et conventum
sydenum” (the coitus and conjunction
of stars), particularly “nostri trium supe-
rionum, Saturni, Iovis et Martis” (our
three most distant bodies: Saturn,
Jupiter, and Mars).

Nonetheless, we seem to need he-
reos, defined as courageous icono-
clasts who discerned germs of mod-
ern truth through strictures of an-
cient superstition—and Fracastoro
therefore wins fake accolades under
our cultural myth of prescience
(“ahead of his time”), followed by re-
jection and later rediscovery, long
after death and well beyond hope of
earthly reward. For example, the En-
cyclopedia Britannica entry on Fracas-
toro ends by proclaiming:

Fracastoro’s theory was the first
scientific statement of the true nature of
contagion, infection, disease germs,
and modes of disease transmission.
Fracastoro’s theory was widely praised
during his time, but its influence was
soon obscured by the mystical doctrines
of the Renaissance physician
Panacelsus, and it fell into general
disrepute until it was proved by Koch
and Pasteur.

But Fracastoro deserves our
warmest praise for his brilliance and
compassion within the beliefs of his
own time. We can appreciate his ge-
nius only when we understand the fea-
tures of his work that strike us as most
odd by current reckonings—par-
ticularly his choice of Latin epic poetry
as a medium for describing syphilis
and his christening of the disease for a
mythical shepherd whose suffering also
reflected Fracastoro’s political needs
and beliefs. In his article on Fracastoro
for the Dictionary of Scientific Biog-
raphy, Bruno Zanobio gives a far more ac-
curate description, properly rooted in
sixteenth-century knowledge, of Fra-
castoro’s concept of contagious seeds:

They are distinct imperceptible
particles, composed of various elements.
Spontaneously generated in the course
of certain types of putrefaction, they
present particular characteristics and
faculties, such as increasing themselves,
having their own motion, propagating
quickly, enduring for a long time, even
far from their focus of origin, [and]
exerting specific contagious activity . . . .

A good description to be sure, but
not buttressed by any hint that these
semina might be living microorgan-
isms. “Undoubtedly,” Zanobio con-
tinues, “the seminaria derive from

Splendors of
Southeast Asia

Thailand, Cambodia (Angkor Watt), Vietnam,
Hong Kong & Singapore. Luxury Eastern &
Oriental Express train from Singapore to
Bangkok through Malaysia. Cruise through
Myanmar (Burma) aboard the deluxe Oriental
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Democritean atomism via the *semina* of Lucretius and the gnostic and Neoplatonic speculations renewed by St. Augustine and St. Bonaventura.” Fracastoro, in short, remained true to his Renaissance conviction that answers must be sought in the wisdom of classical antiquity.

Fracastoro surely probed the limits of his time, but medicine, in general, made very little progress in controlling syphilis until the twentieth century. Guaiacum failed, and mercury remained both minimally effective and maximally miserable. (We need only recall Erasmus’s sardonic quip that in exchange for a night with Venus, one must spend a month with Mercury.) Moreover, since more than 50 percent of people infected with the spirochete never develop symptoms of the dreaded third stage, the disease, if left untreated, effectively “cures” itself in a majority of cases (although spirochetes remain in the body). Thus one can argue that traditional medicine usually did far more harm than good—a common situation, recalling Benjamin Franklin’s remark that although Dr. Mesmer was surely a fraud, his ministrations should be regarded as benevolent because people who followed his “cures” by inducing “animal magnetism” didn’t visit “real” physicians, thereby sparing themselves such useless and harmful remedies as bleeding and purging.

No truly effective treatment for syphilis existed until 1909, when Paul Ehrlich introduced preparation 606 (Salvarsan). Genuine (and gratifyingly easy) cures only became available in 1943, with the discovery and development of penicillin. Identification in the first stage, followed by one course of penicillin, can control syphilis, but infections that proceed to later stages may still be intractable.

I make no apologies for science’s long record of failure in treating syphilis—a history that includes both persistent, straightforward error (the poisoning and suffering of millions with ineffective remedies based upon false theories) and, on occasion, morally indefensible practices as well (most notoriously, in American history, the Tuskegee study that purposely left a group of infected black males untreated as “controls” for testing the efficacy of treatments on another group; in a moving ceremony, President Clinton recently apologized for this national disgrace to the few remaining survivors of the untreated group). But syphilis can now be controlled and may even be a good candidate for total elimination (as we have done with smallpox), at least in the United States, if not in the entire world. We owe this blessing, after so much pain, to knowledge won by science. There is no other way.

And so, while science must own its shame (along with every other institution managed by that infuriating and mercurial creature known as *Homo sapiens*), science can also find cures, or at least discover some means of relief, for human miseries caused by external agents that must remain beyond our control until their factual nature and modes of operation become known. The sequential character of this duality—failures as necessary preludes to success, given the stepwise nature of progress in scientific knowledge—leads me to contrast Fracastoro’s Latin hexameter with the stodgy prose of the 1998 *Science* article on the genome of *Treponema pallidum*, the syphilis spirochete.

The recent work boasts none of Fracastoro’s grace or charm (even in Tate’s heroic couplets)—no lovely tales about mythical shepherds who displease sun gods and no intricate pattern of dactyls and spondees. In fact, I can’t imagine a duller prose ending than the last sentence of the 1998 *Science* article, with its impersonal subject and its entirely conventional plea for forging onward to further knowledge: “A more complete understanding of the biochemistry of this organism derived from genome analysis may provide a foundation for the development of a culture medium for *T. pallidum*, which opens up the possibility of future genetic studies.” Any decent English teacher would run a big blue pencil through these words.

But consider the principal and ever so much more important difference between Fracastoro’s efforts and our own. In an article written to accompany the genomic presentation, M. E. St. Louis and J. N. Wasserheit, of the Centers for Disease Control and Prevention in Atlanta, write:

Syphilis meets all of the basic requirements for a disease susceptible to elimination. There is no animal reservoir; humans are the only host. The incubation period is usually several weeks, allowing for interruption of transmission with rapid prophylactic treatment of contacts, whereas infectiousness is limited to less than twelve months even if untreated. [Tertiary syphilis may be both dreadful and deadly, but the disease is not passed to others at this stage—S. J. G.] It can be diagnosed with inexpensive and widely available blood tests. In its infectious stage, it is treatable with a single dose of antibiotics. Antimicrobial resistance has not yet emerged.

Interestingly, Fracastoro knew that syphilis infected only humans, but he regarded this observation as a puzzle under his theory of poisonous airborne particles that might, in principle, harm all life. He discusses this anomaly at length in part 1 of *Syphilis sive morbus Gallicus*:

Sometimes th’infected air hurts trees alone,
To grass and tender flowers pernicious known.
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When earth yields store, yet oft some strange disease
Shall fall and only on poor cattle seize.

Since then by dear [in the British sense of "costly"] experiment we find
Diseases various in their rise and kind
Of this contagion let us take a view
More terrible for being strange and new.

Thus, the very phenomenon that so puzzled Fracastoro for its anomalous nature under his concept of disease becomes an important clue under the microbial theory.

Similarly, the deciphering of a genome guarantees no automatic or rapid panacea, but what better source of information could we desire for a reservoir of factual hope? Already, several features of this base-level knowledge (base-level, that is, in both the literal and the figurative sense) indicate potentially fruitful directions of research. To cite just three items that caught my attention as I read the technical article on the decipherment of \textit{T. pallidum}'s genome:

1. Several genes that promote motility—and that may help us to understand why these spirochetes become so invasive in so many tissues—have been identified and found to be virtually identical to known genes in \textit{B. burgdorferi}, the spirochete that causes Lyme disease.

2. \textit{T. pallidum}'s genome includes only a few genes coding for integral membrane proteins. This fact may help us to explain why the syphilis spirochete can be so successful in evading the human immune response. For if our antibodies can't detect \textit{T. pallidum} because the invader, so to speak, presents too "smooth" an outer surface, then our natural defenses can be crippled. But if these proteins, even though few, can be identified and characterized, then we may be able to develop specific remedies or potentiation for our own immunity.

3. \textit{T. pallidum}'s genome includes a large family of duplicated genes for membrane proteins that act as porins and adhesins—in other words, as good attachers and invaders. Again, genes that can be located and characterized become targets for study and candidates for demobilization.

Science may have needed nearly 500 years to reach its current state of hope, but we should look on the bright side of the differences between then and now. Fracastoro wrote verse and invented shepherds because he knew effectively nothing about the causes of a frightening plague whose effects could be specified and described in moving detail well suited for poetic treatment. The thirty-three modern authors, in maximal contrast, have obtained the goods for doing good. We may judge their prose as uninspired, but the greatest "poetry" ever composed about syphilis lies not in Fracastoro's hexameter of 1530 but in the intricate and healing details of a schematic map of 1,041 genes made of 1,138,006 base pairs, forming the genome of \textit{Treponema pallidum} and published with the 1998 article—the adamantine beauty of genuine and gloriously complex factuality, full of lifesaving potential. Fracastoro did his best for his time; may he be forever honored in the annals of human achievement. But the modern map embodies far more beauty, both for its factuality and utility and as Fracastoro's finest legacy in the history of increasing knowledge—a truly epic tale that we must not shy from labeling by its right and noble name of progress.

Stephen Jay Gould teaches biology, geology, and the history of science at Harvard University. He is also Frederick P. Rose Honorary Curator in Invertebrates at the American Museum of Natural History.
World traveler Everett Hoffman's stories of his adventures are filled with curious children, roving wildlife, sultry afternoons and African dictator's cronies. These days his adventurous spirit has led him to the AMNH and the research expeditions of its scientists to every continent of the globe.

In fact, he is so impressed with this facet of the Museum's mission that he has established the Everett Hoffman Endowed Fund for Research Expeditions. He recently set up this fund with a Charitable Gift Annuity and will supplement it with a future bequest.

A Gift Annuity is a way to support the Museum and provide lifetime income to one or two people. When low-yield stock is used to fund the plan, capital gains tax is avoided.

Says Mr. Hoffman, "Creating a Gift Annuity was easy, and since I don't travel myself anymore, the endowed fund is a way to send surrogate travelers in my place while helping the Museum's research mission. At the same time, I get a check every three months for my own use."

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<th>Age</th>
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<th>Income Tax Deduction</th>
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Doubling Time

Half of all research papers ever published in astrophysics have appeared in the past fifteen years.

By Neil de Grasse Tyson

Of all the sciences cultivated by mankind, astronomy is acknowledged to be, and undoubtedly is, the most sublime, the most interesting, and the most useful. For, by knowledge derived from this science, not only the bulk of the Earth is discovered... but our very faculties are enlarged with the grandeur of the ideas it conveys, our minds exalted above the low contracted prejudices of the vulgar.

Astronomy Explained Upon Sir Isaac Newton's Principles

—James Ferguson, 1757

I couldn't agree more.

James Ferguson was rejoicing in the insights to the universe that one could derive from the *Principia*, Sir Isaac Newton's seminal work published seventy years earlier. This masterpiece established a foundation for both physics and mathematics that made possible the birth of the Industrial Revolution and the modern era of cosmic discovery.

By any measure, we are living in the golden age of astronomy. The rate at which research papers are being published is the highest ever. The number of astrophysicists in the world is 50 percent greater than just a decade ago. And the power of the world's telescopes—now gathering all wavelengths of light—has allowed astronomers to see more objects at greater distances than ever before. Not a week goes by that a newspaper headline doesn't reveal a newly discovered fact or feature of the universe—and no greater nightmare disturbs the sleep of a textbook author. Decades ago, new editions of astronomy textbooks came out more often than necessary, just to short-circuit the lucrative market for used books. Now the release of new editions could be justified almost monthly, simply to keep pace with discoveries in the field.

But let's stop and think for a moment. How often do experts ever write "We hardly know anything about anything" or "Gee, I wish we weren't living in such backward times"? It seems whenever we humans talk about our knowledge of the natural world, we wax poetic about how far we've come and how much we know. Apart from Thomas Edison's famous party-pooping remark "We don't know one millionth of one percent about anything," praise for the depth and breadth of contemporary knowledge is the rule rather than the exception. The preface
to Chris Impey and William K. Hartman’s Universe Revealed, a college textbook published last year, agrees:

*Astronomy is the oldest science, but it is also tremendously active right now. Discoveries are being made by large new telescopes on high mountain tops and by sophisticated new observatories in space.*

The preface to *The System of the Stars*, a treatise on the known universe written 110 years ago by the prolific astronomy popularizer Agnes M. Clerke, makes the same case. She was sure that she was living in the golden age of discovery:

> Now, in the history of the human intellect, there is no more astonishing chapter than that concerned with the sidereal researches of the last quarter of a century.

Thirty-five years earlier, in 1855, Elias Loomis mused with similar emotion in the preface to his highly acclaimed *Introduction to Practical Astronomy*:

> The rapid advance in the cultivation of Practical Astronomy which has recently been made in the United States is one of the most encouraging features of the age.

One could analyze, decade by decade, the political, social, economic, and cultural forces that promoted cosmic discovery, but astronomy was not uniquely favored. It was simply one of many fields enjoying an explosive growth of knowledge, as noted by the editor David A. Wells in his preface to the 1852 *Annual of Scientific Discovery*:

> The progress of invention and discovery, of improvement and application, is so rapid, unceasing and continuous, that it would require a volume many times the size of the present to record, even in a summary manner, all that transpires of scientific interest in the course of a single year.

Wells was convinced he knew why:

> One fact must be apparent to all, that is, that the number of persons now engaged in contributing to the advance of every department of natural and physical science is greater than at any former period. The evidence of this is to be found in the . . . greatly increased publication and circulation of scientific books and journals.

When a field of research grows exponentially in a generation, that generation perceives itself as living in a special time. A quantitative analysis reveals this as well. Recently, while browsing the stacks of Princeton University’s astrophysics library, I paused by the wall of shelves containing the *Astrophysical Journal*, which has been around since the birth of modern astrophysics and is the leading research journal in the field. Since all the issues were on display, from the first volume in 1895 to the most recent publication, the halfway point in this record of research (at the middle of the wall) was easy to find. Taking into account the changing length and width of the *Journal’s* average page over the years, the halfway point fell among the journals dated fifteen years ago.

Yes, half of all research papers ever published in astrophysics have been published in the past fifteen years. But fifteen years ago, others strolling along the same wall could have made this identical statement. As they could fifteen years before that. And fifteen years before that, and so on. My colleagues in other sciences share similar tales:

> Are scientists today more verbose than yesterday? Are we writing more research papers just to obey the proverbial imperative to publish or perish? I think not. There have always been ver-

bose scientists, and there have always been more papers written than substance justified. One way to calibrate the rate at which important research gets published is to assess how quickly you fall behind when you don’t read the journals regularly. During my own professional career, this interval has dropped from years to months.

Gordon Moore, cofounder of the Intel Corporation, recognized as early as 1965 that the growth of the electronics industry enabled computing power (and associated advances in computer technology) to double every twelve to eighteen months. This now-famous Moore’s law for the pace of change in computing power—with its much shorter doubling time than for science in general—has held remarkably true for the past thirty-five years and shows no sign of losing its relevance to the information revolution. My first electronic mail account was up and running in 1982, back when only a few thousand scientists and engineers used this newfangled technology. Moore’s law made it inevitable that today, at least twelve doublings later, my friends and family would all be online with fresh e-mail accounts.

Our minds seem poorly equipped to grasp the consequences of exponential growth. Consider the following example. If you came upon a small lake in which a particularly fecund species of algae was doubling its population every day and you then returned after one month to find the algae covering half the lake, how much longer would you have to wait before the entire lake was carpeted with algae? Answer: one day. Exponential arithmetic such as this enables half of all the algae (at all times) to declare that they were “born yesterday” and that the population growth of their era was like none preceding it. My favorite doubling experiment is the one in which somebody gives you a penny a day, doubled, for every day of a 31-day month. That is, one cent the first day, two cents the
second day, four cents the third day, eight cents the fourth day, and so on.
How much money is your friend handing you on the last day of the month?
Answer: $10,737,418.24.

To sustain exponential growth, modern science requires, at the very least, the free exchange of ideas. Without it, science flounders. We saw this happen in the seventeenth century, when Galileo was tried and his writings were censored by the Inquisition, but it has also happened more recently. The idea that characteristics acquired during life are transferable to your offspring is traceable to one of the "laws of evolution" put forth by the eighteenth-century French biologist Lamarck. Soviet biologist T. D. Lysenko carried Lamarckian ideas into the twentieth century with the power of political authority. In 1938 Lysenko was appointed president of the Lenin All-Union Academy of Agricultural Sciences and in 1940, director of the Institute of Genetics of the Academy of Sciences of the USSR.

Big mistake.

For three decades, right up till the death of Khrushchev in 1971, Soviet biology moved backward just by standing still. Lysenkoism resonated with the political agenda of the Central Committee of the Communist Party, which officially endorsed Lysenko's view and repressed mainstream Mendelian genetics. A resolution from the USSR's Academy of Sciences soon followed, outlawing the study and teaching of Mendelian genetics altogether. Soviet agriculture suffered the most from not applying the latest techniques garnered from the world's ongoing genetic research. While Lysenkoism in Russia was being praised, first by Stalin and then by Khrushchev, biology in the rest of the world enjoyed two doublings in research and productivity, including the Nobel prize-winning discovery of the DNA molecule.

There's no crime in being wrong. Most scientists are wrong most of the time. In this case, however, the unholy mix of science and politics perverted the process of self-correction, which is so crucial to the discovery of scientific truth. Science advances quickest wherever and whenever it can stay clear of prejudice, religious dogma, and political agendas (unless, of course, the political agenda itself is the advancement of science). In Europe and the United States, these conditions have largely been met—especially in the physical sciences—since the Industrial Revolution. It's therefore no accident that both regions have become such powerful economic and industrial forces.

But not all intellectual or creative enterprises are having a golden age. While I'm no expert in the arts, and can claim no knowledge beyond what I glean from conversations at cocktail parties, I have never heard anyone claim that we live in the golden age of painting or sculpture or music or film or poetry or novel writing. For many, the golden age was far away and long ago. This rearward-looking posture may simply be the consequence of one's inability to know for sure whether new art (in any medium) will survive the ever shifting breezes of fashion, taste, and commerce. In the sciences, however, if an idea is demonstrably wrong, it will not one day be proved correct, which enables us to discard such ideas in the spirit of simply tidying up around the house.

Sometimes people look longingly rearward even when doing so is unwarranted. Consider what is widely described as the golden age of space exploration: the Mercury, Gemini, and Apollo programs of the 1960s that led to the first Moon landing in 1969. No doubt those were special times, but were they more special than today? Not really. We are now building a space station with reusable space vehicles that we launch multiple times per year. We have launched space probes that at this moment are orbiting Mars, Jupiter, and the asteroid Eros and another that is on its way to Saturn. Three of our space probes have left the solar system altogether and are now adrift in interstellar space, carrying earthlings' assorted greetings to whoever stumbles upon them. We also maintain hundreds of communications satellites (in both low and high Earth orbit) as well as a dozen space-based telescopes. Not having Moon bases and other unrealized dreamscape's doesn't mean that our presence in space has not grown exponentially.

Moore's law that computer power and speed double every twelve to eighteen months has held remarkably true.

One can rightly ask, though, how science and scientists continue to sustain an exponential pace of discovery. Back in the 1960s—the Jurassic days of computing—you wrote your scientific paper by hand. Background research required a trip to the library, where you would read anything you needed to know. You would also take copious notes, for photocopiers were not yet a common feature of the office environment. You gave the finished text to a typist, who typed it on a manual typewriter—complete with added typos. All the special mathematical characters were hand-drawn in place. Figures and diagrams were plotted by hand on graph paper and then farmed out to a graphic artist. The research paper was then mailed to the journal, with carbon copies kept for your records.

Nowadays, using the Internet, you choose keywords to search every published paper in nearly every astrophysics journal for material related to your own research. And it's done in a
minute or two. You download any or all of these papers to your laptop computer (without its getting heavier for having done so) and read them at your leisure. You observe the universe from telescopes that are controlled in real time by a user-friendly interface on your PC. Your data are plotted and formatted within seconds while you "typeset" your manuscript using simple software tools provided by the journal that is publishing your work. And you submit the paper to an online service so that your colleagues around the world can read the final draft before the next day’s morning coffee.

All exponential growth must end somewhere. It ends when our fecund algae have no lake left to take over. It ends when we reach the quantum limit to computing speeds. And of course, there cannot be more scientists than people on Earth. All true. But the end is not otherwise in sight. I cannot imagine what another half century will bring—three scientific doubling times and thirty Moore’s law doublings of computing power. If exponential growth continues to hold, the early twenty-first century will look like a primitive era in which research moved like molasses and the real potential of the infant Internet had not yet been realized.

Modern science’s golden age of discovery flows not from a particularly prodigious rate of research but from the consistency with which we have maintained the exponential growth of this research. By that measure, our golden age began with the Industrial Revolution and shows no sign of letting up. And there will be no rest for the weary textbook writers, who must continually rewrite new editions as they chase the cosmic frontier, just as they did a hundred years ago.

Neil de Grasse Tyson, an astrophysicist, is the Frederick P. Rose Director of New York City’s Hayden Planetarium and a visiting research scientist at Princeton University.
Pushing the Envelope

Scientists who study environmental extremes are looking at how organisms—including humans—adapt to such conditions.

By Steven N. Austad

People tell me that after my first (and definitely last) bungee jump into the gorge just below Victoria Falls, I appeared to be intoxicated by the experience. Not only was I giddier than usual (with relief), but for days my eyes were as bloodshot as if I had just survived the mother of all New Year’s Eve parties. Thanks to Oxford University physiologist Frances Ashcroft’s fascinating new book, *Life at the Extremes,* I now know that the small hemmorhages commonly precipitated in the eyes of bungee jumpers are caused by the great g- (for “gravitational”) forces exerted on the head as the bungee cord snaps taut during free fall. What’s more, sky divers, who are relatively more sensible than bungee jumpers, do not suffer such injuries: parachutes cause falling bodies to decelerate less abruptly, and sky divers don’t open their parachutes when their heads are below their feet.

Ashcroft describes the physiological effects of positive (toward the feet) and negative (toward the head) g-forces by outlining the complex and destructive bodily impact of orbiting Earth: after a few weeks in a space capsule, most astronauts are incapable of standing up without fainting when they first return to terra firma. The experience also induces muscle loss, anemia, cardiac irregularities, and bone thinning. After reading Ashcroft’s book, I now have little doubt that the White House had a backup speech ready in case John Glenn’s inspiring space flight at the age of seventy-seven ended less happily than it did.

Besides detailing the rigors of athletic feats and space flight, the book explores the physiological impact—on whales, birds, and bacteria as well as on us—of such extremes as plunging into oceanic depths and experiencing very high and very low temperatures. In so doing, Ashcroft explains a lot about how the human body operates under normal conditions. She also points out the engineering logic of the artificial environments we have created to preserve us as we journey to places our bodies are normally unequipped to handle.

She discusses at length, for example, the mechanics of what happens to people at high elevations, especially to mountaineers and lifelong residents of the high Andes and the Himalaya, and describes reactions that can lead to the lungs fatally filling with fluid. Equally interesting are the specific physiological changes—chiefly a fivefold to sevenfold increase in breathing rate—that allow the body to gradually acclimatize to high altitudes, thus enabling particularly hardy mountaineers to ascend Mount Everest without supplemental oxygen. She also imparts potentially useful, if not exactly reassuring, tips on what to do when your plane depressurizes; you have slightly less than thirty seconds to put on that dangling oxygen mask before you lose consciousness. In the Concorde, however, it’s probably not worth bothering with, because at the cruising altitude of that aircraft, you couldn’t survive even breathing pure oxygen. “The low barometric pressure at these altitudes,” writes Ashcroft, “means there is simply not enough room in the lungs for the necessary amount of oxygen.”

Having amassed a wealth of historical information on each topic, Ashcroft provides an endless resource for cocktail party conversationalists—and for teachers of biology such as myself. For instance, John and Charles Deane rescued some horses from a burning barn in the early nineteenth century by improvising a breathing device out of the helmet on a suit of armor “supplied with air via a hose and a hand pump.” They later patented the device for fire fighting. In 1828 the brothers came up with a diving suit, an apparatus that allowed them to open the first marine salvage business in England. Equally intriguing, the physiologist father of the great English biologist J. B. S. Haldane invented the method of staged ascent, which allows today’s scuba divers to avoid the bends. Ashcroft cites 236 feet as the world record free dive (on a single breath and without a diving suit) and 436 feet with a rock and a rocket (for rapid descent and ascent).

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in comparison with the achievements of animals specialized for living there. Elephant seals can dive to depths of almost a mile without getting the bends. The bar-headed goose does not need to acclimatize to flying over the Himalaya, even though it may have taken off from sea level earlier the same day. What differences in body design allow seals and birds to do what no unaided human can do? This book provides the answers.

But one topic it doesn’t discuss is what drives people to purposely seek out these extreme environments in the first place. In 1911, in an age when exploration was the road to fame and fortune, Roald Amundsen wanted to be (and succeeded in becoming) the first person to reach the South Pole. Yet even he concocted some scientific cover for his quest, declaring that “the main object is a scientific study of the Polar Sea itself.”

The scientist-adventurers or adventurer-scientists profiled in Peter Lane Taylor’s Science at the Extreme are modern-day Amundsens—ostensibly collecting scientific data but in reality more interested in being the big kahunas of their particular field of neck risk- ing. Suckers for these semi-suicidal tales, we get most of the thrills but none of the pain, risk, or tedium. Among the picaresque crew Taylor trailed after with his camera and pen is the blunt but swashbuckling George Irvine, director of the thirteen-year-old Woodville Karst Plain Project, whose mission is to model the subsurface hydrology of northern Florida’s underwater caves. Irvine has penetrated more than three miles into a cave 300 feet underwater on a single dive. Taylor also profiles such fellows as Giovanni Badino, a physicist who explores caves, rivers, and lakes inside and beneath some of Europe’s largest glaciers, and Craig Ferreira, a shark specialist who occasionally free swims among great whites for some (I’m sure it must be scientific) reason.

Mixing eloquent prose with breathtaking photographs of his subjects in their chosen environments, photographer and naturalist Taylor produces a book you won’t soon forget. But what happened to the cardinal rule of dare-devilry, whereby you mention your close calls only to your best friends after a few drinks late at night? This new breed of adventurer never seems to tire of reiterating how dangerous the work is, how many people have died doing it, or how good he himself is compared with the competition. No one actually beats his chest on the page, but you feel that the chest-beating happened just around the corner.

Dangers do, of course, present themselves during the pursuit of science. Ecologist Ronis Da Silveira (see “Secrets of the Flooded Forest,” Natural History, 3/00) puts radios on some of the largest and most dangerous crocodilians in South America in order to learn about their habitat requirements, and botanist Steve Sillett clammers in the crowns of redwoods so that he can study the epiphytic plants that thrive several hundred feet off the ground. There is no other way to learn these things, but the scientific discoveries that emerge from all this risk taking are barely mentioned in Taylor’s book. His emphasis is clearly on adventure. That’s enough, however, to keep this reader happy.

Steven N. Austad is a professor of zoology at the University of Idaho and the author of Why We Age: What Science Is Discovering About the Body’s Journey Through Life (John Wiley & Sons, 1997).
An Eye on the Seafloor

By Robert Anderson

Few of us will ever have a chance to visit a deep-sea ridge to witness a volcanic eruption as new oceanic crust is being formed. And since I’m slightly claustrophobic myself, the thought of descending a mile or more in a cramped submersible with tons of water pressing in all around me is not particularly inviting. But now, via the Internet, from my desk well above sea level, I can watch black chimneys spew scalding hot, mineral-laden seawater and observe tube worms and other exotic organisms colonize a submarine lava flow only a few years old.

The researchers at the Pacific Marine Environmental Laboratory of the National Oceanic and Atmospheric Administration (NOAA) (www.pmel.noaa.gov/vents) have focused on the Juan de Fuca and Gorda Ridges because of their proximity to the northwest coast of the United States. At the ridges, where two tectonic plates are moving slowly apart and molten rock erupts to fill the void, NOAA is monitoring some of the most active spots, including a feature called the Axial Volcano. This submarine mountain was the site of a large eruption in January 1998. In July of this year, as part of the New Millennium Observatory (NeMo) Project (newport.pmel.noaa.gov/nemo), a camera was set up in the volcano’s caldera to observe the growth of organisms taking advantage of the mineral-rich hydrothermal vents. While the research is rather technical, the site allows you to observe an ecosystem so remote it was not discovered until 1979, a decade after the moon landing.

Robert Anderson is a freelance science writer in Los Angeles.

BOOKSHELF

Robo sapiens: Evolution of a New Species, by Peter Menzel and Faith D’Aluisio (MIT Press, 2000; $29.95)
A photojournalist and a television news producer have compiled a field guide to more than a hundred intelligent robots.

In Her Hands: Craftswomen Changing the World, by Paola Giainturo and Toby Tittle (Monacelli Press, 2000; $60)
Women artisans speak for themselves about their lives and skills.

Encyclopedia of the Sea, by Richard Ellis (Alfred A. Knopf, 2000; $35)
Marine expert and artist Ellis reports on nearly everything about ocean life, from the argonaut (an octopus) to zooxanthellae (symbiotic dinoflagellates).

Food’s Frontier: The Next Green Revolution, by Richard Manning (North Point Press/Farrar, Straus & Giroux, 2000; $24)
Local solutions for relieving world hunger are discussed by environmental writer Manning.

The Century of the Gene, by Evelyn Fox Keller (Harvard University Press, 2000; $22.95)
“Sequence information” may not be the Rosetta stone of biological functions, cautions MIT historian of science Keller in her chronicle of the twentieth century’s achievements in molecular biology.

A Living Bay: The Underwater World of Monterey Bay, by Lovell Langstroth and Libby Langstroth (University of California Press, 2000; $60, cloth; $29.99, paper).
The array of organisms and habitats of California’s Monterey Bay is stunningly documented.

Songs, Roars, and Rituals: Communication in Birds, Mammals, and Other Animals, by Lesley J. Rogers and Gisela Kaplan (Harvard University Press, 2000; $29.95)
Two Australian scientists investigate the spectrum of animals’ sensory systems.

In what’s left of Australia’s tropical rainforest, American ecologist Laurance pursues fieldwork and conservation interests.

The books mentioned are available in the Museum Shop or through the Museum’s Web site, www.amnh.org.

PHOTOGRAPHY

Jungles, by Frans Lanting (Taschen, 2000; $39.99)
EVENTS

OCTOBER 3
7:00 P.M. Population expert Paul R. Ehrlich discusses themes from his new book, Human Natures: Genes, Cultures, and the Human Prospect.

OCTOBER 4
7:30 P.M. The Hayden Planetarium, in collaboration with the Planetary Society, inaugurates the first International Spaceweek with a panel discussion of NASA's agenda for space exploration and the extent to which it should include the search for life in the universe. For details, go to www.amnh.org/rose.

OCTOBER 5, 19, AND 26
7:00 P.M. Botanist William Schiller, of the Museum's Department of Education, lectures on the spectacle of wildflower displays in some of the world's harshest environments, in a four-part series, concluding November 2, entitled "Biodiversity and Mountain Wildflowers." The same series will be given at 2:30 p.m. on October 16, 23, and 30 and November 6.

OCTOBER 7

OCTOBER 10
7:00 P.M. Parasites, among the world's most successful, sophisticated, and numerous organisms, are the subject of a talk by Natural History columnist Carl Zimmer, author of a new book, Parasite Rex: Inside the Bizarre World of Nature's Most Dangerous Creatures.

OCTOBER 11
7:30 P.M. In the first of four lectures sponsored by the China Institute, anthropologist Myron Cohen, of Columbia University, discusses "China: The Land and People."

OCTOBER 12
7:00 P.M. Naturalist and veteran birder Kenn Kaufman extols the liberating effects of bird-watching, in his talk "Birds and the Undiscovered World."

OCTOBER 16
7:30 P.M. As part of the "Distinguished Authors in Astronomy" series, Donald W. Goldsmith, author of The Runaway Universe: The Race to Discover the Future of the Cosmos, gives a talk about our expanding universe.

OCTOBER 17 AND 24
7:00 P.M. Anthropologist Peter Gold, author of Navajo and Tibetan Sacred Wisdom: The Circle of the Spirit, discusses indigenous concepts of the sacred and their influence on daily life.

OCTOBER 20
7:00 P.M. Zorka Milich, author of A Stranger's Supper: An Oral History of Centenarian Women in Montenegro, talks about Montenegro and presents excerpts from a documentary about the country filmed by her son Mark Wallace Milich.

OCTOBER 23
7:30 P.M. As part of the "Frontiers in Astrophysics" series, astrophysicist Dara Norman, of the State University of New York, Stony Brook, gives a talk entitled "Tales of the Dark Matter: Finding the Unseen."

OCTOBER 26
7:00 P.M. Anthropologist Roy Richard Grinker speaks about the subject of his new biography, the late Colin M. Turnbull, the Museum curator and British anthropologist who studied African peoples.

DURING OCTOBER
The Museum's Department of Education presents free weekend multicultural programs, featuring Greek, Burmese, and Taino cultures, on the theme "Puppets and Drums: Arts Revived." For a schedule, call (212) 769-5315.

Students in grades seven through twelve are invited to compete for the Young Naturalist Awards 2001 on the topic "Go on an Expedition: Find Your Own Place in the Natural World!" Entry forms are available at www.amnh.org/youngnaturalistawards. The deadline is January 2, 2001.

The American Museum of Natural History is located at Central Park West and 77th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100, or visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are now also available online.
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THE NATURAL MOMENT
Bone Appétit

In the popular imagination, drawing the attention, much less the fixed stare, of a vulture is disconcerting. While the sight of an eagle swooping down for a kill evokes a kind of predatory majesty, a circling scavenger signals imminent rot. Vultures, however, are a varied tribe and have developed specialties in their role as carcass feeders. The bearded vulture (so called for the bristles sprouting from its “chin”), also known as the lammergeier (or lamb vulture, though it does not kill newborn livestock), is a large bird of eagle-elegance that soars above Eurasian mountain ranges. Its apt Spanish name—*quebrantahuesos*, or “bone breaker”—refers to its habit of carrying large bones aloft, dropping them on flat rocks, and then extracting the marrow and devouring the shards. Uneaten remnants pile up in extensive bone beds. Bearded vultures pick at dry carcasses and often wait until time and other vultures have exposed a dead animal’s skeleton before beginning their feast of bones. Photographer John Cancalosi waited for days in a blind in the Spanish Pyrenees until this bearded vulture, displaying a ruddy head and ruff, landed at the remains of a domestic sheep. The natural color of the plumage on a mature bearded vulture’s head and belly is pale, but these birds have an innate propensity to seek out and deliberately apply orange hue to themselves by rubbing in iron-oxide-rich dust and mud. Vulture researcher Antonio Margalida and colleagues speculate that the coloring, which intensifies the birds’ red eye rings, is a cosmetic symbol of status. In a stare-down between bearded vultures, the bird with the best rouge wins.—Judy Rice

Photograph by John Cancalosi
I
t was when my young teenage son and his friends started choosing horror films as a treat that I began to explore ideas about the pleasures and uses of fear. They'd lie down in a huddle in front of the video player, shrieking and squealing blissfully as they covered their eyes. Reaching out to embrace the objects of terror—and thus tame them—they were adopting a widespread human defense that can be seen in full force at Halloween.

I once arrived at the San Francisco airport on October 31 to find one ticket clerk wearing an ax through his bleeding head, while another, in full ghoul makeup, began asking me the usual security questions. Halloween guising involves conjuring objects of horror and dread, the more terrible the better. Children won't be dressing up for Halloween this year as good, polite graduates of Hogwart's, the school of magic in the popular children's books about apprentice wizard Harry Potter. Rather, they'll be playacting monsters, vampires, witches, and warlocks—creatures on the side of Harry's implacable enemy, the evil Lord Voldemort.

The ancient, seemingly instinctive game of peekaboo brings many infants their first experience of scary pleasures: the sudden appearance of a mother's eyes from behind her fingers will make a small baby gurgle with surprise. From this gentle exchange, it's a short step to the much rougher game of Boo!, which children love to play, jumping out of a hiding place and giving everyone a fright. (Startling a predator by springing out unexpectedly is also one of the most effective protective devices in nature; a butterfly's suddenly opening its wings to flash a pair of boggling painted eyes exemplifies nature's use in earnest of the Boo! effect.)

Use of this bilabial plosive, as the abrupt Boo! sound is known in phonetics, goes back at least 1420 in English and has been heard in children's games in places as different as the Middle East and North America. The sound may be related etymologically to the Sanskrit bhu, the divine command of being and generation. As the linguist J. R. Firth wittily put it, "God created the world by saying bhu."

Many words for Halloween-type specters are based on this sound: boogie, boggy, boggle-bo, bogeyman; in northern England, boggart; in Scotland, booman; bugaboo in the Isle of Man; a bucca in Cornwall, a buggane in Wales; similarly in Russia, buca; boogerman in the southern United States; in Newfoundland, boo-bagger and bully-boo.

Reptiles—both real (lizards and snakes) and fictional (dragons)—used to dominate the imagery of bogeys, but insects and other arthropods are now taking over. Scales, pro-boscises, pincers, gleaming carapaces, elaborate mouthparts, and bristling antennae from the hidden, subterranean territory of creepy-crawlies characterize the scary cast of current fantasy. In the latest Harry Potter book, the young wizard and his friends have to learn to handle vicious, scorpionlike "skrewts," while in real-life supermarkets, parents hoping to add thrills to their children's bath time can buy giant bugs encased in translucent bars of soap.

The more fragmented and incoherent it feels to inhabit the technological world (and the more sophisticated the special effects that same technology makes possible), the more terrifying are the images produced by today's monster makers. It is revealing that they often mix and shuffle elements from various species, combining the antlers of a stag beetle and the feelers of a fly, or a butterfly's proboscis and an ant's thorax, to create fantastic new hybrids. Predatory space aliens are imagined with the hugely magnified eyes of flies and wasps; the film Alien pictured the invaders as reptilian bugs hatched from a monstrous, maggoty queen ant; Men in Black imagined an apocalyptic takeover by a colossal cockroach.

With these insect connections in mind, I was intrigued recently to discover that the word "bugs" originally meant demons. The Coverdale translation of the Bible, made for Henry VIII and published in 1535, is known as the Bug Bible on account of its translation of line 5 of Psalm 91: "Thou shalt not need to be afraid of any bugges by night"—and the line doesn't refer to mosquitoes. These perils include Beelzebub, the devil who is "Lord of the Flies" (2 Kings 1:2). Children's stories, horror films, and Halloween parties, carrying on the traditional ritual combat against monsters, are once again closing the gap between "bug" meaning insect and "bug" meaning devil.

Marina Warner is a novelist and historian who writes about myths and fairytales. This essay is adapted from her most recent book, No Go the Bogeyman: Scaring, Lulling and Making Mock, published by Farrar, Straus & Giroux in 1999.
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Who's Really on First?
As the principal investigator of the Meadowcroft/Cross Creek Project since 1973 and as collaborator on the Monte Verde investigations for nearly a decade, I feel compelled to correct some of the misinformation presented in Anna Curtenius Roosevelt’s recent review, “Who’s on First?” (7/00–8/00), in which she questions the validity of virtually all sites that place humans in the Americas before about 12,000 years ago. Among other things, she confidently cites an article by Stuart Fiedel that questioned some of the artifact sources and documentation at Monte Verde. All of Fiedel’s misapprehensions have been thoroughly refuted by Thomas D. Dillehay and his colleagues on their Web site (www.uky.edu/Projects/MonteVerde).

An informed visitor to Monte Verde and/or a careful reader of the final reports would know that the stratigraphy at that site is not discontinuous; that there are many objects of indisputable human manufacture, including such items as cordage and worked wood, some of which have been directly dated; and that the radiocarbon (carbon 14) dates cluster convincingly at ca. 12,750 B.P. (before the present). The dates are not inconsistent with the age of the associated projectile points, as documented at other South American sites, and there is no evidence that the site is contaminated by bitumen or other substances that would distort the radiocarbon dates.

Roosevelt also charges that Meadowcroft Rockshelter has questionable dates as a result of contamination. Previous research by four different radiocarbon laboratories, as well as a recent micromorphological study, conclusively found no evidence of particulate or dissolved contaminants or even of a possible source of such contamination (see the Journal of Field Archaeology 26, Fall 1999).

Contrary to its listing on Roosevelt’s map, the date cited for Meadowcroft (19,100 ± 810 B.P.) is not associated with the lanceolate point that was discovered there. This item and dozens of others at the site (notably prismatic blade flakes) fall within layers bounded by radiocarbon dates of 11,300 ± 700 and 12,800 ± 870 B.P. There are seven additional earlier dates, consistently ordered within the stratigraphy, all of which are directly associated with objects of indisputable human manufacture and some of which have a margin of error (standard deviation) of as little as 165 radiocarbon years. Even if the two earliest dates are discounted, the remaining five indicate that humans were present at this site sometime between 14,555 and 13,955 B.P.

The essential facts are that the Clovis hunting culture is no longer first and that the majority consensus in the profession is very different from the reviewer’s.

J. M. Adovasio
Director
Mercyhurst Archaeological Institute
Erie, Pennsylvania

Anna Curtenius Roosevelt Replies: Contrary to what J. M. Adovasio implies, by the time Monte Verde was visited by an independent team of archaeologists, the crucial early deposits no longer could be inspected. The complex, discontinuous stratigraphy is documented in the final, two-volume site report, which also explicitly records, as possible contaminants, numerous occurrences of bitumen and volcanic ash, as well as modern pollutants (detergents, pesticides, and other chemicals derived from geological carbon). The researchers avoided dating objects with likely contaminants. The possible corral and food plants and the indisputable artifacts were not directly dated. And there is no clear connection between the two bipoints and their reputed dates, which are 2,000 to 7,000 years older than dates for similar bipoints elsewhere.

My published comments about the dating problems at the site preceded Fiedel’s critique. (Incidentally, the response to Fiedel—and Adovasio is one of the coauthors of the response—mentions bitumen.)

Regarding Meadowcroft, as a visitor to the site, I’ve observed that coal is present and thus—in the form of particles or solutes from hearth ash or groundwater—is a potential contaminant. The soil micromorphology study found weak evidence for groundwater influence but did not test for coal chemistry or contamination of samples. One test for contamination is to date solids and solutes separately; a study by Vance Haynes, which Adovasio does not acknowledge, found that Meadowcroft carbon solutes were earlier than the solids, so contamination was likely. As for the date of 19,100 ± 810 B.P. listed on my map (which included just the earliest possible dates for each site), according to Adovasio’s site reports, it is from the deepest occupational levels, in which biface fragments and possible blades were found.

While some scholars do accept Monte Verde and Meadowcroft, my point is that our reconstructions of the past should rely on sites that satisfy the standard criteria of validity.

Natural History’s e-mail address is nhmag@amnh.org.
In 1991 a gigantic marine reptile, an ichthyosaur, was discovered in the wilderness of British Columbia. Canadian-American paleontologist Elizabeth Nicholls visited the site and quickly realized that the 23-meter-long fossil skeleton was by far the largest marine reptile ever found. Nicholls has spent the last three years painstakingly excavating and studying the ichthyosaur, overcoming countless obstacles to extract the fossil from its limestone bed on a remote riverbank flooded for part of the year. This exceptional specimen, which is over 200 million years old, could open up whole new areas of knowledge of the earth's prehistory. For this initiative, Elizabeth Nicholls was selected out of more than 2,000 applicants as one of the Laureates of the Ninth Rolex Awards for Enterprise.

Details of all the winners and application forms for the Rolex Awards 2002 can be found at www.rolexawards.com
CONTRIBUTORS

Biologist Craig Packer (“When Lions Ruled France,” page 52), who teaches in the Department of Ecology, Evolution, and Behavior at the University of Minnesota, has been coordinating field studies of lions in six different reserves in South Africa for more than two decades. Since 1978 he has headed the Serengeti Lion Project, which began in 1966 and is one of the longest continuous field studies of animals. His book Into Africa (University of Chicago Press, 1994) includes an account of his work with lions. Jean Clottes, archaeologist and expert on prehistoric art, officially retired last year after a distinguished career as a conservator of France’s decorated caves. He has served as chairman of the International Committee for Rock Art and now heads the team that is conducting scientific and conservation work at Chauvet Cave in southern France. Clottes is a contributing author of Dawn of Art: The Chauvet Cave (Abrams, 1996) and wrote Le Musée des Roches: L’art rupestre dans le monde (Seuil, 2000).

Based in Kunming, the capital of China’s Yunnan province, Beijing-born Lu Yuan and her Virginia-born husband, Sam Mitchell (“Land of the Walking Marriage,” page 58), direct the China-Yunnan Study Abroad program of the School for International Training in Brattleboro, Vermont. They became interested in the Mosuo, a matrilineal people who live near Lugu Lake, while working with their students in the area. Lu, formerly a Xinhua News Agency journalist and editor of the magazine Chinese Journalist, has published numerous articles on Chinese history and culture. Mitchell, who recently received a doctorate in Asian history from the University of Hawaii, worked in India and Nepal before moving to China. Both are honorary professors at Yunnan Normal University, the base for their foreign study program.

In his new book, Promiscuity: An Evolutionary History of Sperm Competition and Sexual Conflict (Harvard University Press, 2000), Tim Birkhead (“Hidden Choices of Females,” page 66) explores the sophisticated ways in which creatures maximize their reproductive success. He became interested in the subject in the 1970s while studying the mating strategies of common murres on the Welsh island of Skomer for his doctoral dissertation. A professor of behavioral ecology at the University of Sheffield, Birkhead focuses his research on birds, from buffalo weavers in Namibia to seabirds in the Canadian Arctic, zebra finches in Australia, and feral chickens in Sweden. Magpies were the subject of his previous article in Natural History, “Britain’s Magpie Parliament” (3/94).

Louise Emmons (“Stealth Moms,” page 72), a freelance researcher with a doctorate in neurobiology and behavior, has studied and written about bats, brush-tailed porcupines, mice, ocelots, jaguars, and squirrels. With the support of the National Geographic Society, the Douroucouli Foundation, and the Chicago Zoological Society, she spent two years in the forests of Borneo, making the first detailed study (by radio tracking) of treeshrews. These enigmatic creatures are the subject of her article in this month’s Natural History. Her latest book, Tipai: A Field Study of Bornean Treeshrews, from which her article was adapted, will be published this month by the University of California Press. As this issue goes to press, Emmons is in Noel Kempff Mercado National Park in Bolivia, where she is studying the effect of climate change on mammals that inhabit the edges of rainforests and savannas.

Martin Harvey (“The Natural Moment,” page 94) worked as a guide for South African National Parks in Zimbabwe and South Africa’s Natal Parks Board before becoming a professional wildlife photographer in 1993. Traveling the world from the Arctic to Australia’s deserts, he has captured images of wildlife that have been published in National Geographic World, BBC Wildlife, and Natural History. Among his projects have been photoessays on Indian tigers and central African gorillas, commissioned by the World Wide Fund for Nature. Harvey spends six months a year in wilderness areas. Many of his photographs are available on a compact disc, African Wildlife Collection (volume 1), and others can be viewed on his Web site, www.wildlifepics.co.za/mharvey.
Destructive farming practices and the over-exploitation of timber have destroyed 90 percent of Ecuador's native forest, causing severe erosion and soil degradation. Determined to protect the remnants of indigenous forests, while at the same time improving living standards for rural people, Maria Eliza Manteca Onate has established a nature reserve near her home village in the north of the country. She has also launched a successful education program, whereby adults and children learn sustainable farming techniques at a model farm. For this initiative, Maria Eliza Manteca Onate was selected out of more than 2,000 applicants as one of the Laureates of the Ninth Rolex Awards for Enterprise.

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AT THE MUSEUM

The Road to Ancient Helike

A Museum astronomer’s scientific journey started with earthquakes and led to a significant archaeological discovery in Greece.

By Henry S. F. Cooper Jr.

Science moves in curious ways, particularly in this multidisciplinary age. Consider the part played by Museum astronomer Steven Soter in the recent discovery of what may be classical Helike, on the southern shores of Greece’s Gulf of Corinth.

Helike, a city mentioned by Homer in the Iliad, has been one of the last major puzzles of classical archaeology in Greece. In 1968 Spyridon Marinatos, director-general of antiquities for the Greek ministry of culture who had searched unsuccessfully for the city, called attention to what were then three important problems in Greek archaeology: the sites of ancient Thera, ancient Thebes, and ancient Helike. He had just found Thera, and ancient Thebes turned up beneath modern Thebes. Only Helike remained.

Soter, who also works as a geoarchaeologist (a scientist who uses geology to investigate archaeological sites) is codirector, with Greek archaeologist Dora Katsonopoulou, of the Helike Project, which sent a dozen scientists and students into the field this past August and September. On a coastal plain of the northern Peloponnese, near modern Eliki, the team unearthed what is almost certain evidence of ancient Helike, which sank beneath the gulf during a major earthquake in 373 B.C. (the discovery is to be announced near the site on October 7, as we go to press). In the course of digging four trenches, the team turned up, in addition to earlier Archaic material and later Hellenistic material, a layer containing classical pottery shards together with marine shells and what may be the remains of seaweed—possible evidence that Helike’s ruins were once beneath the sea. All this is awaiting further analysis, as is a corroded bronze coin discovered on September 12, the last day of this year’s excavations.

This past summer, the Helike Project unearthed what may be one of the ancient city’s roads.

How did a Museum astronomer get mixed up with such subterranean doings? He was studying methods of predicting earthquakes. And how did he get mixed up with earthquake prediction, normally the domain of geologists with seismometers and strain gauges?

Soter, a soft-spoken staff scientist in the Museum’s Division of Physical Sciences—Astrophysics, got his doctorate in astronomy from Cornell University in 1971 and for fifteen years was on the staff of Cornell’s Center for Radiophysics and Space Research. He worked as a research associate at the center with Thomas Gold, an astrophysicist who thinks that earthquakes are triggered by the release of gases that were incorporated into Earth during its formation and are now under enormous pressure from the overlying rock. Forcing their way up through cracks in the upper mantle, these gases can counteract the pressure that clamps Earth’s tectonic plates together. The high-pressure gas reduces the friction across a fault, allowing the shearing forces in the rock to shift the plates sideways, sometimes catastrophically. From Gold’s standpoint, it is a sudden decrease in fault strength, not a gradual increase in rock stress, that triggers an earthquake.

In the late 1970s, Gold asked Soter to study earthquake literature, with a particular eye out for precursor events that might confirm his maverick ideas. Soter found many phenomena of this kind that might be related to “outgassing,” including, for example, numerous anecdotal reports of odd animal behavior before earthquakes. Many animals are far more sensitive to smell and other physical changes than are humans, and some of their strange behavior might be a reaction to the effects of venting gas as it permeates the soil. The earliest account of such odd animal behavior comes from the Greek rhetorician Claudius Aelianius, or Aelian, writing in the second century A.D. and drawing on sources now lost. He noted that for five days before the earthquake in 373 B.C. at Helike, “all
The Tibetan system of medicine was once practiced throughout the Himalayas and beyond. Today, Ladakh in northern India is one of the few places where it remains central to community life. In the past, Amchis, or traditional doctors, provided their skills free of charge, with villagers shouldering their farming chores in return. But the introduction of conventional modern medicine and a growth in social mobility have seen that barter system fall from favor. With it, Amchi skills themselves have begun to disappear. Laurent Pordié, a young French anthropologist and ethno-pharmacologist, wants to re-establish these skills and improve health care in the region. For this initiative, Laurent Pordié was selected out of more than 2,000 applicants as one of the Laureates of the Ninth Rolex Awards for Enterprise.

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the mice and martens and snakes and centipedes and beetles and every other creature of that kind in the town left in a body by the road that leads [south] to Keryneia." According to Aelian, the people were amazed and did not know what this meant. Then the earthquake struck, and the city was submerged by the sea. Spartan warships anchored in the harbor disappeared. All that showed of Helike above water, according to Pausanias, a Greek geographer and traveler writing in the same century as Aelian, were the tops of trees from a sacred grove dedicated to Poseidon. For centuries, fishermen snagged their nets on the ruins.

In the course of his research, Soter became fascinated with the possibility of finding Helike. The coast of the Gulf of Corinth and the alluvial plain, where Helike once stood, are located in one of the most seismically active areas of Greece, at the foot of the mountains of Achaea in the northwest Peloponnese. While the mountains here are moving upward, the coastal plain is slipping downward along the roughly parallel Helike and Aigion fault lines, which slice the area as if it were a loaf of bread. Quakes occurred along these faults in 1748, 1817, 1861, 1888, and 1995. All in all, it is a good place to look for precursors.

Because of its sudden plunge, the ancient city could have been as well preserved as a shipwreck, but researchers’ efforts to locate Helike had until now proved elusive. At the urging of Spyridon Marinatos, Harold Edgerton, inventor of sonar that is capable of subbottom penetration, looked for the city in the 1960s and did not find it. Suspecting that Helike, after centuries of sedimentation and uplift, might lie buried beneath the inland alluvium, Soter and Dora Katsonopoulou, whom Soter had met at Cornell, began in 1991 to sink borings into the coastal plain. They found what appear to be buildings from the Roman period overlying material from the classical period as well as the Bronze Age and the Neolithic period.

In June of 1995, while Soter and Katsonopoulou were digging up bits of ancient pottery and brick, another earthquake—of magnitude 6.2—struck the area. Soter collected a dozen accounts of strange events preceding this temblor. Minutes before the earthquake struck at 3:15 A.M., a geophysicist from the Helike Project, working in a hotel room near the site, heard the sound of wind growing louder than any storm. But when he went outside to investigate, the trees and air were completely still. Some people told of subterranean boomings before the quake; others of strange lights in the sky, red glows, and fireballs. Local fishermen reported the appearance of large numbers of octopuses. A man driving his car near Eliki the night before the quake found dozens of dead mice on the road, all run over by cars while apparently heading south toward the mountains. A dog chained outside a house howled unaccountably every night for a week until the quake struck, then broke his chain and was not seen again after the ground nearby erupted, spewing sand and warm water high into the air. (In the same area during the 1861 earthquake, a man was killed by a similar explosive venting. A painting made afterward shows sand volcanos: mounds of sand topped with vents.)

To Soter, these accounts may be evidence of the release of gas before and during earthquakes. On windless days gas can vent with the sound of a gale; if the gas is flammable, it can ignite into fireballs from the friction of dust particles entrained with it; or it can insinuate itself into the porous soil, driving ground-dwellers out of their burrows.

Luckily, Soter was able to add to these anecdotal data actual instrumental observation of a precursor event. By chance, a few days before a 1993 quake in the nearby Bay of Patras, oceanographers at the University of Patras had been using a thermal probe to record the water temperature near the bottom, some sixty-five feet below the surface. When they looked at their data after the quake, they found that the temperature, which normally hovered at about 63°F, had shot up to 73°F in the hours before the quake. Afterward, the temperature had returned to normal. Ten days later, using side-scan sonar, the oceanographers discovered a field of craters in the seafloor surrounding the thermal probe, some hundreds of feet across and still venting gas bubbles. Such pits could be the undersea counterparts of sand volcanos on land.

Maybe people will learn to pay attention to the sound of wind on a calm day, the howling of dogs, and the appearance of octopuses and will head for the hills—just as the mice did at modern Eliki and ancient Helike alike.

Steven Soter and Dora Katsonopoulou by a Hellenistic wall excavated at Helike
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EVENTS

NOVEMBER 1, 8, 15, 22, AND 29
7:00 P.M. In conjunction with the Museum’s current live butterfly exhibition, Eric L. Quinter, senior scientific assistant in the Division of Invertebrate Zoology, presents six seminars (the last on December 12) covering many aspects of lepidopterology.

NOVEMBER 1, 15, AND 29
7:00 P.M. The concluding lectures in the “China Survey” series, cosponsored by the China Institute, are “Themes in Imperial China,” by Madeleine Zelin, director of Columbia University’s East Asian Institute; “The Arts of China,” by Maxwell K. Hearn, curator of Asian art at the Metropolitan Museum of Art; and “China in the Twentieth Century,” by Renqiu Yu, associate professor of history at SUNY Purchase.

NOVEMBER 2
7:00 P.M. William W. Fitzhugh, director of the Smithsonian Institution’s Arctic Studies Center and coeditor of the exhibition catalog Vikings: The North Atlantic Saga, discusses the history of the Norse people who made their way across the North Atlantic to America.

THE 2000 MARGARET MEAD FESTIVAL:
NOVEMBER 3–11
The twenty-fourth annual Margaret Mead Film and Video Festival features a retrospective of the work of Mira Nair (director of Salaam Bombay!). Also highlighted are the surrealistic documentaries of naturalist-filmmaker Jean Painlevé (1902–1989). The closing night film, On and Off the Rest w/ Charlie Hill, is a portrait of the Native American stand-up comic. For a program guide, call (212) 769-5305.

NOVEMBER 13
7:30 P.M. In the Space Theater, as part of the “Distinguished Authors in Astronomy” series, science writer Marcia Bartusiak gives a talk entitled “Einstein’s Unfinished Symphony: The Search for Gravity Waves.” After the lecture, Neil de Grasse Tyson, director of the Hayden Planetarium, will present a brief sky show using the Zeiss Mark IX star projector.

NOVEMBER 16
7:00 P.M. Drawing on his latest book, The Triumph of Evolution, Niles Eldredge, curator of invertebrates in the Division of Paleontology, discusses the role of organic and inorganic nature in the evolutionary process.

NOVEMBER 16 AND 30
7:00 P.M. The basic principles of geology are discussed in three sessions (the last on December 7) by geologist Sidney S. Horenstein, coordinator of environmental public programs at the Museum.

NOVEMBER 17, 20, AND 28
7:00 P.M. Scholars offer a series of lectures in conjunction with the exhibition “Vikings: The North Atlantic Saga.” The first evening’s talk, “Art and Culture of the Viking Age,” is followed on subsequent evenings by “Viking Sagas and Social History” and “Greenland Vikings.”

NOVEMBER 18

1:30 P.M. For children of all ages, folklorist Rolf Kristian Stang tells stories from the Norse saga tradition about the life of Viking leader Leif Eriksson.

NOVEMBER 19
12:30 P.M. Drawing from his book A Viking Voyage, author W. Hodding Carter describes his attempt to sail from Greenland to Newfoundland in the Snorri, a replica of a Viking ship.

NOVEMBER 21
7:00 P.M. Marine artist and writer Richard Ellis talks about the creation of his latest book, Encyclopedia of the Sea.

NOVEMBER 27
7:30 P.M. As part of the “Frontiers in Astrophysics” series, Evalyn Gates, chair of the Department of Astronomy at Chicago’s Adler Planetarium, discusses the exotic kinds of dark matter in and around our Milky Way galaxy, in a talk entitled “WIMPs, MACHOs, and Little White Dwarfs.”

NOVEMBER 30
7:00 P.M. George Plimpton and Dmitri Nabokov give a dramatic reading of correspondence between Edmund Wilson and Vladimir Nabokov, in Terry Quinn’s play Dear Bunny, Dear Volodya.

DURING NOVEMBER
The Department of Education presents free weekend multicultural programs featuring the Gullah traditions of the Sea Islands, on the theme “Puppets and Drums: Arts Revived.” For a complete schedule, call (212) 769-5315.

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IN THE FIELD

Constant competition among bull elks ensures that only the best traits are passed on to the next generation—but the system exacts an unseen toll.

Autumn’s Deep Rut

The sounds came faintly at first—ethereal chords that seemed to rise on the wind and then fall off into the valley far below. As I continued along the high trail, the strange, sporadic notes gradually resolved into a chorus of bellows, squeals, and honks. Finally, over the next ridge, the source revealed itself.

On a treeless mountainside a half mile distant, forty or more elks were milling about like so many performers waiting for curtain time, and a few would-be stars were exercising their vocal chords now and again to stay warmed up. It was late September in the San Juan Mountains of Colorado, and the rut was about to begin.

Through binoculars I watched an old patriarch with regal antlers standing passively by while three younger bulls engaged in intermittent jostling and tentative, experimental trumpeting (the word “rut” is derived from the Latin rugitus, “a roaring,” but “bugling” more aptly describes elk vocalizations). The rest of the group—cows of various ages—also seemed indifferent to the ruckus raised by the restless bulls. This indifference would be short lived,
All deer are polygamous, with males competing for females, but the manner in which each species approaches courtship has much to do with the nature of its environment. Deer that live in the dense deciduous forests of the East and coniferous forests of the North range over large areas. As the males wander, they search out females one at a time and follow them until they are receptive. The female, in essence, becomes the center of a moving territory, with the male attempting to limit her wandering and win the right to mate with her by warding off rival males. (It is to the female's advantage to incite as much competition as possible through her widespread roaming and conspicuous estrus, so that by the time she is receptive, the males will have sorted themselves out and she will breed with the most fit.)

For elks, however, the parklike forest habitat of the western United States and Canada dictates a different tactic. Females normally congregate in open areas, where group vigilance facilitates protection of the young from predators. In this situation, bulls not only have an easier time finding females but can try to monopolize several cows at once during the rut. Such harem tending is physically taxing, however, since the open terrain that makes this strategy possible also puts dominant bulls in full sight of challengers. In addition, cows may be more easily lured away by competing males and thus require the constant attention of the harem master.

Attempts by bull elks to manipulate a harem often involve clamorous activity, including the bullying of straying cows back into the group. But what appears to be a mating system based on male dominance is actually a ritual dictated by female choice, with very high stakes for the cow. A male in a polygamous system can breed somewhat indiscriminately. If he mates at all (which is not a certainty, because

however. By early October, the older male would become intolerant of the younger ones' antics and would drive them away from the cows, holding them at bay with body language that communicated hard-earned authority. The cows, too, would become attentive to the bugling males and begin to vie for a dominant position in the breeding queue.
he must first win the right to do so by outcompeting other males), he will usually mate more than once. Siring only one fit offspring is sufficient to perpetuate his genes. For the female, however, the wrong choice may be disastrous. Because she invests her yearly reproductive effort in a single pregnancy, she must be discriminating in her selection of a male. So cows in a harem are not above switching allegiance the moment a more fit bull appears on the scene.

A bull elk, then, has to continually advertise—through bugling and antler display—his own fitness in order to counter the claims of others and to attract and hold his harem. And in the rankings of elks, voice says it all. A deeper, lower pitch is indicative of larger size, which in turn means proven ability to obtain sufficient food, to successfully avoid or fend off predators, and to survive the rigors of winter. So when an elk bugles, everyone listens, males and females alike: females to assess the fitness of the bull, males to judge whether to challenge him for the right to mate. This constant testing ensures that only the best traits in the population are passed on, but the system also exacts an unseen toll.

One late October day, after observing rutting behavior in another large group of elk, I encountered a lone pair of bulls, still relatively young, with stately antlers yet obviously excluded from the local breeding activities. With no cows in sight, they were nonetheless testing their strength, head to head, in what looked much like a playful shoving match. But this apparent casualness masked the importance of the ritual. When these bulls mature, bugling and brief pushing will usually suffice to establish dominance, especially among unequal-sized contestants (mortal combat is relatively rare and generally involves the accidental locking of horns, from which the combatants cannot free themselves). To the victors go the genetic spoils, but several weeks of constant attention to philandering cows and rival bulls means little time to eat and often leads to caloric bankruptcy by the end of the rut. The early arrival of deep snow and cold weather may then spell disaster. High winter mortality, particularly among young bulls, takes its toll, leaving a strongly skewed sex ratio in elk herds. In this contest, the winner, as in the prophetic lyrics of the Grateful Dead, sometimes loses all.

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Dominating the western third of Virginia, the Allegheny and the Blue Ridge Mountains run northeast to southwest. These ranges, as well as the eight- to twenty-mile-wide valley that separates them, are part of the Appalachian Mountains. To the east lie two other geological zones: a broad plateau, known as the Piedmont, and the coastal plain. The line of demarcation between these last two zones is rather subtle. It is called the Fall Line because as streams flow across it they sometimes form waterfalls or rapids. A number of important Virginia cities—such as Arlington, Fredericksburg, Richmond, and Emporia—originally sprouted as settlements just downstream from rapids on navigable riverways. Today Interstate Highway 95, which connects these cities, roughly traces the Fall Line.

On the Piedmont side of the Fall Line and about ten miles south of downtown Richmond is Pocahontas State Park. This heavily forested, twelve-square-mile park is traversed by Swift Creek, which has been dammed to form the sinuous Swift Creek Lake. Nearby, a smaller lake was created by damming a tributary creek. It is called Beaver Lake, even though the animals were not responsible for making it. Some of the finest natural areas in the park are not easily accessible except by boat, but others are crisscrossed by hiking trails.

Several wetland habitats lie along Beaver Lake, particularly in some of the lake’s shallow necks. Dense stands of the ten-foot-tall soft-stem bulrush grow in a few places. Its name notwithstanding, this species is not a rush but a type of sedge. While most sedges possess triangular stems, its stem is round in cross section. Air spaces inside the stem cause it to crush easily when gently pinched.

Low areas bordering Swift Creek, its tributaries, and Swift Creek Lake support bottomland forests with broad-leaved trees and abundant wildflowers. Somewhat of a surprise here is the occasional winged elm, a tree usually found in very dry habitats. In dry, barren soil the elms are stunted, but in this bottomland they may top off at a good fifty feet. Upslope, the bottomland forests gradually merge into mesic, or moist, forest, and on the ridgetops, where exposure to the sun...
is greatest, is a dry forest with a preponderance of loblolly pines. A common grass on the ridges is curly grass, whose previous year's leaves curl up at the plant's base.

In some spots the loblolly pines, towering up to eighty-five feet tall, grow in stands so dense that little other vegetation can survive in the acidic soil beneath them (the accumulation of pine needles causes the acidity). One exception is ground pine, which often carpets areas of several square feet. Despite its name, this evergreen is not a pine but a spore-bearing plant related to ferns.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

For visitor information, contact: Pocahontas State Park 10301 State Park Road Chesterfield, VA 23838 (804) 796-4255 www.state.va.us/~der/parks/pocahont.htm

HABITATS

Wetland communities include, in addition to stands of soft-stem bulrush, very marshy areas with water plantain and broad-leaved arrowhead, two closely related species whose flowers have three white petals. In summer, two kinds of jewelweeds, or touch-me-nots, bloom in the marshes, one with orange flowers and the other with pale yellow ones. When the fruit is ripe, it explodes at the lightest touch, catapulting the seeds several feet away from the parent plant. The clear, sticky sap in jewelweed stems often brings soothing relief to the itch of poison ivy and the burning sensation of stinging nettle.

Bottomland forest contains swamp chestnut oak, a massive tree that may grow seventy-five feet tall and attain a girth of more than three feet. The most common tree, however, is sweet gum. Willow oak, with its narrow toothless leaves, and winged elm also grow here.

Mesic forest has American beech, white ash, bitternut hickory, basswood, and red mulberry. Shorter trees are eastern redbud, flowering dogwood, American hornbeam, and eastern hop hornbeam. Common beneath the canopy are pawpaw, with its fleshy yellow fruit (which wild animals are likely to get to first); strawberry bush, whose bright red fruit resembles that of the strawberry plant, though it is inedible and the two species are not at all related; and bladdernut, which produces inflated, also inedible fruit.

A dazzling display of wildflowers appears in May. Dutchman's breeches has fernlike foliage and pairs of pointed white petals that resemble the legs of trousers. Squirrel corn has identical foliage but pairs of rounded white petals (its common name refers to its underground corns, or stem bases, which look like yellow kernels of corn). Other wildflowers are common Solomon's-seal, false Solomon's-seal, two kinds of golden bellworts, hepatica, wild columbine, monkshood, bloodroot, toothwort, and wild ginger.

Dry forest, dominated by loblolly pine, usually contains at least ground pine and may include various broad-leaved trees—black oak, northern red oak, southern red oak, white oak, black walnut, and pignut hickory—as well as an array of wildflowers. The first wildflower to bloom each year is field puseytoes, whose small, white, soft flower heads appear in late March at the tips of four-inch-long stems. Scattered across the forest floor during May are two types of blue-flowered violets. In summer, goat's rue, with its two-tone flowers of creamy yellow and pink, and pencilflower, with its tiny, yellow-orange, sweet-pea-shaped flowers, are found beneath more robust plants—woodland sunflower, feverfew, and Indian- physic. A member of the rose family, Indian- physic is a potent diuretic. An assortment of goldenrods and blue-headed asters close out the flowering season in autumn.
What's in a Name

Deciding what to call our heavenly neighbors proves no simple task.

By Richard Panek

It's probably impossible to grasp what it was like to be alive at the time of Galileo and to hear about the discovery of Jupiter's four moons. For as long as people had been studying the heavens, the number of objects up there had remained the same—roughly 6,000. The very occasional comet or nova might suddenly appear, disrupting the seeming sameness of the night sky to deliver a portent from the gods, but it would disappear just as suddenly, and the number of celestial objects would be right back to what it had always been.

Then, in 1610, that number changed. Overnight (literally) it grew by four. Galileo's discovery of the Jovian satellites (made possible by the invention of the telescope) didn't so much overturn an ancient assumption.
Every advance in astronomical technology brings the discovery of more celestial objects—satellites of planets, planets themselves, asteroids, satellites of asteroids. And each of these objects needs to be named.

Since 1919 the International Astronomical Union (IAU), based in Paris, has been in charge of reviewing and approving names for most solar system objects as well as the surface features—such as craters, valleys, mountains, and “seas”—that may be found on them. Every three years, the IAU’s General Assembly formally adopts the names that scientists and laypersons have submitted in accordance with certain conventions.

Satellites of Uranus, for instance, generally follow a Shakespearean theme (although two are named after characters from Alexander Pope’s *Rape of the Lock*). This past August, four of the planet’s moons—Caliban, Sycorax, Prospero, and Stephano, all discovered within the past three years—officially joined such *Tempest* castmates as Ariel and Miranda. In contrast, large Martian craters are named after scientists who have contributed to the study of Mars, as in the case of a sixty-mile-wide crater honoring Carl Sagan that is located near the planet’s equator.

In recent years, the IAU has also approved a couple of other themes. Craters on the asteroid Eros are to be named, appropriately enough, after legendary lovers or romantic figures, a list that now includes Cupid, Lolita, and Don Quixote. And craters on the asteroid Mathilde, an especially dark object, are to be named after Earth’s coal basins, from Aachen to Zulia.

Nomenclature for asteroids themselves no longer follows a theme. The practice in the nineteenth century was to give them female names (often those of deities), but now the discoverer gets to pick any
name, which the IAU then reviews to avoid duplication or impropriety. This year’s crop of new asteroid names includes Leviathan and Rosse, inspired by the telescope at Birr Castle, Ireland—nicknamed “the Leviathan”—which was for seventy-five years the largest telescope in the world and was recently restored by the seventh earl of Rosse. Also receiving celestial immortality are three former presidents of the London-based Royal Astronomical Society: Bernard Lovell, Carole Jordan, and Fred Hoyle.

And this list only hints at the array of names approved by the IAU. Make what you will of the nomenclature; for astronomers the salient concern is what to make of the numbers. How, for instance, should they categorize the dozens of newly discovered planets that are orbiting stars other than the Sun? The IAU deferred a decision on this until its next meeting, in 2003, but there’s no escaping the implication. The advent of the space age, together with

**THE SKY IN NOVEMBER**

**Mercury** puts in its best appearance of the year beginning on November 8, when it rises soon after 5:00 A.M. and becomes easily visible an hour later in the eastern sky as an ochre-hued “star” shining brighter than zero magnitude. Between the 8th and the 20th, a slowly brightening Mercury rises just before dawn and hence is visible, albeit briefly, in a dark sky. It attains its greatest elongation (19.3°) west of the Sun on November 15. Although it swings back toward the Sun after the 15th, it remains visible until nearly the end of the month as it brightens to magnitude -0.7. A thin sliver of Moon, one day from new phase, can be seen just above Mercury on the morning of the 24th.

**Venus** puts in a spectacular appearance in the southwestern evening sky, setting at about 6:45 P.M. on November 1 and at 7:30 P.M. by the 30th. A crescent Moon lies close to Venus on the evening of November 29.

**Mars** rises between 2:30 and 3:00 A.M. throughout the month. Continuing its slow approach toward Earth, it brightens ever so slightly to magnitude 1.7. By month’s end, its distance from us will be down to 192 million miles.

**Jupiter and Saturn** both arrive at opposition to the Sun; they rise as the Sun sets, reach their highest point in the southern sky at midnight, and set at sunrise. Saturn reaches opposition first, on the 19th, followed by Jupiter on the 27th. Jupiter peaks at a dazzling -2.9 magnitude, while Saturn glows at magnitude -0.4, the brightest it has appeared to us in more than a quarter century. Separated by about 10°, the two planets are also in the general vicinity of the beautiful Hyades and Pleiades star clusters; the planets and stars together create a very eye-catching scene in the late autumn sky. The combination of Jupiter’s cloud bands and four bright satellites and Saturn’s spectacular rings (now tilted 23.6° toward Earth, making them more visible than usual) provides a veritable banquet for telescope users all month. Saturn appears below and to the left of the full Moon on the night of November 11. On the following night the Moon appears near Jupiter and the ruddy first-magnitude star Aldebaran.

**The Moon** is at first quarter on November 4 at 2:27 A.M. Eastern Standard Time (EST). The full Moon
advances in computerized telescope technology, have not only accelerated the rate of astronomical discovery but also underscored just how crowded the night sky is. What the ongoing need to name new celestial objects reveals about our space-exploring culture isn’t so much how far we’ve come but how far we’ve yet to go.

**Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens (Penguin, 1999).**

By Joe Rao

occurs on November 11 at 4:15 p.m. EST. Last quarter is on November 18 at 10:24 A.M. EST, and new Moon is on November 25 at 6:11 p.m. EST.

The Leonid meteor shower is predicted to reach its peak this year during the night of November 17–18. Last year it produced a brief surge of more than sixty meteors per minute for favorably placed sky watchers in Europe. Optimal viewing will be from a dark spot, far from city lights. Choose a place where you can see as much of the sky as possible. Don’t stare at any one place; instead, keep your eyes moving across the sky. Begin your watch soon after 11:00 p.m. and carry on until the first light of dawn. The meteors will radiate from the Sickle of Leo, which rises in the east-northeast. Stay alert for brilliant fireballs or bolides (expanding meteors). The outlook remains favorable for a spectacular display, even though the last-quarter Moon will be brightening the sky. The best available predictions suggest that this year’s maximum activity will be attained at 2:51 a.m. on November 18.

Unless otherwise noted, all times are given in local standard time.

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**BOSE**
Soon after birds branched off from dinosaurs and gained the power of flight, some may have branched off again as land-bound runners. Why do some people have a problem with that?

By Stephen Jay Gould

One fine day, or so the legend proclaims, Joseph Stalin received a telegram from his exiled archrival, Leon Trotsky. Overjoyed by the apparent content, Stalin rounded up the citizenry of Moscow for an impromptu rally in Red Square. He then addressed the crowd below: "I have received the following message of contrition from Comrade Trotsky, who has obviously been using his Mexican retreat for beneficial reflection: 'Comrade Stalin: You are right! I was wrong! You are the leader of the Russian people!'"

But as waves of involuntary applause rolled through the square, a Jewish tailor in the front row—Trotsky's old school chum from yeshiva days—bravely mounted the platform, tapped Stalin on the shoulder, and took the microphone to address the crowd. "Excuse me, Comrade Stalin," he said. "The words, you got them right; but the meaning, I'm not so sure." Then the tailor read the telegram again, this time with the intended intonation of disgust and the rising inflection of inquiry: "Comrade Stalin: You are right?? I was wrong?? You are the leader of the Russian people??"

I have never been able to regard this joke with equanimity, because I can't help wondering what happened to the poor tailor, who probably suffered more than Trotsky, albeit anonymously. But I value the tale as a lesson about the importance of context. We may get every word right but, in a pungent military acronym (the superlative degree of SNAFU, I have been assured by army grammarians), still get the meaning FUBAR (defined by the dictionary, in genteel terms, as "fouled [euphemism] up beyond all recognition"). As I write this penultimate essay of 300 and look back upon a few successes in a sea of persisting ambivalence, I can only conclude that my central subject for "This View of Life"—evolution itself—must surpass all other disciplines in featuring straightforward facts enshrouded in difficult or ambiguous meanings.

The popular understanding of evolution includes at least two false assumptions, so widely shared and so
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Birds did not evolve from tyrannosaurs but rather from small, two-legged, meat-eating running dinosaurs.

deeply (if unconsciously) embedded in the context of conventional explanations that many plain facts, easily grasped at a superficial level of overt recitation, almost always enter the public discourse of newspapers, films, and magazines in a highly confused form that “science writers” either mistake for the actual opinions of scientists or, more cynically, choose to present as the literary equivalent of “easy listening” for succor in drive-time traffic jams.

In the picture conveyed by these two related fallacies, evolution becomes, first of all, the transformation of one kind of entity into another, body and soul. So fish evolve into amphibians in a “conquest” of the land, and apes leave the safety of trees, eventually to become human by facing the dangers of terra firma with a weapon in a liberated hand and a fresh twinkle of insight behind the eye. In the second component of this transformational view, descendants win victory from the heart of their valor in the face of natural selection—for “later” must mean “better,” as the land yields to explorational metaphors of conquest or colonization while the African savannas, for the first time in planetary history, hear sounds of progress in the voice of real language.

But evolution proceeds by the branching of bushes, not by the morphing of one form into another, with the old disappearing into the triumph of the new. Novelities begin as little branches on old trees, not as butterflies of Michael Jordan refashioned from the caterpillar components of Joe Airball. Moreover, most novelities, at least at their origin, grow as tiny twigs of addi-
tion to persisting and vigorous bushes, not as higher realizations of ancestors that literally gave their all to a transcendence of their former grubby selves.

Amphibians and all their descendants have done well enough on land, but fins beat feet on the vertebrate bush, where the majority of twigs (species) sprout among fishes. I do not deny the transient success, and interesting novelties, of humans. But Homo sapiens occupies only one twig on a modest primate bush of some 200 species, and even our most distantly related subgroups, in both evolutionary and geographic terms (say, the San of southern Africa and the Sami of northern Finland), show very little genetic divergence, whereas two populations of the same species of chimpanzee, separated by only a few hundred miles of African real estate, have evolved many more genetic differences, one from the other. (This initially surprising fact makes evident sense once we recast our conceptions in properly bushy terms. All living humans descended from common ancestors who lived in Africa less than 200,000 years ago—despite our subsequent spread throughout the world. The two chimpanzee populations may have remained in geographical proximity, but they split from a common ancestor far longer ago, thus providing much more time for the evolution of genetic differences in the separated groups.)

Finally, and at the broadest scale, we will grasp the principle that novelty arises by branching and not by the wholesale transformation of all ancestors into better descendants only when we recognize that bacteria still constitute most of life's tree—including the entire basal trunk that they built by themselves at life's cellular origin—and that all multicellular kingdoms occupy just a few, if admittedly quite healthy, branches at the terminus of a single bough.

During the quarter century that I have been writing these columns, I have continually returned to this theme of mentally liberating bushes versus constraining ladders because I believe that no other misconception so skews public understanding of evolution. I have treated a variety of topics under this rubric: why the air bladders of fishes evolved from lungs and not vice versa, as nearly everyone assumes (including Darwin himself in this case); why the cramming of primates into a halfway corner, and not at a triumphant terminus, of a linear walk through this Museum's hall of fossil mammals makes such revolutionary sense; and why the "out of Africa" theory (on the origin of all modern humans from a recent population of African ancestors) and not the multiregional theory (of our threefold parallel origin from ancestral Homo erectus populations in Europe, Africa, and Asia) represents conventional evolutionary thought based on origin by branching and not the iconoclastic shock featured in most press reports, which have also misconstrued the truly peculiar and theoretically unlikely multiregional the-
ory as transformational orthodoxy. May I therefore venture one last time into this particular breach (before writing my Agincourt of next month’s true finale)? I have desisted in applying this favorite theme to serious public misunderstandings of the apparently accurate claim that birds descended from dinosaurs—probably because I don’t like to attack generalities head-on but prefer the path of insinuation by small but fascinating tidbits and also because dinosaurs really are just a tad overexposed and scarcely need more publicity from this student of snails. But my tidbit arrived just in time in the professional literature, thus permitting a swan song about the bushy reform of avian origins at two levels: first the dreaded generality and then the tidbit.

1. The basic relationship of birds and dinosaurs. I don’t mean to toss any cold water upon the almost surely valid claim, and one of the most interesting conclusions of late-twentieth-century paleontology, that birds descended from a lineage of small-bodied, bipedal dinosaurs. But the conventional interpretive “take” on this accurately stated fact could benefit from a flat-out dousing, if only because the gain in general understanding of evolution might more than compensate the loss of a charming but truly misleading characterization of a fact.

I should point out, first of all, that the basic claim does not justify the feelings of surprise or weirdness conveyed by most popular accounts. Birds did not evolve from massive sauropods or antediluvian, tanklike ankylosaurs or even from the large tyrannosaurs (which do, in fact, branch fairly close to birds on the dinosaur bush). Rather, birds branched off from a lineage of small, two-legged, meat-eating running dinosaurs—full members of the group by proper criteria of descent (hence the validity of the one-liner that “birds evolved from dinosaurs”) but scarcely a version calculated to evoke either the fear or the power associated with our usual icon of dinosaurian immensity.

Moreover, the assertion of this evolutionary linkage during the past twenty years does not mark a stunningly new and utterly surprising discovery but rather reaffirms an old idea that seemed patently obvious to many paleontologists in Darwin’s day (notably to T. H. Huxley, who defended

It is the foolish claim of many popular articles that dinosaurs didn’t die out after all but remain among us, twittering in the trees. the argument in several publications) but then fell from popularity for a good reason based on an honest error.

The detailed anatomical correspondence between *Archaeopteryx*, the earliest toothed bird of Late Jurassic times, and the small running dinosaurs now known as maniraptors (and including such popularized forms as *Deinonychus* and *Troodon*) can hardly fail to suggest a close genealogical relationship. But following Huxley’s initial assertion of an evolutionary link, paleontologists reached the false conclusion that all dinosaurs had lost their clavicles, or collarbones—a prominent component of bird skeletons, where the clavicles enlarge and fuse to form the furcula, or wishbone. Since complex anatomical structures, coded by numerous genes working through intricate pathways of development, cannot reevolve after a complete loss, the apparent absence of clavicles in dinosaurs seemed to preclude a directly ancestral status to birds, though most paleontologists continued to assert a relationship of close cousinship.
This knee-jerk formulation sounds right in the superficial sense that buttresses most misunderstandings in science, for the majority of our errors reflect false conventionalities of hide-bound thinking (conceptual locks) rather than failures to find the information (factual lacks) that could resolve an issue in purely observational terms. After all, if birds evolved from dinosaurs (as they did) and if all remaining dinosaurs perished in a mass extinction triggered by an impacting comet or asteroid 65 million years ago—well, then, we must have been wrong about dinosaurian death and incompetence, for our latter-day tyrannosaurs in the trees continually chirp the New Age message of Jurassic Park: life finds a way. (In fact, as I write this paragraph, a mourning dove mocks my mammalian pretensions in a minor key, from a nest beneath my air conditioner. *Sic non transit gloria mundi!*)

Only our largely unconscious bias for conceiving evolution as a total transformation of one entity into a new and improved model could buttress the common belief that canonical dinosaurs—the really big guys, in all their brontosaurian bulk or tyrannosaurian terror—live on as hawks and hummingbirds. For we do understand that most species of dinosaurs just died, plain and simple, without leaving direct descendants. Under a transformational model, however, any ancestral bird carries the legacy of all dinosaurs at the heart of its courageous persistence, just as the baton in a relay race embodies all the efforts of those who ran before.

However, under a corrected branching model of evolution, birds didn’t descend from a particular totality but only from the particular little bough that generated an actual avian branch. The dinosaurian ancestors of birds lie among the smallest bipedal carnivores (think of little *Compsoognathus*, tragi-
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cally mistaken for a cute pet in the sequel to *Jurassic Park*—creatures that may be “all dinosaur” by genealogy but that do not seem incongruous as progenitors of birds. Ducks as direct descendants of Diplodocus (a sauropod dinosaur of maximal length) would strain my credulity, but ostriches as later offshoots from a dinosaurian line that began with little Oviraptor (a small, lithe carnivore of less than human, and much less than ostrich, height) hardly strains my limited imagination.

As a second clarification offered by the branching model of evolution, we must distinguish similarity of form from continuity in descent: two important concepts of very different meaning and for too frequent confusion. The fact of avian descent from dinosaurs (continuity) does not imply the persistence of dinosaurs (similarity in form and function). Evolution does mean change, after all, and our linguistic conventions honor the results of sufficiently extensive changes with new names. I don't call my dainty poodle a wolf or my car a horse-drawn carriage, despite the undoubted ties of genealogical continuity.

To draw a more complex but precise analogy in evolutionary terms: Mammals evolved from pelycosaurs, the “popular” group of sail-backed reptiles often mistaken for dinosaurs in series of stamps or sets of plastic monsters from the past. But I would never make the mistake of claiming that Dimetrodon (the most familiar and carnivorous of pelycosaurs) still exists because I am now typing its name, while whales swim in the sea and mice munch in my kitchen. In their descent from pelycosaurs, mammals evolved into such different creatures that the ancestral name, defined for a particular set of anatomical forms and functions, no longer describes the altered descendants. Moreover, and to reemphasize the theme of branching, pelycosaurs included three major subgroups, only
two bearing sails on their backs. Mammals probably evolved as a branch of the third, sailless group. So even if we erroneously stated that pelycosaurs still lived because mammals now exist, we could not grant this status to a canonical sail-backed form, any more than we could argue for brontosaurian persistence because birds descended from an entirely unrelated lineage of dinosaurs.

2. A tidbit with feathers. If birds evolved from small running dinosaurs, and if feathers could provide no aerodynamic benefit in an initial state of rudimentary size and limited distribution over the body, then feathers (which, by long-standing professional consensus and clear factual documentation, evolved from reptilian scales) must have performed some other function at their first appearance. A thermodynamic role has long been favored for the first feathers on the

I don’t call my dainty poodle a wolf or my car a horse-drawn carriage, despite the undoubted ties of genealogical continuity.

But standards have begun to coagulate, and at least one genus—Caudipteryx (“feather-tailed,” by etymology and actuality)—holds undoubted status as a feathered runner that could not fly. And so at least until the initiating tidbit for this essay appeared in the August 17, 2000, issue of Nature, one running dinosaur with utterly unambiguous feathers on its tail and forearms seemed to stand forth as an ensign of Huxley’s intellectual triumph and the branching of birds within the evolutionary tree of ground-dwelling dinosaurs. But the
new article makes a strong, if unproven, case for an inverted evolutionary sequence, with Caudipteryx interpreted as a descendant of flying birds, secondarily readapted to a running lifestyle on terra firma, and not as a dinosaur in a lineage of exclusively ground-dwelling forms (T. D. Jones, J. O. Farlow, J. A. Ruben, D. M. Henderson, and W. J. Hillenius, “Cursoriality in Bipedal Archosaurs,” Nature 406, August 17, 2000).

The case for secondary loss of flight rests upon a set of anatomical features that Caudipteryx shares with modern ground birds that evolved from flying ancestors—a common trend in several independent lineages, including ostriches, rheas, cassowaries, kiwis, moas, and others. By contrast, lineages of exclusively ground-dwelling forms, including all groups of dinosaurs suggested as potential ancestors of birds, evolved different shapes and proportions for the same features. In particular, as the accompanying illustration shows, ground-running and secondarily flightless birds—in comparison with small dinosaurs of fully terrestrial lineages—tend to have relatively shorter tails, relatively longer legs, and a center of gravity located in a more forward (headward) position. By all three criteria, the skeleton of Caudipteryx falls into the domain of flightless birds rather than the space of cursorial (running) dinosaurs.

Jones and colleagues have presented an interesting hypothesis demanding further testing and consideration, but scarcely (by their own acknowledgment) a firm proof or even a compelling probability. Paleontologists have unearthed only a few specimens of Caudipteryx, none complete. Moreover, we do not know the full potential for ranges of anatomical variation in the two relevant lifestyles. Perhaps Caudipteryx belonged to a fully terrestrial lineage of dinosaurs that developed birdlike proportions for reasons unre-
lated to any needs or actualities of flight.

I do not raise this issue here to vent any preference (for I remain neutral in a debate well beyond my own expertise). Nor do I regard the status of Caudipteryx as crucial to the largely unsettled question about the dinosaurian ancestry of birds. If Caudipteryx belongs to a fully terrestrial lineage of dinosaurs, then its feathers provide striking confirmation for the hypothesis, well supported by several other arguments, that this defining feature of birds originated in a running ancestor for reasons unrelated to flight. But if Caudipteryx is a secondarily flightless bird, the general hypothesis of dinosaurian ancestry suffers no blow.

Rather, I mention this tidbit to close my essay because the large volume of press commentary unleashed by the hypothesis of Jones and his colleagues showed me yet again—this time for the microcosm of Caudipteryx rather than for the macrocosm of avian origins in general—just how strongly our transformational biases and our failure to grasp the reality of evolution as a branching process distort our interpretations of factual claims easily understood by all. In short, I was aston-

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Once thought to be a feathered dinosaur, Caudipteryx (left) is now considered a secondarily flightless bird. Oviraptor (below) was named "egg thief" because its skeleton was found atop fossilized eggs. Later studies showed it was probably protecting its own nest.
ished to note that virtually all these commentaries reported the claim for secondary loss of flight in *Caudipteryx* as deeply paradoxical and stunningly surprising (even while they noted the factual arguments supporting the claim with accuracy and understanding).

In utter contrast, the hypothesis of secondary loss of flight in *Caudipteryx* struck me as interesting and eminently worthy of further consideration but also as entirely plausible. After all, numerous lineages of modern birds have lost their ability to fly and have evolved excellent adaptations for running in a rapid and sustained manner on the ground. If flightlessness has evolved in so many independent lineages of modern birds, why should a similar event surprise us merely because it occurred soon after the origin of birds? (I might even speculate that Cretaceous birds exceeded modern birds in potential for evolutionary loss of flight, for birds in the time of *Caudipteryx* had only recently evolved as flying forms from running ancestors. Perhaps these early birds still retained enough features of their terrestrial ancestry to facilitate a readaptation to ground life in appropriate ecological circumstances.) Moreover, on the question of timing in our admittedly spotty fossil record, *Archaeopteryx* (the first known bird) lived in Late Jurassic times, while *Caudipteryx* probably arose at the beginning of the subsequent Cretaceous period—plenty of time for a flying lineage to redeploy one of its species as a ground-dwelling branch.

After considerable puzzlement, I think that I finally understand the reason for such a stark contrast between my lack of surprise and the sense of deep paradox conveyed by most press reports. As an implication of my view (expressing a professional consensus) that evolutionary novelty arises by a process of branching, the discovery of an earlier “first time” for a common and repeated event—loss of flight and secondary adaptation to effective ground running—surely attracts interest as a lovely nugget of discovery but scarcely evokes any theoretical surprise.

But in the usual public misconception of evolution as a story of wholesale transformation into something better, such an early “falling off” from “the program” seems almost perverse. After all, birds had just taken to the air a few tens of millions of years (at most) before the appearance of *Caudipteryx*. Why would a lineage fall out of step so early in the game? Sure, once the program rolls to a full and triumphant completion, then evolution might permit an ostrich or two to slip off the main line and pursue its own bohemian path in a new strange but once ancestral land. But such events surely cannot occur in the vigorous youth of a lineage that has just snatched winged victory from the jaws of terrestrial dinosauroid death.

Perhaps I have treated a garden-variety error with unfair disdain in the sarcasm of the last paragraph. But the fallacy behind this common feeling of surprise, evoked by the eminently plausible hypothesis of *Caudipteryx* as a flightless bird, originates in a pervasive bias that renders much of the fascination of evolution inaccessible to millions of genuinely interested students and lovers of science.

The vigorous branching of life’s tree, and not the accumulating valor of mythical marches to progress, lies behind the persistence and expansion of organic diversity in our tough and constantly stressful world. And if we do not grasp the fundamental nature of branching as the key to life’s passage across the geological stage, we will never understand evolution aright. Tennyson caught the essence of life’s challenge when he personified nature’s unforgiving geological ways, as expressed in the fossil record of extinction:

> From scarped cliff and quarried stone<br>She cries, “A thousand types are gone: I care for nothing, all shall go.”

Yes, all shall eventually go, but some shall branch, thus permitting life to persist. To cite a sardonic song of self-mockery in leftist circles: “Trotsky got the ice pick . . . and so say all of us.” And I do shudder even to contemplate the fate of the poor tailor. But life feints, dodges, and branches—and therefore, above all, hangs on in beauty and fascination. Psalm 1 invokes the right picture for a different purpose: “And he shall be like a tree planted by the rivers of water . . . its leaf also shall not wither; and whatsoever he doeth shall prosper.” And Darwin employed the same image, both as metaphor and as literal topology this time, in the final words of the focal chapter in the *Origin of Species*—chapter 4, entitled “Natural Selection,” with its closing literary flourish on extinction and branching as the motors of evolution’s tree and life’s glory:

> As buds give rise by growth to fresh buds and these, if vigorous, branch out and overtop on all sides many a feeble branch, so by generation I believe it has been with the great Tree of Life, which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever branching and beautiful ramifications.

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From Alaska's Northern lights, to Mexico's winter solstice, to India's exotic coast—an exciting adventure awaits.

distinctive DESTINATIONS
EACH YEAR, CENTRAL MEXICO WELCOMES A UNIQUE group of tourists — some 250 million monarch butterflies. Butterfly enthusiasts from all over the world travel to Michoacan, Mexico, each year to see this beautiful phenomenon.

The monarchs migrate each September from Canada and east of the Rockies. In mid November they arrive at their winter home — the deep and shady oyamel fir forests at some 10,000 feet above sea level in the mountains of Central Mexico's Michoacan. From December to winter's end, an estimated 100,000,000 butterflies cover every tree. The monarchs congregate with such intensity that the tree's canopy takes on a flaming orange. Fluttering from tree to tree, they fill the air with the noise of their beating wings, turning this usually green area into a bright orange landscape.

In March, they head northeast in search of milkweed plants on which to lay their eggs. The monarchs mate just before leaving Mexico in the second week in March. Then, they begin their trek north back to the US and Canada. Each monarch butterfly makes this journey twice in its short life span of two years. Scientists estimate the migration has been taking place for 40,000 years.

The Mexican government protects most of the monarch's wintering areas. The Transvolcanic Mountains in Mexico have eleven to fourteen known monarch butterfly sites each year. Of these areas, the Mexican government has created eight sanctuaries, and three of these are open year-round to visitors.

CHICHEN-ITZA
Twice a year, people worldwide come to Chichen Itza, in Mexico's Yucatan Peninsula, where the serpent god Kukulcan — or Quetzalcoatl — "reappears," slithering down the pyramid of El Castillo's long stairway. In fact, it's Kukulcan's shadow, thanks to Maya astrology and pyramid engineering.

During the fall and spring equinoxes, in March and September, the sun creates a shadow on each of the pyramid's four sides when directly overhead. The shadow of Quetzalcoatl, the Maya feathered serpent god, emerges, descending the building to its base, where it melds with a carved serpent head. This phenomenon has become one of the most spiritual festivals in Mexico.

Chichen Itza — known as one of the most spiritual spots on earth — is filled with cosmological symbolism. The pyramid's four sides have 365 steps symbolizing the solar year. Its 52 panels stand for each year in the Maya century and its 18 terraces for the number of months in the religious year. Other highlights include an astronomical observatory, a deep and circular cenote, or sacred well, and the Temple of the Warriors and the group of the 1,000 columns.

Primarily a ceremonial center, Chichen Itza is actually a mixture of two cities: a sixteenth-century Maya city and a Toltec-Maya city that emerged around 1000. El Castillo, also known as the pyramid of Kukulcan, displays a mixture of these two influences, which spanned several hundreds of years of intermittent inhabitation.
I became a part of this world over 3,000 years ago, and they named me Nueva España. Today I am affectionately called México, and I am full of intrigue and wonder.

I am ancient.

I am outwardly beautiful and quite cultured, yet part of my being remains a mystery. I am remarkably versed in the arts, and I have many stories to tell.

I have many states of mind. My adventurous side leads to lush rain forests. Spectacular beaches beckon my playful attitude, with crystalline waters that are clearly invigorating. I am also sophisticated, presenting the ballet, the opera, and hundreds of museums filled with exquisite treasures. I will entice you with tantalizing cuisine, and when excitement stirs, my nights dance until dawn. I am México. For more information, call 800-44-MEXICO.
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Now in its 24th year, World Explorer Cruises, is embarking on its 2001 season—May through August. A new, 28-page full-color brochure details eight, full two-week cruises aboard the SS Universe Explorer—a 731-passenger American-built cruising vessel. All of the 14-night cruises begin and end in Western Canada’s largest city, Vancouver. World Explorer Cruises offer Alaska’s most extensive itineraries with an average of 11 hours in each port—more time ashore than any other Alaska cruise operator.

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Highlights of the World Explorer’s new “Land of the Ancestors” itinerary includes Metlakala, Alaska’s only Tsimshian Indian reservation; Kodiak, founded by the Russians and now a busy fishing port and gateway to the Aleutian Islands; Glacier Bay, the gem of Alaska’s natural heritage; Seward, a quiet seaport village; Juneau, Alaska’s colorful capital city; Skagway, historic Alaskan gold-rush era town, Sitka, capital of Czarist Russia’s Alaska; Ketchikan, Gold Rush-era supply depot and now center for Tongit, Haida and Tsimshian cultures; and Victoria, British-flavored, flower-bedecked British Columbia’s capital city.

“Route of the Pioneers” tours include Wrangell, a fishing and timber community with an impressive collection of totem poles; Valdez, known as the Switzerland of Alaska; as well as Juneau, Skagway, Glacier Bay, Seward, Sitka, Ketchikan and Victoria, B.C.

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Inside Passage

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Robert Service sure hit the nail on the head.
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The giant valleys gulp the night;
The monster mountains scrape the sky,
where eager stars are diamond-bright.”

listened to a classical
trio in blue jeans.

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Since the early 1980s, sustained development has become a watchword for Caribbean tourism. Belize is well known for the preservation and conservation of its natural and cultural resources. Currently 40 percent of its land is protected. Some newer additions to Belize's growing list of eco-tourism sites and ecological preservation efforts include:

Programme for Belize: 260,000 acres of tropical forest in the northwest are used for research and visited annually by hundreds of U.S. students, who are given week-long courses in rainforest ecology and marine biology. The program also involves bird conservation and is visited by numerous bird enthusiasts.

Chaa Creek Blue Morpho Butterfly Breeding Centre: a resort and compound where visitors enjoy an education about the butterfly's metamorphosis from caterpillar to striking blue butterfly. About 45 percent of the 200 butterflies bred each day are released.

San Ignacio Resort Hotel — Green Iguana Conservation Project: Once plentiful, but in decline in recent years due to habitat loss and hunting, the green iguana is protected through the project's efforts. Visitors are encouraged to tour the project to understand the importance of the species.

 websites

INFORMATION

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For some snakes, being flexible is a matter of life and death, and swallowing.

Imagine that you knew nothing about snakes. You’d most likely be skeptical of a friend trying to convince you that a vertebrate could move without legs or wings. You might scoff at descriptions of a snake catching animals far bigger than its head and swallowing them whole. And yet, though God’s punishment for the snake in the Garden of Eden was an apparently absurd body plan, snakes have thrived for more than 90 million years, ever since their lizardlike ancestors lost their legs. At the University of Washington, zoologist Brad Moon is exploring one secret of their success: the way they have elevated bending to a high art.

The skeleton of a snake is essentially a skull connected to a very long spinal column and rib cage. Most of the muscles in a snake’s body run longitudinally between vertebrae or ribs; some are short, connecting one rib to the next, while others may span forty vertebrae, connecting with other muscles and anchored to the vertebrae and ribs at several points along the way. When a muscle contracts, it pulls its anchors closer together, forcing the skeleton to bend to one side in the process. To study the bending process, Moon implants electrodes in the long muscles so that their activity can be sensed. He then films the snakes (mostly gopher and king snakes) as they crawl and feed.

What Moon has found is that a snake slithers by bending its body into a series of S-shaped curves produced by alternating waves of muscle contraction that start at the reptile’s head and move back toward its tail. The snake contracts small blocks of muscle, repeatedly switching from one side to the other and thus causing the bends created by the contractions to move back to side also. As the contractions move back through the snake, so do the bends. And as the bends move back, they push against the ground, propelling the snake forward. Since the arrangement of muscles in a snake’s body is far more complex than that in our own rib cage, these animals can adapt their bending to practically any landscape, from a rocky path to a rodent burrow.

Many snakes also use their bending skills to kill their prey by coiling tightly around them. Using sensors implanted inside mice, Moon measures the pressure that snake muscles exert on the animals. To constrict a mouse, a snake quickly and simultaneously contracts many muscles on one side of its body. In this case, rather than forming an S, its body forms one or more loops that enclose the prey.

Surprisingly, Moon has found that snakes don’t remain rigid while constricting; instead, they periodically relax their muscles when the mice are motionless and tighten them again only when they feel twitching muscles, a beating heart, or a pumping lung.

Suffocation is one common explanation for how coiling kills. But it takes about four minutes for a rat to die of asphyxiation, whereas a snake can constrict a rodent to death in just one. Moon’s research suggests that the reason lies in the way the snake interferes with the circulation and heartbeat of its prey. His measurements show that constriction can cause the pressure inside a mouse to rise to twice the animal’s normal blood pressure. As a result, the heart cannot keep pumping blood to the brain, lungs, and other tissues, and the mouse may die of a stroke or heart attack long before it would suffocate.

Once the mouse is dead, the snake begins to maneuver the carcass into its stomach. Unable to tear its prey into little chunks, the reptile loosens its jaws and alternately “walks” the left and right sides of the jaws over the prey.

Dangerous Curves

Story by Carl Zimmer ~ Illustration by Sally J. Bensusen
But getting something into your throat is just the beginning. You have to finish swallowing it. In humans, throat muscles give the food a little push, and the esophagus, which has its own embedded muscle fibers, handles the job from there. A snake’s thin esophagus, however, cannot generate the force necessary to push the entire body of a large animal down into its stomach. Without some sort of extra push, a snake could starve with a throat full of food.

In order to swallow, Moon has found, snakes sometimes crawl over their food. A feeding snake contracts the muscles on either side of its body in alternating waves, similar to those used for locomotion. But now muscles in part of the snake’s body are pushing inward against the food. If the prey is small enough, the contracting, bending muscles will force it through the esophagus; all the snake has to do is sit still and squeeze the food down to its stomach. If the prey in the throat is large and heavy, however, it stays in place as the snake crawls forward, swallowing as it moves. In such a case, the forward propulsion comes from the snake’s pushing both against the ground and inward against the heavy meal. Snakes’ ability to handle large prey can be truly impressive: research by Harry Greene, of Cornell University, has shown that some snakes can swallow prey with a body mass up to one and a half times their own.

Moon’s research is a splendid example of a general rule in biomechanics: often, with a little adjustment, the same set of bones, muscles, and nerves can do many different jobs. Snakes cannot walk, sink their claws into prey, or even chew their food. But by bending they can move, kill, and eat. If you can do only one thing, these master benders are telling us, just do it well and you will be able to accomplish many things.

Carl Zimmer is the author of At the Water’s Edge and Parasite Rex.
t is a rainy October morning in the south of France. The two of us, a field biologist and an archaeologist, are preparing to enter Chauvet Cave, above the Ardèche River. The purpose of our visit is to share thoughts and observations on both the Paleolithic paintings in the caves and their subjects—great cats that have been extinct for

At Chauvet Cave, 32,000-year-old paintings tell of extinct big cats and the artists with whom they shared their domain.

By Craig Packer and Jean Clottes

When Lions Ruled France

African lions stare at Cape buffalo on the Serengeti Plain, above. A painting in Chauvet Cave records their ancient counterparts, right, watching a herd of European bison with similar concentration.
more than 12,000 years. As we approach Chauvet, we admire the tall gray limestone cliffs that flank the winding river as it twists its way down to the broad valley of the Rhône. The landscape is lush with low trees and shrubs, and the canyon walls are honeycombed with shallow caves and deep caverns. That humans lived in Europe long before the last glaciation is well known, but the vivid and abundant evidence of their early presence in this region is still startling. Artwork and human remains indicate that some 40,000 years ago, our ancestors shared this landscape with rhinoceroses, bison, mammoths, aurochs, wild horses, and giant elk. In those days, the Ardèche region had a cli-
mate like that of southern Sweden today, and the low-lying flatlands around the river were covered with grass. People lived in small communities of perhaps twenty to thirty individuals, scattered thirty to forty miles apart. Using spearheads made from reindeer antlers, they hunted large ungulates, mostly reindeer and bison.

But people were not the only hunters of these large, hoofed mammals. Wolves, leopards, hyenas, and cave lions also preyed upon them. Cave lions (*Panthera atrox*) were a different species from the lion we know today in Africa and India. Larger than Siberian tigers, cave lions once ranged throughout the Northern Hemisphere. Their bones are common in the La Brea tar pits of Los Angeles, and mummified remains have been found in Alaska and Siberia. Chauvet Cave contains an extensive record of cave lions' behavior—thanks to the talented artists who settled there 32,000 years ago. Before its discovery in 1994, only a few images of lions were known from European caves. Chauvet is one of the most profusely decorated Paleolithic caves in the world and is unique in its large gallery of lion portraits. [See “Rhinos and Lions and Bears (Oh, My!),” *Natural History*, May 1995.]

Perhaps the most famous landmark in the Ardèche is the Pont d'Arc, a natural arch formed by a sharp meander in the river that eventually cut through a narrow limestone wall hundreds of thousands of years ago. The river now passes under the resultant rock bridge, which is a half mile from the cave. A wide loop of its former course filled in and became a fertile pasture near the water's edge, attracting large numbers of herbivores during drier months. Drawn to the area by the abundant game, local hunting tribes were probably impressed by the spectacular rock formations; unusual geological features still inspire stories and origin myths among the world's tribal peoples. We know from their engravings that ancient hunters saw resemblances between unusually shaped rocks and the figures of mammoths and bison. Perhaps they perceived some of the giant rock formations here as animals turned to stone. At any rate, the significance of the cave as a major sanctuary may well have been related to its proximity to the Pont d'Arc.

The opening of the cave is situated about two hundred feet above the riverbed, and the cliff be-
neath the entrance is steep. Anyone sitting in this opening would have had a clear view of the valley without the risk of being surprised by an approaching animal or human. Perhaps its inaccessibility is also the reason the cave remained so long undiscovered by moderns.

Cave bears (the size of modern-day Kodiak bears) hibernated in Chauvet, and their bones still litter the floor, but humans left behind few signs other than the spectacular animals they drew on the walls in ocher or charcoal or by scratching into the soft wall surfaces. Chauvet Cave contains hundreds of paintings—some rudimentary, some astonishingly vivid. Those made in charcoal have been dated to 32,000 years ago.

But today we are putting aside our scientific concerns of dating and preservation and are attempting to let the paintings reveal their stories to us. What can they tell us about the extinct lions and the humans who observed them? We switch on the lights of our miners' helmets and begin to make our way inside.

The drawings near the entrance are rendered in ocher and are sketchy and crude. Some seem schematic rather than representative of living, breathing animals. Some might even be impromptu flights of fantasy. Passing deeper into the cave, we can see occasional smudges of charcoal on the walls where someone rubbed a pine-branch torch 27,000 years ago while heading for the cavern’s older paintings—artistic masterpieces created thousands of years earlier. Sidestepping the ancient bear skulls on the floor, we carefully make our way along the thin strip of black plastic that constitutes the scientists’ and conservators’ only approved path. (Although the cave is in a remarkable state of preservation, like all Paleolithic sites it is fragile and easily damaged if someone steps on a delicate impression or rubs against a drawing. Chauvet Cave is closed to the public, since even the breath of too many visitors could alter the cave’s climate and foster molds that would destroy the ancient artwork.)

Soon we arrive at a series of charcoal renderings in the middle gallery. Next to a striking set of four horse heads, plus various aurochs, bison, and rhinoceroses, we can see two cave lions, one of which is snarling while in a pose of submission. With a few simple lines, the drawing captures the expression and movement of the two lions and the way they place their bodies in relation to each other. The artists accurately recorded the way the big cats point their ears and hold their heads.

These postures can occur in two different situations. When a male lion stands close to a female that is not ready to mate, the female will resist contact by growling, snarling, and keeping her suitor at bay. Alternatively, following an aggressive encounter, a victorious animal of either sex will sometimes strut past the submissive loser, which snarls in defeat, edging nervously away from its rival. Whichever situation is represented here, the painting seems like a snapshot of lion behavior, a realistic representation of a true-life event the painter witnessed firsthand. And the artist must have been fairly close to record the nuances of the lions’ facial expressions. This lifelike portrait adorns one wall of a small alcove, while a more stylized lion has been sketched on the opposite side of the nook. The latter image is unnaturally stiff, but the viewer senses that the artist did not intend to create a realistic representation in this case. Although the lion is for the most part anatomically correct, its paws have been drawn as hooves. Many scholars believe that such distortions are deliberate and indicate a belief that various animals, and sometimes even humans, can take on the characteristics of other species. Such beliefs are particularly common in societies that have shamanistic religions. Even today, in some parts of the world, shamans are thought to take spirit journeys to underworlds, where they gain the powers of animal spirits.

Anyone who has spent time studying African lions will be stunned by the cave artists’ skill at observing and recording animal behavior.
Backtracking slightly, we enter a narrow passageway. There is no room to spare on either side, and we must be very careful not to graze the walls, which are adorned with yet more ancient drawings. The passage broadens, and in the widened chamber we see another pair of lions, nine feet across and breathtaking in their naturalness. Conveying a fluid sense of motion, simple outlines portray two lions walking abreast. The male is in the background and is much larger than the female at his side. His scrotum is conspicuous beneath his tail, and he has lowered his shoulders to be level with hers. Male African lions perform this maneuver when they consort with a receptive female, herding her in the desired direction. But while the cave lion may have courted his females in a manner similar to that of his modern African cousins, the painting reveals a conspicuous difference between the two species: the European lion had no mane.

Anyone who has spent time studying and photographing African lions will be stunned by the cave artists’ accomplishments in observing and recording the behavior of the big cats. For the ancient artists to have made these observations, the lions must have been very relaxed in their presence. Modern-day African lions almost always flee from Masai pedestrians; tourists can approach within several yards only if they remain in their vehicles.

Farther along, the chamber opens out into the most spectacular gallery in Chauvet. Here the paintings extend high up the wall, and a series of lions faces a Paleolithic menagerie of rhinoceroses, bison, and mammoths. The outlines and shading of many of the lions are exquisite. And beneath these astonishing images, on the floor of the cave, we see a heap of charcoal. Probably used for making the drawings, it is as freshly preserved as if the burnt wood had been doused yesterday.

The first notable point about this great portrait gallery is that the sheer number and postures of the lions imply group living. Several pairs sit parallel, gazing at the same distant object—behavior often observed in Africa. In the best paintings in the gallery’s upper regions, the postures are accurate and the facial expressions precise. One lion, with its front legs extended, appears to be crouching. Several of these portraits are so detailed that they depict the varied patterns of whisker spots, which biologists today use to identify individual lions in the field.

But a closer look reveals some peculiarities about this group of lion images. In some cases, we see a sophisticated, realistic painting next to a rather crude sketch, perhaps a copy of the original by an apprentice. In other cases, the lion is drawn as a grotesque caricature: one of these was nicknamed “the hippo” by cave researchers. A few meters to the right of the grand panorama is a strange group of four lions, all standing right next to each other and depicted in profile. While one member of this quartet is a reasonable approximation of an actual lion, the others are somewhat distorted. One has an odd, dome-shaped head; another has a bizarre body shaped more like a bison’s; and still another is little more than a medallion, a shield-shaped form with ears. While the main panel was at least partly inspired by individual lions, this group seems to reflect a deliberate transmutation of the animals’ natural appearance; perhaps it is an illustration of a legend or of shamanic shape-shifting.

Midway between the panorama and the four bizarre leonine images is a third panel, showing two lions below a bison that looks directly at them, just as modern-day wildebeests warily eye African lions on the Serengeti Plain. Hanging from the ceiling in the midst of the three panels is a jagged rock formation containing a painting known to the cave’s research team as “the Sorcerer.” It appears to depict a bison’s head and forequarters attached to a human-like body.
The artists who created this wealth of imagery may have considered the huge, deep cave to be a genuinely supernatural underworld that humans could physically enter on certain occasions. One can easily imagine that this final, deepest chamber may have been used by the early inhabitants of the Ardèche as a sort of grand chapel. Blocked by walls festooned with a glorious array of stalactites and stalagmites, the passage ends here.

Clearly, those who lived in the region saw something very special in the lion. The seventy-three representations of this animal here in Chauvet Cave exceed the total from all the other caves in Europe, and compared with these, all the previously discovered lion drawings are crude sketches. Yet these are so much more ancient: 32,000 years old compared, for example, with Lascaux's 17,000.

Why were these remarkable artworks produced at Chauvet? We can only speculate. Perhaps an exceptional set of circumstances came together at that time and place. Certainly, one or more artists of extraordinary talent—not only gifted draftsmen but also keen observers of wildlife—lived in the vicinity. Perhaps they sat on the cliff above the Ardèche River, surveying the pasture beside the Pont d'Arc, watching a pride of lions take down a large mammal. Possibly the artists and their families had learned to let the lions bring down the bison for them. The people could then steal the meat rather than having to spear it on the hoof. A good pasture next to a permanent supply of water would have been a highly desirable stretch of real estate for both lions and humans. Perhaps the local pride had become relatively habituated to humans by the time our artists picked up their charcoal.

The Paleolithic inhabitants of the Ardèche represented the terrifying but useful cave lion as a potent, magical creature, sometimes giving it hooves, sometimes transforming a lifelike image into a caricature or a symbol. We will never know why these talented artists chose to portray these particular scenes or how they got so close to the maneless, pride-dwelling lions. But we can be sure they had courage and patience as well as a degree of curiosity that rivals that of the best naturalists of our own era.

Ancient artists observed how lions often sit next to each other and collectively gaze at potential threats or prey. The drawing at Chauvet, below, is recreated in living tableau by modern African lions, left.
For the Mosuo of China, it’s a woman’s world.

By Lu Yuan and Sam Mitchell

There are so many skillful people,
but none can compare with my mother.
There are so many knowledgeable people,
but none can equal my mother.
There are so many people skilled at song and dance,
but none can compete with my mother.

We first heard this folk song around a blazing fire in southwestern China in the spring of 1995. It was sung enthusiastically by women of Luoshui village—members of the Nari, an ethnic group more commonly known to outsiders as the Mosuo. During the past few years, we have returned several times to visit these people, who celebrate women in more than song. Although the majority of China’s ethnic groups follow a strong patrilineal tradition, the Mosuo emphasize matrilineal ties, with matrilineally related kin assisting one another to farm, fish, and raise children. Women also head most households and control most family property.

Marriage as other cultures know it is uncommon among the Mosuo; they prefer a visiting relationship between lovers—an arrangement they sometimes refer to in their language as sisi (walking back and forth). At about the age of twelve, a Mosuo girl is given a coming-of-age ceremony, and after puberty, she is free to receive male visitors. A lover may remain overnight in her room but will return in the morning to his own mother’s home and his primary responsibilities. Children born from such a relationship live with their mother, and
MARRIAGE
the male relatives responsible for helping to look after them are her brothers. Many children know who their fathers are, of course, but even if the relationship between father and child is quite close, it involves no social or economic obligation. And lovers can end their relationship at any time; a woman may signal her change of heart by simply no longer opening the door. When speaking Chinese, the Mosuo will call the sisi arrangement zou hun (walking marriage) or azhu hunyin (friend marriage, azhu being the Mosuo word for friend); nevertheless, the relationship is not a formal union.

Chuan-kang Shih, an anthropologist at the University of Illinois at Urbana-Champaign and an authority on the Mosuo, points out that many aspects of their family system have parallels elsewhere in the world. For example, although in most societies a husband and wife live together (usually near his relatives or hers), in others they continue to live in separate households, and one spouse must make overnight nuptial visits. Matrilineal kinship systems, in which a man looks after the interests of his sisters’ children, are also well known. And although men commonly wielding the power, even in matrilineal societies, women may play important political and economic roles. But the absence of a formal marital union may quite possibly be unique to the Mosuo.

In this respect, only the precolonial practices of the matrilineal Nayar of southern India come close. As Shih explains, among some Nayar groups, a woman would take lovers (with due regard for social class), who would establish and maintain their relationships to her through a pattern of gift giving. Despite being expected to acknowledge maternity, the lovers incurred no obligations to their offspring. Still, the Nayar had a vestigial form of marriage: shortly before puberty, a girl would be wed to a young man; although this marriage lasted only three days and was often purely ceremonial in nature, the union marked the girl’s transition to adult life and legitimized the birth of her children.

In Luoshui we stayed with thirty-year-old A Long, who runs a small guesthouse. His family consisted of his mother, grandmother, younger brother and sister, and sister’s two-year-old son. Each evening A Long departed with his small overnight bag; each morning he returned to help his mother and sister. After several days of eating with the family and becoming friendly with them, we asked A Long what he thought about the sisi system. “Friend marriage’ is very good,” he replied. “First, we are all our mother’s children, making money for her; therefore there is no conflict between the brothers and sisters. Second, the relationship is based on love, and no money or dowry is involved in it. If a couple feels contented, they stay together. If they feel unhappy, they can go their separate ways. As a result, there is little fighting.” A Long told us that he used to have several lovers but started to have a stable relationship with one when she had her first child.

“Are you taking care of your children?” we asked.

“I sometimes buy candy for them. My responsibility is to help raise my sister’s children. In the future, they will take care of me when I get old.”

A Long’s twenty-six-year-old sister, Qima, told us that the Mosuo system “is good because my friend and I help our own families during the daytime and only come together at night, and therefore there are few quarrels between us. When we are about fifty years old, we will not have ‘friend marriage’ anymore.”

Ge Ze A Che is the leader of Luoshui, which has a population of more than 200 people, the majority of them Mosuo, with a few Han (China’s majority ethnic group) and Pumi as well. He spoke proudly of this small settlement: “I have been the leader of the village for five years. There has been little theft, rape, or even argument here. ‘Friend marriage’ is better than the husband-wife system, because in large extended families everyone helps each other, so we are not afraid of anything. It is too hard to do so much work in the field and at home just as a couple, the way the Han do.”
The Mosuo live in villages around Lugu Lake, which straddles the border between Yunnan and Sichuan provinces, and in the nearby town of Yongning. They are believed to be descendants of the ancient Qiang, an early people of the Tibetan plateau from whom many neighboring minority groups, including the Tibetans themselves, claim descent. As a result of Han expansion during the Qin dynasty (221–206 B.C.), some Qiang from an area near the Huang (Yellow) River migrated south and west into Yunnan. The two earliest mentions of the Mosuo appear during the Han dynasty (A.D. 206–222) and the Tang dynasty (618–907), in records concerning what is now southwestern China.

The Mosuo do not surface again in historical accounts until after Mongol soldiers under Kublai Khan subjugated the area in 1253. During the Yuan dynasty (1279–1368), a period of minority rule by the Mongols, the province of Yunnan was incorporated into the Chinese empire, and many Mongol soldiers settled in the Mosuo region. In fact, during the 1950s, when the government set out to classify the country’s minority nationalities, several Mosuo villages surrounding Lugu Lake identified themselves as Mongol, and some continue to do so today. When we walked around the lake, as the Mosuo do each year in the seventh lunar month—a ritual believed to ensure good fortune during the coming year—we passed through villages that identified themselves variously as Mosuo, Mongol, Naxi, Pumi, and Han. The “Mongol” people we encountered dressed the same as the Mosuo and spoke the same language. Their dances and songs, too, were the same, and they sometimes even referred to themselves as Mosuo.

Tibetan Buddhism first entered the region in the late thirteenth century and has greatly influenced the lives and customs of the Mosuo. Before the area came under the control of the Communist government, at least one male from almost every family joined the monastic community. The local practice of Buddhism even incorporated aspects of the sisi system, although the women did the “commuting.” On the eighth day of the fifth lunar month, monks traveling to Tibet for religious study would camp in front of Kaiji village. That night, each monk would be joined by his accustomed lover—a ceremonial practice believed to enable the monks to reach Lhasa safely and to succeed in completing their studies. And the local Mosuo monks, each of whom lived with his own mother’s family, could also receive lovers. Such arrangements seem to defy the injunctions of many schools of Tibetan Buddhism, but by allowing the monks to live and work at home, outside the strict confines of monastic life, they helped the Mosuo maintain a stable population and ensure an adequate labor force to sustain local agriculture.

The area around Lugu Lake did not come under the full control of China’s central government until 1956, seven years after the founding of the People’s Republic. In 1958 and 1959, during the Great Leap Forward, the nearby monasteries, notably the one at Yongning, were badly damaged. Now, however, with a combination of government funds and donations from local people, they are slowly being rebuilt. One element of recent religious revival is the Bon tradition, which is accepted by the Dalai Lama as a school of Tibetan Buddhism but believed by many scholars to be derived from an earlier, animist tradition. During our walk around Lugu Lake, we witnessed a Bon cremation ceremony and visited the Bon temple on the eastern shore of the lake. The Mosuo also retain a shamanic and animist tradition of their own, known as Daba.

Instead of marriage, Mosuo lovers prefer a visiting relationship. Children live with their mother, whose brothers help look after them.
In the twentieth century, the West became acquainted with the Mosuo through the work of French ethnographers Edouard Chavannes and Jacques Bacot and through the contributions of Joseph Rock, a Vienna-born American who first journeyed to Yunnan in 1922 while on a botanical expedition. A flamboyant character, Rock traveled through remote Tibetan borderlands accompanied by trains of servants and bodyguards and equipped with such dubious necessities as a collapsible bath-tub and a silver English tea set. He made the Naxi town of Lijiang his home for more than twenty years, until the victory of the Chinese Communist Party in 1949 spelled an end to foreign-funded research and missionary activity in the area.

Besides conducting botanical surveys and collecting plant and animal specimens, Rock took many photographs and became the West’s foremost expert on the region’s peoples and their shamanic practices. He identified the Mosuo as a subgroup of the Naxi, who, although their kinship system is patrilocal, speak a language closely related to that of
the Mosuo. The Mosuo strongly contest this classification, but it has been retained by the present government, which has been reluctant to assign the Mosuo the status of a distinct minority. The Communists claim that the Mosuo do not fit the criteria for nationality status as defined for the Soviet Union by Joseph Stalin. According to Stalin, as he phrased it in a 1929 letter, "A nation is a historically constituted, stable community of people, formed on the basis of the common possession of four principal characteristics, namely: a common language, a common territory, a common economic life, and a common psychological make-up manifested in common specific features of national culture."

In keeping with Marxist interpretations of historical development, Chinese ethnologists have also regarded Mosuo society as a "living fossil," characterized by ancient marriage and family structures. This view draws on theories of social evolution formerly embraced by Western anthropologists, notably the American ethnologist Lewis Henry Morgan (1818–81). Morgan proposed that societies pass through successive natural stages of "savagery" and "barbarism" before attaining "civilization." He also proposed a sequence of marriage forms, from a hypothetical "group marriage" of brothers and sisters to monogamy. Chinese scholars have argued that a minority such as the Mosuo, with its unusual kin-

"A small family is not good for work," says Lama Luo Sang Yi Shi. "Also, mothers and their daughters-in-law cannot get along well."
The government, which adheres to Stalin’s definition of nationality, has been reluctant to assign the Mosuo status as a distinct minority.

ship system, fits into this scheme and thus validates Marxist views. Of course, the application of Morgan’s theories to minority cultures in China has also enabled the Han majority to see itself as more advanced in the chain of human societal evolution. This kind of thinking, long discredited in the West, is only now beginning to be reexamined in China.

With the coming of the Cultural Revolution (1966–76), the Mosuo were pressured to change their way of life. According to Lama Luo Sang Yi Shi (a Mosuo who holds a county-government title but is primarily a spiritual leader), “during the Cultural Revolution, the governor of Yunnan came to Yongning. He went into Mosuo homes and cursed us, saying that we were like animals, born in a mess without fathers. At that time, all of the Mosuo were forced to marry and to adopt the Han practice of monogamy; otherwise, they would be punished by being deprived of food.” During this period Mosuo couples lived with the woman’s family, and divorce was not permitted. But even though they held marriage certificates and lived with their wives, the men kept returning to their maternal homes each morning to work.

Luo Sang Yi Shi criticized this attempt to change the Mosuo and explained that “at the end of the Cultural Revolution, the Mosuo soon returned to their former system of ‘friend marriage.’ A small family is not good for work. Also, mothers and their daughters-in-law cannot get along well.”

Today the Mosuo maintain their matrilineal system and pursue sisi relationships. Yet how long will this remain the case? The government of Yunnan recently opened Lugu Lake to tourism, and vans full of visitors, both Chinese and foreign, are beginning to arrive. To some degree, this added exposure threatens to envelop the Mosuo in a society that is becoming increasingly homogeneous. Yet the tourists are drawn not only by the beauty of the lake but by the exotic qualities of the Mosuo people. Ironically, their unique qualities may well enable the Mosuo to endure and prosper.

We asked Ge Ze A Che, the Luoshui village leader, if tourism would change the lives of the Mosuo. “It has already changed their lives to some extent,” he observed. “Our young people now like to wear Han clothes, speak Chinese, and sing Chinese songs. In the future they will lose our people’s traditions and customs.”

And what would happen to “friend marriage”? we wondered.

“It will also change—but very, very slowly!”
Terry Roberts is a builder in Cambridge, England, whose hobby is breeding birds. Not just any old birds. His aim is to breed a hybrid between a chaffinch and a canary. Ever since the 1500s, when canaries were first kept in captivity, enthusiasts have been fascinated by the possibility of hybridizing them with other finches. In the nineteenth century, coal miners used canaries to warn them of poisonous gas underground. If the canary fell off its perch, it was time to get out. Miners became fond of their birds, and as well as breeding the canaries with one another, they started to produce crosses—or mules, as they called them—with British finches such as goldfinches and greenfinches. Finch mules have always been more difficult to breed than the canaries or finches themselves, but some were less difficult.

Females may have a chance to be picky about their mates even after the sperm are on their way to meet the egg.

HIDDEN CHOICES OF FEMALES

By Tim Birkhead

Shortly after entering a female's reproductive tract, some human sperm (blue) are engulfed by white blood cells (orange) and destroyed before they can reach the egg.
that others. The ease with which a mule can be produced depends on the evolutionary similarity between the two species. The canary is, after all, a kind of finch. The greater the genetic similarity between the two species, the easier the mule is to produce. The reason the chaffinch–canary mule is so elusive is that the chaffinch is genetically less similar to the canary than are other finches. But this explanation is far from complete. A male chaffinch may be happy to copulate with a female canary, but something in the female’s oviduct recognizes the chaffinch ejaculate as alien and prevents his sperm from either getting near the egg or fertilizing it. The female possesses some mechanism telling her that chaffinch sperm are not right and, on 99 percent of occasions, blocking further progress.

We do not know exactly what this process might be in the canary, but studies of the chicken indicate that the block to the sperm’s progress lies in the vagina. If you artificially inseminate a chicken with semen from a turkey, few if any of the sperm find their way into the females’ sperm store, and at best, only 2 to 3 percent of the eggs will be fertile. If, however, you were to perform a deep artificial insemination, placing the turkey semen beyond the vagina, you would find that 20 to 30 percent of the eggs would be fertilized and produce viable offspring.

Something very similar happens in fruit flies. If one fruit-fly species inseminates another, the female may fail to lay any eggs. If you dissect one such female and examine her reproductive tract under a microscope, you see that she has received plenty of sperm, so her failure to reproduce is not due to a shortage. In fact, her sperm stores are likely to be full, so it looks as though the sperm are trapped there and unable to get out. Speculating that the sperm were waiting for the right message,
Mice provide an even more remarkable example. The rate at which sperm are transported through a female’s oviduct depends upon the match between the male and female genotypes. In mice, the signal that facilitates sperm movement probably does not reside in the seminal fluid but is provided by the sperm themselves. This is an unexpected finding, because for a long time, sperm were thought not to express on their surface any of the genetic material they carry in their highly condensed nucleus. However, an increasing number of studies indicate that sperm must “advertise” something about themselves—otherwise, how could the female’s body sense whether a particular male’s sperm was a good match and transport it? Referred to in convenient shorthand as female sperm “choice,” this process hardly lends itself to observation, since it takes place at a microscopic level and inside the female reproductive tract. For this reason, it is known as “cryptic female choice.”

The idea came of age in 1996 with the publication of Female Control: Sexual Selection by Cryptic Female Choice, by William G. Eberhard, a staff scientist at the Smithsonian Tropical Research Institute. In the book, Eberhard documents dozens of instances, across the entire animal kingdom, where females might exert postcopulatory control over which male—or which sperm—fertilizes their eggs. In the 1940s and 1950s, however—long before Eberhard’s work—a few reproductive biologists had speculated that the female reproductive tract might do rather more than simply act as a conduit for sperm and eggs. Later, in the 1980s, Randy Thornhill, of the University of New Mexico, drew specific attention to the idea that females might copulate with several males and then, only after having received their sperm, would discriminate among them. Although Thornhill’s 1983 paper about cryptic female choice in the scorpion fly was a landmark, there was no intellectual stampede to see whether cryptic female choice was fact or simply a nice idea. Immediate interest may have been lacking not only because behavioral ecologists were still busy trying to demonstrate the kinds of choices females make before mating but also because the social climate was not right; scientists were still entrenched in a male view of sexual selection.

In hindsight, it seems entirely logical that under certain circumstances, females would benefit from being able to control which sperm fertilized their eggs. The most likely circumstance in which such an ability might evolve is when females have limited control over their choice of mates. Throughout the natural world, females can exert considerable choice over who inseminates them, but there are some instances in which females are bullied or coerced into copulating. In many insects, such as the yellow dungfly, females are simply grabbed and forcibly copulated with by the larger males. Much the same appears to happen in some reptiles and in several ducks. In these circumstances, it seems obvious that females would benefit from being able to reject ejaculates from unattractive males and retain those from preferred males.

Many female animals eject sperm following insemination. In some species, including humans, ejection appears to be relatively passive, whereas in others, such as zebras, sperm are forcibly ejected, presumably by powerful muscular contractions of the reproductive tract. If cryptic female choice is reality and not fantasy, and if females possess the ability to reject or accept the sperm of particu-
lar males, an interesting evolutionary scenario emerges. It means courtship isn’t the only arena of choice: even after mating, each sex continues to battle for control.

Eberhard has identified at least twenty different ways in which female insects can modify or control the outcome of mating with two or more partners. Obviously, at a behavioral level, female animals can decide which male to copulate with. This is particularly true when a cryptic female choice occurs in the comb jelly _Beroe ovata_. I well remember seeing preserved comb jellies in my undergraduate practical classes, mainly because they never looked anything like the illustrations in our textbook. In life, _B. ovata_ is a beautiful, bell-shaped beast, but as a museum specimen it resembles nothing more than a blob of mucus, albeit a large one. Years later, off Cabot Island in the Canadian Arctic, I saw my first live comb jelly. It was exquisitely beautiful: fist-sized, blood-red, and bearing row upon row of iridescent cilia driving it slowly through the icy waters. Embryologists working earlier in this century were also in love with _B. ovata_ because its large (one millimeter in diameter), uniquely transparent eggs flagrantly exposed the secrets of fertilization. Years after seeing my first live comb jelly, I gave a talk at the Spermatology Congress in Cairns, Australia, to a varied audience that included andrologists (clinicians who study human male reproductive biology), anatomists, and a smattering of developmental biologists. They were titillated by the evolutionary view of sperm competition and openly skeptical of the possibility of cryptic female choice. But Gerry Schatten, a reproductive biologist now at Oregon Health Sciences University and a specialist in what happens inside the egg just after fertilization, came up to me afterward and told me about two French biologists who had recently described something that he thought sounded like cryptic female choice going on in a _B. ovata_ egg. Typically, several sperm

Since sperm competition is played out inside the female’s body, it may be relatively easy for females to manipulate sperm.

copulatory choice. Even after she has started to copulate with a male, however, a female can exert choice in a variety of ways. She may allow a male to copulate with her but then, by failing to provide the right sensory feedback, prevent him from transferring sperm. A female may also regulate the duration of copulation. In many insect species, sperm transfer can take several minutes and sometimes even hours. By regulating the duration of copulation, a female can manipulate how much sperm she receives from a particular male and hence the likelihood of that male’s fertilizing her eggs. Females that cannot regulate the duration of copulation might be able preferentially to retain or eject the sperm from particular males. Or a female may fail to transport the sperm of particular males to storage organs or to the point of fertilization. Still another possibility is for her to control either her ovulation or the maturation of her eggs after she is inseminated by certain males. Even after fertilization has taken place, a female has the potential to exert some control over her reproductive success by the differential abortion of zygotes, by the preferential nurturing of those fathered by particular males, or even, conceivably, by the selective feeding or killing of neonates.

One of the most extraordinary and convincing examples of cryptic female choice occurs in the comb jelly _Beroe ovata_. I well remember seeing preserved comb jellies in my undergraduate practical classes, mainly because they never looked anything like the illustrations in our textbook. In life, _B. ovata_ is a beautiful, bell-shaped beast, but as a museum specimen it resembles nothing more than a blob of mucus, albeit a large one. Years later, off Cabot Island in the Canadian Arctic, I saw my first live comb jelly. It was exquisitely beautiful: fist-sized, blood-red, and bearing row upon row of iridescent cilia driving it slowly through the icy waters. Embryologists working earlier in this century were also in love with _B. ovata_ because its large (one millimeter in diameter), uniquely transparent eggs flagrantly exposed the secrets of fertilization. Years after seeing my first live comb jelly, I gave a talk at the Spermatology Congress in Cairns, Australia, to a varied audience that included andrologists (clinicians who study human male reproductive biology), anatomists, and a smattering of developmental biologists. They were titillated by the evolutionary view of sperm competition and openly skeptical of the possibility of cryptic female choice. But Gerry Schatten, a reproductive biologist now at Oregon Health Sciences University and a specialist in what happens inside the egg just after fertilization, came up to me afterward and told me about two French biologists who had recently described something that he thought sounded like cryptic female choice going on in a _B. ovata_ egg. Typically, several sperm
penetrate the egg. The female's genetic material in the pronucleus then glides through the cytoplasm, visiting each male pronucleus in turn before returning to one and fusing with it. (The parallel between the precopulatory choice of females in species that form leks—groups of displaying males—and what happens inside B. ovata's egg is striking.) Thus here, at the level of organelles, cryptic choice appears to be occurring. Unfortunately, we know little more than this—including whether the sperm that an ovum appears to choose are from the same or different males. Clearly B. ovata provides an opportunity to investigate the basis of cryptic choice.

Recent research has made it abundantly clear that females are not passive participants in sexual reproduction. When one set of contestants comprises a swarm of tiny, highly mobile sperm and the other a few large, immobile eggs, there is a certain inevitability about the outcome. Males, however, do not have everything their own way, and at least for species with internal fertilization, the evolutionary battleground where sexual conflict occurs—the female reproductive tract—is designed by evolution to counter the ability of sperm to run circles around eggs. This is perhaps the most significant discovery in reproductive biology of the past two decades—that male and female reproductive attributes coevolve. Both sexes are in a state of dynamic flux, each evolving in response to adaptations in the other. The idea that there exists a battle between the sexes implies there are winners and losers, but if we think about sexual interactions as part of a coevolutionary process of adaptation and counteradaptation, it is not obvious that either sex can ever be a clear winner. At any moment, one sex may have slightly more control than the other, but the battle between the sexes is an evolutionary seesaw—subtle, sophisticated, and inevitable.
was originally drawn to study treeshrews not just because I am fond of small, little-known creatures but also because they were reported to have one of the most enigmatic parental care systems known among mammals. During the 1960s, at a research facility in Seewiesen, Germany, Robert Martin had observed the maternal behavior of several species of captive treeshrews. He found that the mother treeshrew gives birth to tiny, hairless young in a nest remote from her own and then seemingly abandons them, apart from a visit of about two minutes once every other day to suckle them. Surprisingly little information was available about the ecology of wild treeshrews that might have put this odd behavior in context or revealed its function. Intrigued, I decided to see how they live in the wild. So I went to the island of Borneo, which has more species of treeshrews than anywhere else.

Treeshrews suffer from a chronic case of mistaken identity. They are not shrews, and most are not found in trees. Nor have scientists agreed on just where they fit into the mammalian family tree. For most of the past century, scientists thought they were primitive primates, but more recent evidence shows that these mammals form an order of their own, the Scandentia. I began my study in Sabah, one of two Malaysian states on the island of Borneo. There the local people refer to treeshrews and squirrels by the same common name: *tupai*, a Bahasa Indonesian word reflected in the scientific name for treeshrews (*Tupaia*). The twenty or so species in the subfamily Tupaiinae are active forest creatures whose alertness borders on the neurotic. They have brownish fur; large, dark, lashless eyes; short, bare ears; and a large, wet nose pad, like a pencil eraser on the tip of a long muzzle. Males and females are outwardly identical. Squirrel-like in size and color, with a long bushy tail they flick to signal danger, treeshrews chatter, whine, or whistle when alarmed. At a sudden noise, they flinch as if struck. It is hard for a biologist in the field to escape their notice, so it is hard to observe them closely. One usually catches a brief glimpse of a small brown animal flashing across a trail, racing down a log, or bounding from sapling to sapling. To get the information I wanted, I needed to follow them continuously.

Sabah is a quiet, rural region on Borneo’s northern tip, where at least seven species of treeshrews dwell in the remaining tropical rainforest. From 1989 to 1991, my fieldwork there took place on the ridges and steep ravines of Mount Kinabalu, at the Poring HotSprings ranger station, and in the evergreen dipterocarp forest of the Danum Valley Conservation Area.

Among the most satisfying moments for a field biologist is the instant of realization that one can predict where an animal or plant can be found. At that moment, one has begun to understand the organism. Over the course of several months, I learned to identify treeshrew species by walking along trails in the study area and by catching the animals in live traps baited with bananas. The captured treeshrews were fitted with radio collars and released. My assistants and I were then able to follow them on all their daily travels. I studied five of the nine Bornean species in the genus *Tupaia*: the mountain, the slender, the plain, the lesser, and the large treeshrews. I also studied the pentail treeshrew, *Ptilocercus lowii*, the sole member of its subfamily and considered to be the closest in general form to the ancestors of treeshrews. *Ptilocercus* is the only

A large treeshrew, or *Tupaia tana*, prepares to feed. Avid insectivores, treeshrew species differ in their choice of invertebrate prey. Some rummage through moist fallen leaves for earthworms, others scan low-growing foliage for caterpillars, and some hunt in trees for ants and termites.

For treeshrews in the forests of Borneo, a good mother is an absent mother.

By Louise Emmons
More kinds of treeshrews are found on the island of Borneo than in any other part of the world. Right: The tropical rainforests of Sabah, a Malaysian state in northern Borneo, are home to at least seven species.

Nocturnal treeshrew, is strictly arboreal, and also offers other contrasts with the more typical and numerous Tipaisa species.

All treeshrews are adept climbers and leapers, but unlike virtually all other families of tree-leaping mammals, among treeshrews truly arboreal lifestyles are rare. Nevertheless, even the large treeshrew, Tipaisa tana, one of the most terrestrial species, occasionally travels by clinging, leaping, and jumping, moving with ease from one understory sapling to the next. Because pentails, the species most like the treeshrew prototype, are arboreal in morphology and habits, I hypothesize that the living nonarboreal treeshrew species probably derive from a tree-dwelling ancestor.

Treeshrews are strongly insectivorous but supplement their diet with fruit. As soon as my assistants and I began to radio-track them, we discovered that they often spent much of their day around fruit trees. At Poring figs were abundant and seemed to be the favorite, but other relatively small, soft fruits were also consumed. Although the home ranges of the treeshrews I observed in Sabah varied up to tenfold in size depending on the species, the most evident specific destination and focal point of a day’s activity in a home range would often be a fruit tree. One of my more exciting discoveries regarding their diet came as I watched a plain treeshrew feeding on a small green fruit. After chewing, the animal spit out wads of plant fiber with the juices sucked out, a habit previously observed only in bats.

While treeshrew species overlap in their choice of fruit, they differ in their choice of invertebrate prey. The way treeshrews divide up feeding roles
closely parallels the way birds segregate into highly specific insect-feeding guilds. Beetles, ants, spiders, caterpillars, and cockroaches were the categories of insects most often taken in Sabah. But each treeshrew species had a specialty—and a different tactic for finding its preferred prey. In effect, species that foraged in the same microhabitat further divided the turf, thus avoiding competition. Among the three terrestrial species that shared the lowland forest floor, for example, one gleaned the undergrowth foliage for caterpillars, one gathered ants and termites from surfaces other than foliage, and the third dug into the decomposing leaf litter and woody surfaces for earthworms, as well as feeding on noxious arthropods, such as centipedes and scorpions, that were not eaten by the other two species.

The outstanding feature of treeshrew activity is the sheer amount of it. Most of the animals' time and energy seems to be spent in solitary foraging and feeding. The long, active days and the lengthy routes the treeshrews traveled showed that their food supplies were scattered, small, and hard to find. The *Tupaia* species we followed left their nests before 6:00 A.M., just as the first gray light touched the forest floor, and returned about eleven hours later. All had multiple sleeping sites and moved from site to site almost daily. None of the 204 sleeping sites we identified was used by more than one individual at a time, and although pairs shared a defended territory, mates never shared a nest. In contrast, the pentails behaved quite differently: the one group we followed used just one sleeping site, with up to four nestmates sharing it.

The nest site is a primary defense against exposure and predation. All six species I studied in Borneo had different kinds of sleeping sites. Some were in the tree canopy, others in the mid- or understory. The site could be in a woody crevice or tree hollow or tucked into a tangle of vines. Very unexpectedly, and thanks to radio tracking, we found that one species, the plain treeshrew, even nests in underground burrows. All the nests were quite similar, each consisting of a sphere whose outer shell of large, overlapping leaves surrounded an inner lining of woody fibers. (Some of the nests built in hol-

**Although few treeshrews have a truly arboreal lifestyle, all are adept climbers and leapers, moving easily through the understory.**
Helpless and bare, newborn treeshrews are left in the nest unattended except for brief maternal visits. The system works, as evidenced in these photographs taken at the National Zoo in Washington, D.C. A nestling is able to drink about one third of its weight in milk in a minute flat, storing it in a relatively huge stomach, above. A litter, right, limited to two, thrives on this regimen and remains in the nest for more than a month.

My field colleague Alim Biun used his forester's skills to build a small platform, completely screened with palm fronds, six feet up in a tree a few yards from the nest hole. From there we could watch and videotape F109's visits (although not the goings-on within the nest). In the predawn darkness, one of us would climb into the blind and wait silently, listening for the female's radio signal through an earphone. We saw her come to the nest six more times, but we also kept watch on some of the alternate days to verify that she did not approach on those days. During our intensive monitoring of this female for twenty-three of the presumably thirty-four or so days of her lactation, we were able to verify that the absentee care system did indeed exist in the wild.

On April 26, just after F109 had paid a nursing visit, we climbed to the nest and found two young, which we extracted briefly to weigh, measure, and mark with ear tags. Within the cavity, the newborns were curled in a clean nest of overlapping leaves lined with woody fibers. On her nursing visits, which were always in the early morning, F109...
spent an average of less than three minutes in the hollow. On one visit she carried a single leaf in her mouth into the hole but left without it. She often varied her path, coming and going by different routes. Sometimes she jumped from tree to tree on slender understory saplings without touching the ground anywhere near the nest tree. Instead of running up or down the tree, she usually jumped to it from a neighboring treecat at the level of the nest entrance. The radio signal, too, indicated that she was wary, often hesitating nearby before running into the nest. Before exiting the hole, she would poke her head out and scan the surroundings. We never heard any vocalizations or deliberate sounds made by mother or young, and the timing of the visits—while the early morning light was still wan—further cloaked F109’s movements. In all ways, the visits were as discreet as possible.

Miles Roberts, of the National Zoo in Washington, D.C., has videotaped and vividly described some of the nursing behavior of tree shrews in the zoo. His account also hints at some of the adaptations that maintain the absentee system. The female enters and perfunctorily makes herself available to the young. Sensing their mother’s presence, the hairless young “push themselves up on wobbly forelegs and thrust their heads up as high as they can... waving their heads in the air like leeches searching for warm-blooded prey. Within seconds, each makes contact and nurses at one of her four nipples with what can only be described as hysteria.” After switching nipples a few times and consuming about one-third their weight in milk within sixty seconds, the babies are bloated and the mother is restless. “Suddenly, with no warning, without as much as a departing look, she simply vanishes. The babies, engorged and seemingly intoxicated with milk, collapse onto one another and laboriously reconfigure themselves into the huddled ball that will best conserve their body heat. Within seconds, they enjoy the sleep of the dead.”

In the case of F109, the pattern of alternate-day visits varied only once, a variation also noted by Martin. On the day before the young emerged from the tree hole, the female fed them on an “off” day. When the nestlings finally ventured out, they were at least thirty-four days old. On the day they emerged, Alim, stationed in the blind, saw F109 arrive at a quarter to seven in the morning. Two minutes later, she exited slowly and stopped on the branch of a sapling. The two young came out of the hole and shakily climbed down the side of the tree. When they reached the ground, the mother left for several minutes, returning with food for them. She licked them and then “trained” them to follow her by calling, moving away, waiting for them to approach, and then repeating the process. F109 spent the whole first day and night with her young. They slept on the ground in a thicket under the shelter of a log. The only time she left them during the first two days was when she raced down to the stream and back, presumably to drink. On the second day, she led them to another nest site in a dense treefall, where she left them. That night, she went back to a nest of her own and thereafter did not spend the night with her offspring. In contrast to her abrupt treatment of the young in the nest, however, she spent many of the daylight hours with them. Because she often joined them in the early morning, she may have continued to nurse them, but the young also began to forage on their own soon after they left the nursery nest.

F109’s mate, M111, which we had also radio-collared, spent a lot of time with her while the young were nestbound and, according to his radio signals, was always somewhere on the home range they shared. But on or about the day the young emerged, he suddenly disappeared. After a month we picked up his signal again; we don’t know exactly when he returned, but by August he seemed to have taken up residence in the territory again. Perhaps he had found a neighboring female to breed with, or perhaps F109 had driven him away when her newly emerged young were still vulnerable. (I did once see her violently drive another T. tana away from the next tree.)

To succeed, the absentee maternal system requires a suite of behavioral, physical, and physiological adaptations. A major feature of the system is the limit of two young per litter. The transfer of milk is highly specialized: the mother must be able to store and then instantly release two days’ worth of milk, and the young must be able to consume it rapidly through intense suckling and store it in a giant stomach. In addition, the newborns need to stay warm on their own, resist dehydration, and save energy by refraining from movement, including the exploratory behavior common in young mammals.
Thus, after feeding, the nestlings sleep close together for up to forty-eight hours.

While we had largely expected to corroborate Martin's nest observations, we were surprised to see the enormous amounts of attention the T. tana female gave her offspring after they left the nest. *Tiupaia* species had previously been viewed as exhibiting the least possible amount of maternal care among mammals, showing barely the rudiments of behaviors that are normal in other nesting species. But the long, attentive postnesting care we observed in T. tana suggests that treeshrews are not maternal minimalists. After leaving the confines of their tree hollow, the offspring were groomed, possibly still suckled, and possibly taught to forage. Newly emerged young may need help to survive the weaning phase and adapt to the arduous life of an adult treeshrew. Most nesting mammals invest considerable time and energy in the physical care of nestlings and then abandon them as soon as they emerge. Treeshrews—at least *T. tana*—seem to have reversed the usual sequence of care.

How and why might the absentee system have evolved in these creatures? The cautiousness of treeshrews on approaching the nursery nest suggests that avoiding predators has played a role. In Sabah the predators include various birds of prey and small felines, such as marbled cats and leopard cats. Among other mammal species that have an absentee maternal system (or something similar) are hares, rabbits, deer, and antelope, all of which must run to escape predators. Their young lie hidden until they are old enough to flee their predators, and the rarity of the mother's visits helps keep them inconspicuous. Elephant shrews (no relation), pikas, and *Tiupaia* treeshrews share both absentee-like maternal care and diurnality—that is, they are active during the day, when prey is more easily spotted by predators. *Tiupaia* treeshrews, however, differ from other species with absentee-like maternal care in that the adults and young use nests and the young are altricial, or helpless at birth. Like squirrels and other small mammals, *Tiupaia* treeshrews use nests as shelters from predators and the elements.

Adult treeshrews have a very strong, musky odor, but when I sniffed the nursery nest and the young, I found both clean and dry, with no perceptible scent. If the mother had stayed in or around the nest, she might have imbued it with a pungent, predator-attracting scent. My observations of yellow-throated martens—large, weasel-like carnivores that hunt by day, diligently sniffing high and low throughout the forest—lead me to think that a treeshrew mother's long absences from the nursery and her roundabout approach to the site are a way of keeping the nestlings away from the attention of such energetic predators. However, I believe that the main evolutionary stimulus for the absentee maternal behavior of treeshrews might be that less of the mother's energy is needed to raise young in this specialized way.

Treeshrews do not appear in the fossil record until about 9 or 10 million years ago—a relatively late date, although they may have existed long before this, and we simply have not yet found their fossils. But treeshrews offer a plausible model of how much earlier mammals might have lived. In size, shape, limb and tail proportions, and even skull outline, some Jurassic mammals that lived alongside the dinosaurs 150 million years ago resembled treeshrews. Our work suggests that these earliest inconspicuous and insectivoruous mammals may well have branched out—adopting slightly different foraging modes and specializing in different prey—without undergoing much physical fine-tuning. Similarly, the look-alike *Tiupaia* treeshrews give little hint of the different roles they play in their shared habitat. Thanks to the array of these small mammals in the northern forests of Borneo, we can now see treeshrew species as distinct ecological entities.
IN SUM

BEETLE BITES
Beetles are the world’s most abundant insects, but the fossil record reveals little about when they diversified. Although there is an excellent fossil record of flowering plants during the Cretaceous, remains of leaf beetles from this period are almost nonexistent, and their fossilized bodies begin to appear in the rocks only 20 million years later.

Since most of the 40,000 known leaf beetle species specialize in feeding on flowering plants, Peter Wilf, of the University of Michigan’s Museum of Paleontology, and colleagues examined fossils of ginger leaves from the Late Cretaceous (66 million years ago) for signs that the beetles had been present. Many fossil leaves, they found, displayed patterns of bite marks characteristic of rolled-leaf hispine beetles, a group that today specializes in eating ginger leaves.

Larvae of these beetles live within the rolled-up leaves of the plant, and their feeding produces a unique pattern of linear strips between the leaves’ veins. (Adult beetles produce a different feeding pattern on the unfurled leaves.) The trace fossils from North Dakota and Wyoming, dating from the Late Cretaceous and early Eocene (52–53 million years ago), push the evolution of hispine beetles back nearly to the time of origin of their flowering host plants. (“Timing the Radiations of Leaf Beetles: Hispines on Gingers From Latest Cretaceous to Recent,” Science 289, 2000)

DIMINISHED RETURNS
Although perching birds stop to rest during migration, many shorebirds make long, continuous transoceanic flights, during which they do not eat. Until recently, scientists believed the birds relied only on stored fat as fuel.

Phil F. Battley, of the Australian School of Environmental Studies, working with a team of ecologists from the Netherlands and China, recently tested that assumption in a study of the great knot (Calidris tenuirostris), a medium-sized shorebird. The great knot flies 3,000 miles from northwest Australia to its breeding ground in eastern China. Samples of the migrants were tagged in Australia and recaptured in China. When Battley and his team weighed and measured the knots’ organs, they found that all the birds showed significant weight loss in their kidneys, liver, skin, and pectoral muscles and that these organs were reduced in size—evidence that large amounts of protein, as well as fat, are utilized during flight. (Once the knots reach their breeding ground, the liver can triple in size in two weeks, while the stomach and kidneys can increase by almost 50 percent.)

Researchers believe that although fat provides the fuel for sustained effort, protein is an essential component of the chemical reactions that convert large quantities of fat into energy during prolonged and extraordinary efforts. From the breakdown process of fat, birds lose important compounds that need to be replenished by amino acids (protein). In addition, their brains require glycogen, which cannot be manufactured without protein breakdown. (“Empirical Evidence for Differential Organ Reductions During Trans-Oceanic Bird Flight,” Proceedings of the Royal Society of London B 267: 191, 2000)

Butterfly Antiaphrodisiac
In the green-veined white butterfly Pieris napi, when a male mates with a female, it transfers, along with its sperm, a chemical chastity belt that wards off other males for a period of time. The chemical, methyl-salicylate, a volatile repellent, is then emitted by the mated female, allowing her to lay her eggs without being harassed by other males. (Persistent suitors can drive a female down among the vegetation, where predatory small mammals, lizards, or insects may lurk.) Males also benefit from a mating system in which females retain sperm before fertilization, and in which the last male to deposit sperm fertilizes the eggs.

Johan Andersson, of the Ecological Chemistry Group at Stockholm’s Royal Institute of Technology, and colleagues have demonstrated that only male butterflies can produce the antiaphrodisiac. Its effects are so strong that most males will refrain from mating even with virgin females (ordinarily more sought after than nonvirgins) to which it has been artificially applied. When P. napi males mate, they also transfer nutrients to the females, increasing the females’ fecundity and longevity. The researchers are still trying to discover which sex controls the gradual decrease in the methyl-salicylate shield that allows females to eventually regain their attractiveness and re-mate. (“Sexual Cooperation and Conflict in Butterflies: A Male-Transferred Antiaphrodisiac Reduces Harassment of Recently Mated Females,” Proceedings of the Royal Society of London B 267: 1271, 2000) —Richard Milner
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**The Search for LUCA**

Did the Last Universal Common Ancestor look like a bacterium—or like one of your own cells?

By Matt Ridley

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**EUKARYOTE FAMILY PORTRAIT**

What was the first organism with DNA like? Scientists have traditionally assumed it was some kind of primitive bacterium. But recent research suggests that the long-looked-for “it” may have been more of a “them.” And according to a controversial new theory, the first organisms equipped with DNA may have resembled one of our own cells more closely than they resembled bacteria.

All living creatures—be they amoebas, beech trees, beetles, or bacteria—share a common ancestor that lived about 4 billion years ago. We infer the existence of this Last Universal Common Ancestor—or LUCA—from the many features shared by all organisms, most notably the unique code that translates the language of DNA into the language of proteins, the things that actually do all the work inside cells. If there were other, rival life-forms here on Earth, they died out long ago.

By comparing the similarities and differences in the genes of different organisms, we can climb down the family tree and observe where it branches. Take our own lineage. Five million years ago, the *Homo sapiens* branch meets that of chimpanzees; a few million years before that, the common ancestor of humans and chimps merges with gorillas; and so on, back to the first mammal, the first reptile, the first vertebrate, the first multicellular animal. Finally we get to the common ancestor of all animals, plants, protists, and fungi. This undoubtedly tiny organism was the last common ancestor of all present-day eukaryotes (organ-
isms possessing cells with a nucleus).

At this juncture, scientists long thought, there was only one convergence left: between eukaryotes and prokaryotes (single celled organisms with no nucleus). For most of the twentieth century, prokaryotes had generally been considered synonymous with bacteria. But in 1977 Carl Woese, of the University of Illinois, found a fundamental division within the prokaryotes: between bacteria and what he called archaea, a diverse group of cells that look very like bacteria but differ genetically and are often found in extremely hot environments, such as hot springs, with temperatures above 203° F. Woese tallied up the genetic differences between the two kinds of prokaryotes and concluded that the tripartition of life—into eukaryotes, bacteria, and archaea—must have occurred more than 3 billion years ago. But which of the three groups appeared first? Are we eukaryotes more closely related to bacteria or to archaea?

To find out, researchers in the mid-1980s turned to the enzyme RNA polymerase and other factors involved in the synthesis of proteins, some of the most ancient and universal pieces of machinery in the cell. After comparing these proteins in species from the three groups of organisms, the scientists concluded that plants, animals, and fungi are more closely related to archaea than to bacteria. Comparisons of other proteins, however, contradicted this conclusion: some suggested that eukaryotes and bacteria were closer kin, while still others suggested that archaea and bacteria were.

By the mid-1990s, the situation had become a mess. The only explanation for these contradictory patterns, according to W. Ford Doolittle, of Dalhousie University in Nova Scotia, is to assume that at some point in the early history of life, there was promiscuous sharing of genes among species—or even mergers of whole organisms. Woese agrees. He now thinks that "the Last Universal Common Ancestor was not a discrete entity but rather a diverse community of cells that evolved as a biological unit."

There the matter might have rested but for a meeting convened in 1996 at Les Treilles, near Paris, to discuss the confusing tree of life. Attending that meeting was Patrick Forterre, a scientist from the Université Paris-Sud. Forterre had a heretical view. He challenged the generally accepted idea that bacteria (or archaea) predated all other creatures on Earth. He even doubted that they were primitive. The long-standing "prokaryote dogma," he claimed, was based on the prejudice that the simple must precede the complex. His own work on a bacterial enzyme called DNA gyrase had convinced him that bacteria are actually quite advanced. Gyrase is a powerful and sophisticated tool—and it's a tool eukaryotes do not possess. The more Forterre considered the streamlined simplicity and effectiveness of a bacterial cell, the more he was convinced that the clunky machinery in eukaryotic cells represented an older, more primitive technology.

Frottere and his colleague Hervé Philippe have now gathered many examples that support their case. Take RNA polymerase. This enzyme creates working copies of DNA (called messengers) used in gene translation. The version we eukaryotes use has up to thirteen components, each made by a separate gene. In addition, it is assisted by twenty or so "transcription factors," by a ten-part "spliceosome" (a machine whose job it is to cut out the pieces of nonmessage text, called introns, that interrupt eukaryotic genes), and by a six-part "polyadenylation device." The RNA polymerase used by archaea also has a large number of components (eight to twelve) and is assisted by only two or three other genes.

The truly striking contrast, however, appears in the version used by bacteria, which has just three components and a single assistant. The traditional view would be that the complications found in eukaryotic RNA polymerase were added over the eons. But it could just as easily have happened the other way round, with bacteria slimming down the RNA polymerase machinery to its most efficient form. In plants, animals, and fungi, the synthesizing, capping, splicing, polyadenylating, and transporting of a DNA messenger takes about thirty minutes. In bacteria, the process is completed in a matter of seconds.

Frottere argues that his scenario of moving from a complex eukaryote-like common ancestor to a simpler but more efficient prokaryotic system is more appealing than the classical hypothesis that views prokaryotes as the more primitive organisms. Appealing, maybe—but how strong a case can be made for his idea?

There is no question that simplification does occur during evolution. Over time, parasitic lineages lose sense organs and brains they do not need. Microsporida are a good example. These pathogens were once thought to be a missing link between primitive prokaryotes and advanced eukaryotes because they are so simple and because they lack mitochondria. We now know that microsporida are nothing so special—they're merely cousins of fungi that have become drastically simplified by their parasitic life. Likewise, many biologists are convinced that viruses, which borrow the biochemistry of their hosts to reproduce themselves, are not derived from primitive independent life-forms but are little packets of rogue genes that have escaped from higher organisms. If viruses are reduced organisms, then why couldn't bacteria be as well?

The eukaryotic cell is stuffed full of features that have no counterpart in bacteria or archaea and that, Frottere argues, no self-respecting life-form would invent unless it absolutely had to. We eukaryotes have telomeres, for example: specially constructed caps of DNA on the ends of chromosomes that prevent the tips from fraying. (Fraying is now thought to be one of the chief
symptoms of aging.) But telomeres are unnecessary in bacteria, which have circular chromosomes and thus no ends to fray. And then there are our spliceosomes: bacteria have no introns and thus no need for spliceosomes.

The most convincing part of Forterre’s case is an argument developed by three New Zealanders: Anthony Poole, Daniel Jeffares, and David Penny, all at Massey University. They point out that a great many of the special features of eukaryotes have working components made of molecules of RNA, which is almost universally regarded as the primitive precursor of DNA. Telomerase, the enzyme that repairs telomeres, has working RNA inside it. So does the spliceosome. And RNA is crucial to the synthesis of proteins. The presence in eukaryotic cells of these working machines made from a more ancient material suggests to Forterre and his like-minded colleagues that they are relics of an earlier age.

Moreover, RNA has a property that DNA lacks almost entirely—it can act as a catalyst to assist chemical reactions. Most current hypotheses about the history of life before LUCA envisage an entire RNA world of “riboorganisms,” with RNA genes and RNA enzymes. Only later, according to these hypotheses, did some fortunate descendant invent both the much subtler catalytic machinery of protein and the much more chemically stable information-storage device called DNA. At that point, RNA was denoted to being the link between DNA and proteins.

If the scenario of an ancestral RNA world is correct, then why, Forterre asks, do eukaryotes have much more complicated RNA machinery in their cells than bacteria and archaea do? And if, as Poole and his colleagues say, all these RNA devices are indeed molecular “living fossils” left over from a different world, then it seems unlikely that eukaryotes would have invented all this machinery to complicate their lives and used an old technology to do so. That would be a bit like finding wooden parts working in the innards of a computer.

Additional support for the idea that eukaryotes evolved before prokaryotes can be seen in the structure of their chromosomes. Each chromosome is a very long molecule of DNA. We humans have twenty-three pairs of them—forty-six separate DNA molecules. Other species of eukaryote have different numbers of paired DNA molecules, but in all of us, the molecules come in separate chromosomes. Compare this with the single, circular chromosome of bacteria and archaea. Now imagine one system evolving from the other. If the prokaryotic system came first, the eukaryotes would have had to chop the ancestral chromosome into sections, add telomeres to their ends, and drop the equipment that closes the circle.

If, however, the eukaryotic system arose earlier, the machinery for making a single circular chromosome would already have been in place: a single enzyme called reverse transcriptase. This enzyme makes a circular DNA copy of an RNA transcript (after the introns have been edited out by the spliceosome). Multiple copies of reverse transcriptase are present in all genomes, having been left there by retroviruses containing genes for the enzyme. The Forterre-Poole hypothesis envisages that some primitive retrovirus left behind a reverse transcriptase gene in a proto-eukaryotic organism, which used it by chance, one day, to make a circular chromosome.

And separate linear chromosomes may not be the only primitive feature of our genome: the very habit of using pairs of chromosomes, one from each parent, may also be a relic from the days when transcription errors were more common and spare copies would thus have come in handy.

If Forterre and Poole are right about eukaryotes being the steam engines of the living world, then how did we manage to remain so successful? The answer may lie in several features of modern eukaryotic cells that bacteria have not invented—in particular, the ability to engulf other cells. This talent allows some protozoa (single-celled eukaryotes) to pursue a largely predatory way of life. It is also the source of our immune system’s ability to consume or otherwise incorporate invading bacteria and sometimes to benefit by their presence. Some bacteria engulfed in this way went on to become mitochondria, symbionts living inside the eukaryotic cell and providing...
it with energy. In addition, the eventual evolution of multicellularity in eukaryotes brought the immense advantages that accompany division of labor in a large body and helped offset the biochemical disadvantages of poorly developed genetic machinery.

As with most attempts to reconstruct the history of life, Forterre’s argument for a eukaryotic LUCA would be greatly strengthened by fossil evidence. The oldest known fossils are the 3.5-billion-year-old stromatolites discovered in western Australia in 1980. These small, pillow-shaped structures were almost certainly laid down by living organisms, but it is difficult to determine for certain what kind of creature built them. Modern stromatolites are usually—but not always—made by bona fide prokaryotes, and the common assumption is that the ancient ones were, too. But there is no hard evidence for this. And last year Jochen Brocks and his colleagues at the Australian Geological Survey Organisation made a remarkable discovery. They extracted hydrocarbon from 2.7-billion-year-old shales in the form of bitumen and subjected it to spectrographic analysis to see what it was made of. They were surprised to find a group of compounds called steranes—hydrocarbons made by eukaryotes but not by prokaryotes. The result, they say, provides persuasive evidence for the existence of eukaryotes 500 million to 1 billion years before the fossil record currently indicates that the lineage arose. In other words, the “age of prokaryotes,” which all the textbooks say preceded the age of eukaryotes, might never have existed.

Forterre’s theory has by no means won the field. But he has done a great service by pointing out what a naked emperor the prokaryotic dogma may turn out to be.

Matt Ridley is the author of Genome: The Autobiography of a Species in 23 Chapters, an adaptation of which appeared in the March issue of Natural History.
Many Hands Stirring Many Pots

Short on recipes but long on learning, a vast history of food caterers to every taste. Almost.

Some twenty years ago in this magazine, I chivied anthropologists for neglecting food in their research on the material culture of human societies. If scholars were willing to record the dimensions of canoe paddles, why not write down how canoe builders fed themselves? This might even have a practical result. Whereas it was improbable anyone would actually reproduce a Bororo paddle, many people might be glad to try an Amazonian recipe for manioc.

In any case, as one could see even then, what we now call globalization was inexorably overwhelming the culinary heritage of marginal—and even not so marginal—cultures. If the recipes of these groups and the lore underpinning them weren't saved, human diversity would be diminished. Something far more easily shared than literature or even music would be lost.

Starting in the 1970s, food historians emerged at the peripheries of academia and began to create an unofficial discipline, often at conferences or in coven of renegade scholars and serious-minded foodies. Epitomizing this intellectual back channel, the 1981 Oxford Food Symposium published its proceedings and sponsored a periodical, *Petits Propos Culinaires*. Oxford still has no chair in food history (nor does any other major university), but in 1999 Oxford University Press published the *Oxford Companion to Food*, by the learned student of fish and fish cookery and the symposium's organizer, Alan Davidson. Having contributed material to it from columns first published in *Natural History*, I hope that I (an admirer of the book) will be pardoned for not discussing it in detail. But I think anyone would say that its 2,650 entries marshal an oceanic amount of information for the thoughtful and curious omnivore.

The act of eating, as well as the acts of food production and cooking that subtend it, is the *Oxford Companion*'s constant focus, from aardvark to zucchini. But the even weightier, brand-new, two-volume, 1,958-page *Cambridge World History of Food*, edited by Kenneth F. Kiple and Kriemhild Coneé Ornelas, is, so to speak, a different kettle of aardvark. Twice as big, far more scholarly and disputatious, it is for the most part as distant from eating in the ordinary sense—from the flavors and even the facts of human eating—as a long book on food could be. So what is it about?

Kiple and Ornelas's history begins in the murky world of "our ancestors," with a technical yet fascinating set of extrapolations based on bones and middens and coprolites (desiccated or mineralized feces), the latter being, according to Kristin D. Sobolik, an anthropologist at the University of Maine, Orono, "a unique source for analyzing prehistoric diet because their constituents are mainly the undigested . . . remains of food items that were actually eaten."

In the next and longest section, fifty-nine authoritative monographs combining biology, history, and contemporary socioeconomic analysis are devoted to domesticated plants and animals. The distinguished *Capsicum* plant authority Jean Andrews, of the University of Texas, Austin, for example, writes on chili (or, as she insists on spelling it, "chilli") peppers. But in all this expert summarizing there is barely a recipe and usually only the sketchiest description of what things taste like. In the course of thousands of fascinating words on camels, anthropologist Elizabeth A. Stephens, of the University of Arizona, goes so far as to explain the method for making yogurt from camel's milk but omits to say how it (presumably) differs in taste or smell or texture from other yogurts more familiar to the (presumably) bovicentric reader.

At the end of a relatively brief section on dietary liquids, James L. Newman, a geographer from Syracuse University, does raise the issue of taste in wines. But my degustation of his essay detected in it a whiff of post-Marxist paranoia about transnational corporations allegedly driving out viticultural

By Raymond Sokolov
diversity and reducing wines from around the globe to a (presumably) stultifying uniformity, all to satisfy the narrow preferences of a cabal of insider wine snobs.

We return to sobriety in the section on nutrients and food-related disorders. The articles herein run the gamut from vitamin A to zinc, from beriberi to scurvy. The section ends on a quietly sensational note, with University of Manchester cardiologist Stephen Seely's pellucid discussion of the physiology of coronary artery disease, in which he deduces from demographic evidence and food-consumption statistics that oats as well as cow's milk may play a decisive role in the delivery of stiffening calcium to the fatty lesions on artery walls.

Whether most of this entirely worthy information belongs in a "history" of food is a legitimate question. Those with a conventional notion of history will, however, find sustenance in volume 2, which includes a survey of all the major culinary sectors of the world. Inevitably, the results are uneven. Marion Nestle, of New York University's Department of Nutrition, Food and Hotel Management, is thorough and compelling on the Mediterranean and its diet, while sociologist Eva Barlösius, of Bonn University, reduces the richest of all the cuisine stories, that of France, to gastrorealpolitik: a tale of decline in global dominance and prestige.

The eighteen essays in the section entitled "History, Nutrition, and Health" cover everything from famine to food fads. And the final section, on contemporary food-related policy matters, ranges over issues of labeling, additives, and public responsibility for nutrition—all the hot buttons of the alimentary present. With grace and finesse, Bowling Green State University historian Kenneth E. Kiple, coeditor of these tomes, ends the encyclopedia with an essay about the relevance of Paleolithic nutrition to modern health.

He ties a neat bow on a lumpy package, but that's not the end of it. Part VIII, a sort of appendix, is a historical dictionary of the world's plant foods. Of course it is incomplete, but it still has much fine gold to pan for—even an entry on the suddenly vogue Viognier grape, which, notes the anonymous lexicographer, "has recently been planted in California, where presumably it will prosper and add even more diversity to the California wine industry."

Who will use this huge and learned work? Foodies will want to look elsewhere for recipes and guidance in matters organoleptic. Specialists won't need to read the essays that summarize their fields so scrupulously. But I'll wager that they and everyone else, from epicure to hunger activist, will soon be consulting these volumes as a quick route to erudition.

In other words, the book is an ungainly but unique beast, and everyone will want to ride it. Yet it is also probably one of the last members of an endangered species—the multi-author encyclopedia in hard copy. The future is digital. Save trees, save time, save your research to disk. In that brave new cyberworld, there will be plenty of room to add recipes to a book that is now almost too heavy to lift and much too dangerous to drop.

Raymond Sokolov, currently the Wall Street Journal's arts editor, is a biographer of A. J. Liebling and a veteran food writer. From 1974 to 1994 he wrote the Natural History column "A Matter of Taste."

PHOTOGRAPHY

The Western Horizon, photographs by Maduff Everton, commentaries and sketches by Mary Heebner (Abrams, 2000; $49.50)
Facts on Foliage

By Robert Anderson

Why do leaves change color? Ask most people this question, and you'll probably get a simple answer, such as "Because winter's coming." Of course, the story is much more complex than that, and at least two good Web sites tell us how nature produces so many vivid hues, seemingly out of thin air.

The first site (willow.ncfes.umn.edu/leaves/leaves.htm) is maintained by the U.S. Forest Service. It explains that the timing of the autumn display, although influenced by rainfall and temperature, is primarily triggered by the decreasing availability of light for photosynthesis as nights grow progressively longer. Also noted is the Forest Service's Fall Color Hotline (800-354-4595), which you can call for reports on peak foliage viewing around the country.

The second good fall-color primer comes from Pacific Union College botanist Bryan Ness. In a feature found at About.com (botany.about.com/science/botany/library/weekly/aa120797.htm?terms=fall+leaves), he goes into considerable detail about the chemistry underlying the fall show. I learned that as leaves die and change color, building materials are salvaged from them for winter storage. The most important of these is magnesium. The green chlorophyll must be broken down to recover this element, and what remains are the less dominant, so-called helper pigments, the carotenoids and anthocyanins, whose yellows, oranges, and reds give the dying leaf its color. Check out Ness's simple chemistry experiment, which reveals the pigments that lie hidden in any green leaf.

Robert Anderson is a freelance science writer based in Los Angeles.

BOOKSHELF

Are We Hardwired? The Role of Genes in Human Behavior, by William R. Clark and Michael Grunstein (Oxford University Press, 2000; $27.50)

Human Natures: Genes, Cultures, and the Human Prospect, by Paul R. Ehrlich (Island/Shearwater, 2000; $29.95)

Microbiologists Clark and Grunstein analyze the relative roles of genes and environment in shaping Homo sapiens. Taking a more panoramic look at human evolution, population expert Ehrlich proposes that our multiple natures are determined as much by culture and environment as by genes.

John James Audubon in the West: The Last Expedition, Mammals of North America, by Sarah E. Boehme, with essays by Annette Bauder, Robert McCracken Peck, and Ron Tyler (Abrams/Buffalo Bill Historical Center, 2000; $45)

Published in conjunction with an exhibition organized by the Buffalo Bill Historical Center in Cody, Wyoming, this compilation of essays and vivid illustrations tells the story behind Audubon's Viviparous Quadrupeds of North America, published after the artist-naturalist's death in 1851.


The protagonist of this tale of disorders and discoveries in the field of neurology is NGF, or nerve growth factor—a hormone that extends the life of neurons affected by diseases such as Alzheimer's and may be the key to treating them.

Dear Mr. Darwin: Letters on the Evolution of Life and Human Nature, by Gabriel Dover (University of California Press, 2000; $27.50)

In a spirited and informed imaginary correspondence with Charles Darwin, geneticist Dover brings the author of the Origin of Species up to date on what's been happening in the field of evolutionary biology.

The Invisible Enemy: A Natural History of Viruses, by Dorothy H. Crawford (Oxford University Press, 2000; $25)

Plague Time: How Stealth Infections Cause Cancers, Heart Disease, and Other Deadly Ailments, by Paul W. Ewald (Free Press, 2000; $25)

Microbiologist Crawford argues that viruses, with their amazing ability to mutate, pose one of the greatest challenges to science. According to Ewald, a biologist of evolutionary medicine, viruses may be responsible for everything from heart disease to diabetes and anorexia.


Tying Down the Wind: Adventures in the Worst Weather on Earth, by Eric Pinder (Tarcher/Putnam, 2000; $24.95)

Inside the Hurricane: Face to Face with Nature's Deadliest Storms, by Pete Davies (Henry Holt, 2000; $25)

Three informative looks at various aspects of the swirling ocean of air that surrounds and sustains the planet.

Mahale: A Photographic Encounter with Chimpanzees, by Angelika Hofer, Michael A. Huffman, and Günter Ziesler (Sterling, 2000; $24.95)

For fifteen years, zoologist Huffman has been studying a community of chimpanzees in Mahale Mountains National Park, on the shore of Lake Tanganyika—vividly documented here in photographs, drawings, and text.
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On Earth As in the Heavens

Until Isaac Newton wrote down the universal law of gravitation, there was little reason to presume that the laws of physics on Earth were the same as elsewhere in the universe. Earth had earthly things going on, and the heavens had heavenly things going on. Indeed, according to many scholars of the day, the heavens were unknowable to our feeble mortal minds. When Newton breached this philosophical barrier by rendering motion comprehensible and predictable, some theologians criticized him for leaving nothing for the Creator to do. Newton had figured out that the force of gravity pulling ripe apples from branches also guides tossed objects along their curved trajectories and directs the Moon in its orbit around Earth.

The universality of physical laws drives scientific discovery like nothing else. Gravity was just the beginning. Imagine the excitement among nineteenth-century astronomers when laboratory prisms, which break light beams into the colors of the spectrum, were first turned to the Sun. Spectra are not only beautiful but contain oodles of information about the light-emitting object, including its temperature and composition. Chemical elements are revealed as unique patterns of light or dark bands that cut across the spectrum. To people’s delight and amazement, the chemical signatures in the light emitted by the Sun were identical to those identified in the laboratory. No longer the exclusive tool of chemists, the prism showed that the Sun, as different as it is from Earth in size, mass, temperature, and appearance, contains the same stuff—hydrogen, carbon, oxygen, nitrogen, calcium, iron, and so forth. But more important than our laundry list of shared ingredients was the recognition that the laws of physics prescribing the formation of these spectral signatures on Earth are also operating on the Sun, 93 million miles away.

So fertile was this concept of universality that it was successfully applied in reverse. Further analysis of the Sun’s spectrum revealed the signature of an element that had no known counterpart on Earth. The new substance was given a name derived from the Greek word for Sun (helios) and was only later observed in the lab. Thus helium became the first—and only—element in the chemist’s periodic table to be discovered someplace other than on Earth.

OK, the laws of physics work in our solar system, but do they work across the galaxy? Across the universe? Across time itself? Step by step, the laws were tested. As with geologists reading Earth’s history in stratified sediments, the farther away we look in space, the farther back we see in time. Spectra from the universe’s most distant objects, whose light has been traveling for billions of years, show the same chemical signatures we see everywhere else. Indeed, a mathematical quantity known as the fine-structure constant, which controls the basic fingerprinting for every element, must have remained unchanged for billions of years.

Of course, not all objects and phenomena in the cosmos have versions of themselves on Earth. You’ve probably never walked through a cloud of glowing million-degree plasma, and you’ve probably never greeted a black hole on the street. What matters is the universality of the laws of physics that describe these phenomena. When spectral analyses were first applied to the light emitted by interstellar nebulae, a signature was discovered that had no counterpart on Earth. At that time, the periodic table of elements had few empty boxes (when helium was discovered, there were two dozen). Astrophysicists invented the name nebulium to serve as a placeholder until they could figure out exactly what was going on. It turned out that in space, gaseous nebulae are so rarified that atoms go long stretches without colliding with one another. Under these conditions, electrons within atoms behaved in ways that had never before been seen in labs on Earth. The hypothetical nebulium was simply the signature of ordinary oxygen doing extraordinary things.

The universality of physical laws tells us that if we land on another planet with a thriving alien civilization, it will be running on the same laws that we have discovered and tested here on Earth—even if the aliens harbor different social and political beliefs. Furthermore, if you want to talk to the aliens, you can bet they won’t speak English or French or even Mandarin. Nor will you know whether shaking their hands—if indeed they have hands to shake—would be considered an act of war or of peace. Your best hope will be to find a way to communicate in the language of science.

Such an attempt was made with the Pioneer 10 and 11 and Voyager 1 and 2...
spacecraft, the only ones with enough speed to escape the solar system's gravitational pull. All four spacecraft bore a golden plaque etched with scientific pictograms showing, among other things, the Sun's location in the Milky Way galaxy and the structure of the hydrogen atom. Voyager also carried recorded sounds from Mother Earth, including the sound of a human heart-beat, whale songs, and selections of music ranging from Beethoven to Chuck Berry. While these offerings humanized the message, it's not clear whether they would mean a thing to alien ears—assuming aliens have ears in the first place. My favorite parody of this gesture was a Saturday Night Live skit that appeared shortly after the Voyager launch. The aliens who recovered the spacecraft had only one reply for Earthlings: "Send more Chuck Berry!"

Science thrives not only on the universality of physical laws but also on the existence and persistence of physical constants. As already noted, the fine-structure constant controls the spectral patterns made by elements. The constant of gravitation, known to scientists as big G, enables Newton's equation to calculate the exact strength of gravitational force. Big G has been implicitly tested for variation over eons. If you do the math, you can determine that a star's luminosity is steeply dependent on it. In other words, if big G had been even slightly different in the past, the energy output of the Sun would have been far more variable than anything that the biological, climatological, or geological records indicate. In fact, there are no known time-dependent or location-dependent fundamental constants—they all appear to be truly constant.

Of all physical constants, the speed of light is probably the most famous. No matter how powerful your engines, you will never overtake a beam of light. Why not? No experiment ever conducted has revealed any object reaching the speed of light, and well-tested laws of physics predict and account for that. I know these statements sound closed-minded. True, some of the most embarrassing predictions believed to have been made in the name of science have underestimated the ingenuity of engineers: "We will never fly." "Flying will never be commercially feasible." "We will never fly faster than the speed of sound." "We will never split the atom." "We will never go to the Moon." You've heard them. But what these predictions have in common is that no established law of physics was invoked to support the claim.

On the other hand, the claim "we will never outrun a beam of light" is a qualitatively different prediction. It flows from time-tested physical principles. Yes, highway signs for interstellar travelers of the future will surely read: THE SPEED OF LIGHT: IT'S NOT JUST A GOOD IDEA. IT'S THE LAW. The good thing about the laws of physics is that they require no law-enforcement agencies (although I do own a geeky T-shirt that says OBEY GRAVITY).

Another class of universal truths are the conservation laws. Under their jurisdiction, certain measured entities remain unchanged no matter what. The three most important of these laws are the conservation of mass and energy, the conservation of linear and angular momentum, and the conservation of electric charge. These laws are in evidence everywhere, from the domain of particle physics to the large-scale structure of the universe.

In spite of this boasting, all is not perfect in paradise. It happens that we cannot see, touch, or taste the source of 90 percent of the gravity of the universe. This mysterious dark matter, which remains undetected except for its gravitational pull on matter we do detect, may be composed of exotic particles yet to be identified. A minority of astrophysicists, however, have suggested
that there is no dark matter—you just need to modify Newton's law of gravity. Simply add a few terms to the equations, and all will be well.

Perhaps one day we'll learn that Newton's gravity indeed requires adjustment. That'll be OK. It happened once before. In 1915 Albert Einstein came up with the general theory of relativity, which reformulated the principles of gravity so that they applied to objects of extremely high mass, a category unknown to Newton and for which his law of gravity breaks down. The lesson here is that our confidence in a law's universality flows from the range of conditions in which it has been tested and verified. The broader this range, the more powerfully that law can describe the cosmos. For ordinary household gravity, Newton's law (still) works just fine. For black holes and the large-scale structure of the universe, however, we need general relativity. Each law works flawlessly in its own domain, wherever that domain may be in the universe.

To the scientist, the universality of physical laws makes the cosmos a marvelously simple place. The psychologist's domain—human nature—is infinitely more complex. In America, classroom curricula can be determined by school board members who vote according to the prevailing social and political winds. Around the world, varying belief systems lead to political differences that are not always resolved peacefully. And some people talk to bus stanchions. The miracle of physical laws is that they apply everywhere, whether or not you choose to believe in them. After the laws of physics, everything else is opinion.

Not that scientists don't argue. We do—a lot. When we do, however, we are usually expressing opinions about the interpretation of ratty data on the frontier of our knowledge. Wherever and whenever a physical law can be invoked in the discussion, the debate is guaranteed to be brief: No, your idea for a perpetual motion machine will never work—it violates laws of thermodynamics. No, you can't build a time machine that will enable you to go back and prevent your parents from ever meeting each other—it violates causality laws. And without violating momentum laws, you cannot spontaneously levitate and hover above the ground, whether or not you are seated in the lotus position (although you could possibly perform this stunt if you managed to let forth a powerful and sustained exhaust of flatulents).

Knowledge of physical laws can, in some cases, give you the confidence to confront surly people. A few years ago, I was having a hot cocoa nightcap at a dessert shop in Pasadena, California. I had ordered it with whipped cream, of course. When it arrived at the table, I saw no trace of the stuff. After I told the waiter my cocoa had no whipped cream, he asserted that I couldn't see it because it had sunk to the bottom. Since whipped cream has a very low density and floats on all liquids that humans consume, I offered the waiter two possible explanations: either somebody forgot to add the whipped cream to my cocoa, or the universal laws of physics were different in his restaurant. Unconvinced, he brought over a dollop of whipped cream to test for himself. After bobbing once or twice in my cup, the whipped cream sat up straight, afloat.

What better proof do you need of the universality of physical laws?

Neil de Grasse Tyson, an astrophysicist, is the Frederick P. Rose Director of New York City's Hayden Planetarium and a visiting research scientist at Princeton University.
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THE NATURAL MOMENT
Tongue Twister

Geckos, which number about a thousand species, are found in almost all the world’s warm climates, from deserts to rainforests. Some consume nectar, pollen, or fruit, and a few large species eat birds and small mammals, but most eat insects. Millions of microscopic hairlike structures on their feet and toes enable them to run up sheer vertical walls, and even across ceilings, with ease.

Most geckos are night stalkers whose pupils are vertical slits, while diurnal geckos have round pupils. Except for a small family of approximately twenty-five species, all geckos lack eyelids. Like snakes, geckos can’t close their eyes, which are protected by a transparent scale, or brille (from the German for spectacles) that is regularly shed and replaced along with the skin.

Among desert-dwelling species, such as the giant ground gecko (Chondrodactylus angulifer), eye licking is a typical grooming behavior, performed to clear the scale of windblown sand. In the cool of the evening, these six- to seven-inch-long lizards become covered with dew from condensed fog, which they drink by licking their own heads and bodies. They ignore standing water and puddles.

While photographer Martin Harvey was camping in southwestern Africa’s Namib Desert, this giant ground gecko was attracted to the insects around his camp light. After capturing the lizard and photographing its behavior, he released it into the African night.

—Richard Milner

Photograph by Martin Harvey
ENDPAPER

A few years ago in the Midlands of England, I witnessed a crowd gathered around a grass snake in a meadow near a footpath. The onlookers were buzzing with excitement because none of them had ever seen a snake in the wild. I myself had seen only one other grass snake and a couple of adders in the course of several years of fieldwork in the area.

In Michigan, where I have lived for the past thirty-two years, the situation is much the same. Several species of snakes that used to be common appear to have been reduced to small, isolated populations. Some wildlife enthusiasts are worried about the possible disappearance of the massasauga, the only poisonous snake in the state. Indeed, I have not seen a smooth green snake in southern Michigan in the past twenty-five years and wonder if it is not because pesticides have killed off the little orthopteran insects and spiders that are the mainstay of this snake’s diet. Frogs and toads, too, appear to be absent or rare in places where they were once abundant, and these anurans are important food items for many snakes.

I look at the decline of snakes through a very particular lens: my life’s work has been devoted to studying their evolution. Snakes are the most recently evolved of all the reptilian lineages. They appear in the fossil record about 95 million years ago, in the late Middle Cretaceous. Their remarkable story in North America includes the Miocene explosion of the family Colubridae, a group that includes most of today’s nonpoisonous species (from tiny worm snakes to eight-foot-long indigo snakes, as well as racers and also hognose, garter, and water snakes). After the latter part of the Pliocene, about 2 million years ago, snakes entered a long evolutionary stasis that has lasted to the present day. Although in North America the Ice Age saw massive extinctions among large mammals (and moderate extinctions in some other groups), snakes—for reasons still being pondered—came through the epoch virtually unscathed.

One wonders what is in store for snakes in the modern world, however. My own first encounter with these reptiles occurred when I was about five years old. My father slammed on the brakes of our car, got an axe out of the trunk, and chopped a harmless hognose snake in half on a dusty road in Indiana. Since then, I have witnessed many “snake-killing congresses” (as the late, famed turtle biologist Archie Carr called them) in several parts of the world. These gatherings invariably consist of a small group of fidgety people who have seen a “viper” and, determined to eradicate it, are milling about with sticks and stones. Unfortunately, fear (which seems to accompany strong fascination) has been the most common human emotion brought on by snakes, and for many years these animals, most of which are harmless, have been persecuted by North Americans.

Some things have changed for the better, fortunately. Interest in snakes has recently exploded to such an extent that books on them are appearing almost as fast as those on dinosaurs. By my own count, at least thirty excellent books on snakes have appeared over the past decade. While people are learning to be more tolerant of these reptiles (perhaps because of better science education), today there are many fewer snakes to be tolerant of. Large-bodied species such as timber rattlers, which take many years to reach maturity, have already been persecuted to the point of endangerment. Other snakes have undergone drastic declines because they are collected for their skins or for the pet trade. If future generations are to enjoy snakes, we must not only stop killing them, we must treat them as we now do the dwindling amphibian populations of the world—by conducting the same kind of scientific studies and by applying similar conservation ethics.

It would be ironic indeed if the most recently evolved of all the reptile groups were driven to extinction so early in their evolutionary history.

Herpetologist J. Alan Holman is an emeritus professor of geology and zoology at Michigan State University. His most recent book, from which this essay is adapted, is Fossil Snakes of North America: Origin, Evolution, Distribution, Paleoecology (Indiana University Press, 2000).
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COVER The first American Museum Journal appeared in April 1900. The magazine changed its name to Natural History in 1919.

PHOTOGRAPH BY CRAIG CHESEK; AMNH

ON BEING HUMAN

A look at the nature of our species and our evolved capacities for learning, language, emotion, laughter, and art

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The Sanctuary That Was Saved.

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Happy Birthday to Us

Natural History is now 100 years old. We like to attribute the magazine’s longevity to the breadth of our subject matter: the natural world. Housed and supported by one of the country’s favorite institutions, the American Museum of Natural History, we are grateful to be beginning our second century of conveying the excitement of science to our readers.

In this issue we celebrate by abandoning our usual stance of biological egalitarianism to allow a single species, Homo sapiens, to claim the limelight. During the magazine’s past 100 years, the natural sciences have altered humanity’s self-image. Discoveries of fossil hominids—from the delicate Lucy to the robust Australopithecus boisei—have undercut the notion of humankind’s singularity. The new technology of DNA sequencing has further closed the gap between us and the other primates on our family tree. (That we share 98 percent of our genetic material with chimpanzees is stated so often that it is by now a cliche.) The emergence of sociobiology and behavioral ecology—as well as their controversial offshoot, evolutionary psychology—reflects our growing sense of connectedness with the rest of the animal kingdom. These days, we are perhaps less inclined to see ourselves as fallen angels than as above-average mammals. In the spirit of this trend, Natural History’s editors asked several scientists and scholars for their end-of-century thoughts about the nature of our species (their essays begin on page 24). We have also used the occasion of our centenary to pay tribute to wildlife photographers, whose work has been integral to our effort to bring the reader face to face with nature (“Photographers As Naturalists” begins on page 92).

Another milestone: “I Have Landed” (page 46) is the 300th essay in Stephen Jay Gould’s influential series “This View of Life.” It is also his valedictory. For twenty-seven years, the magazine has been enriched by Steve’s breadth of mind, his bent for questioning accepted wisdom, and his special ability—akin to that of England’s seventeenth-century metaphysical poets—to produce new insights by yoking together seemingly disparate ideas. Although the series is now completed, Steve will not disappear entirely; having promised to continue as an occasional contributor.

Meanwhile, for readers who crave historical and evolutionary thinking, we are pleased to welcome Jared Diamond (author of Guns, Germs, and Steel) back to our pages.—Ellen Goldensohn
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The principal habitation is mesquite-savanna dotted with numerous ponds. As a result, the area is home to a great variety of species including some found nowhere else in the country such as the colorful green jay and great kiskadee, the striking white-tailed hawk, and the secretive long-billed thrasher. It is also the wintering grounds for many species. By mid-March, the spring wildflowers will be in full bloom, and some species—such as scissor-tailed flycatchers and cave swallows—will have returned from the tropics.

Tour leaders will work with you to address the identification challenges presented by sparrows, shorebirds, and hawks—all groups that are well represented in South Texas at this time of the year.

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As a child, Jared Diamond ("Threescore and Ten," page 24) assumed he would become a physician like his father. The boyhood fantasy wasn’t far off the mark; he eventually earned a Ph.D. in physiology from the University of Cambridge and since 1968 has been a professor of physiology at UCLA’s School of Medicine. Also a research associate in ornithology at the American Museum of Natural History, Diamond spends part of each year doing fieldwork in New Guinea. Working with the “really smart people there, who traditionally only had stone tools,” made him ponder why he was the only one who happened to be using steel implements. Ultimately, such thoughts about the effect of environment on culture resulted in his Pulitzer Prize–winning book Guns, Germs, and Steel: The Fates of Human Societies (W. W. Norton, 1997) and the recognition that “where you are born is the most important thing determining the outcome of your life.”

Mathematical modeling is a rigorous tool for studying biology. Martin A. Nowak ("Homo Grammaticus," page 36), head of the Program in Theoretical Biology at the Institute for Advanced Study in Princeton, New Jersey, has brought mathematics to bear on the question of how human language evolved. Nowak became interested in the topic after hearing a lecture on it by John Maynard Smith and reading Steven Pinker’s Language Instinct. In 1998 he and theoretical biologist David Krakauer proposed a mathematical approach for language evolution. Nowak’s other interests include the dynamics of infectious diseases, antiviral therapy, evolutionary genetics, and the evolution of cooperation and fairness. He is the author, with Robert M. May, of Viruses Dynamics: Mathematical Principles of Immunology and Virology (Oxford University Press, 2000).

A columnist for this magazine since 1995, astrophysicist Neil de Grasse Tyson ("A Cosmic Muse," page 60) is the Frederick P. Rose director of the Hayden Planetarium at the American Museum of Natural History. A New Yorker by birth, he credits his career choice to his childhood visits to the Planetarium and an education at the Bronx High School of Science. Tyson’s long-standing research interest has been the structure and chemical composition of the Milky Way galaxy. His most recent book is The Sky Is Not the Limit: Adventures of an Urban Astrophysicist (Doubleday, 2000).

Ian Tattersall ("A Hundred Years of Missing Links," page 62) does not trace his current interest in human evolution to a childhood spent in East Africa, even though it might make for a good story. Furthermore, his early research focused mainly on the biology of the lemurs of Madagascar (one of the most beautiful of these primates is named for him). But the understanding of animal diversity he gained in Madagascar eventually led him to the study of humanity’s past. A curator in the American Museum of Natural History’s Division of Anthropology for almost thirty years, he is collaborating with University of Pittsburgh professor Jeffrey H. Schwartz on a long-term project to scientifically redescribe the entire human fossil record, in order to provide a needed resource for students and researchers. Tattersall’s latest books include Becoming Human: Evolution and Human Uniqueness (Harcourt Brace, 1998) and, with Schwartz, Extinct Humans (Westview Press, 2000).

Frans de Waal ("Reading Nature’s Tea Leaves," page 66) says he has a fish tank almost as big as the one Konrad Lorenz had but that, unlike Lorenz, he never enters it. Although he started out as a child ethologist catching and observing stickleback fishes in the Netherlands, he later switched to the study of primate societies, with a special interest in conflict resolution, reciprocity, and cooperation. His favorite species for this work are chimpanzees, bonobos, and capuchin monkeys. De Waal is C. H. Candler Professor of Primate Behavior in the psychology department of Emory University and director of the Living Links Center for the advanced study of ape and human evolution (part of the Yerkes Regional Primate Research Center). In 1998, while on sabbatical in China and Japan, he explored differences in attitudes toward nature between Eastern and Western cultures. That research is the subject of The Ape and the Sushi Master: Cultural Reflections of a Primatologist, to be published by Basic Books early in 2001.
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Although his doctoral dissertation on the development of electrical activity in the spinal chord of the chick embryo was followed by research on more than thirty other animal species, **Robert R. Provine** ("The Laughing Species," page 72) eventually decided “it was time to get out of the lab and apply my techniques and findings to human behavior.” The result, based on an investigation of everything from personal ads in newspapers to laugh boxes (Provine owns a hundred of them), was *Laughter: A Scientific Investigation* (Viking Press, 2000). The book includes “Ten Tips for Increasing Laughter” but none for suppressing it (“It’s easy to kill laughter, and many people and enterprises already have mastered this more modest art”). A professor of psychology at the University of Maryland, Baltimore County, Provine plans to continue his research on laughter and tickling and to investigate the behavior of self-replicating machines.

When **Barbara Smuts** ("Common Ground," page 78) was a child, she read Jane Goodall’s accounts of the chimpanzees of Gombe Stream National Park and made up her mind to go to Tanzania and work with Goodall one day. Smuts realized this dream in 1975, when she spent several months at Gombe. She has also studied baboons in Kenya and dolphins off the coast of western Australia. Smuts received her doctorate in behavioral biology from the Stanford School of Medicine and since 1984 has taught at the University of Michigan, Ann Arbor, where she is a professor of psychology. Her current projects include the greeting behavior of baboons and the social relationships of domestic dogs. Smuts is the author of *Sex and Friendship in Baboons* (Aldine De Gruyter, 1985; reprinted with a new preface, Oxford University Press, 1999). For more on our kinship with great apes, Smuts recommends *Kanzi: The Ape at the Brink of the Human Mind* (John Wiley & Sons, 1996), by Sue Savage-Rumbaugh, and *Next of Kin: My Conversations With Chimpanzees* (Bard Books, 1998), by Roger Fouts with Stephen Tukel Mills.

**Ellen Dissanayake** ("Birth of the Arts," page 84) has written three books on art, all published by the University of Washington Press. An independent scholar and interdisciplinary, Dissanayake has presented her ideas at conferences held on topics as disparate as biomusicology, developmental psychology, human ecology, and comparative literature, as well as on art education, art therapy, and art theory. In her view, “E. O. Wilson’s notion of ‘consilience’ is the only acceptable position from which to seek an understanding of human nature—and the arts are a significant part of that nature.” In the 1990s Dissanayake obtained a fellowship to work with child psychologist Colwyn Trevarthen at the University of Edinburgh. There her ideas about mother-infant interaction, evolutionary psychology, and ritual began to coalesce. The result was her book *Art and Intimacy: How the Arts Began* (University of Washington Press, 2000), the basis of her article in this issue of *Natural History*. Her future writing plans include a book on the aesthetics of music and another about her fifteen years in Sri Lanka during the 1970s and 1980s.

Harvard paleontologist **Stephen Jay Gould** ("I Have Landed," page 46) contributes the last in a series of 300 essays that began in January 1974. Most have addressed evolutionary theory and the history of science, but Gould’s topics have ranged from the contingencies of life’s history and geologists’ perception of time to biology, social science, and baseball. According to Michael Shermer, of the Skeptics Society, the shortest essay ("Darwin’s Dilemma,” June 1974) ran 1,475 words, and the longest (“The Piltdown Conspiracy,” August 1980) ran 9,290 words. Many contain new discoveries, such as Gould’s original interpretations of the works of biologist Jean-Baptiste Lamarck, geologist Charles Lyell, and Leonardo da Vinci. During the same period, Gould has also managed to publish 22 books, 101 reviews, and 479 scientific and scholarly papers. His latest book, *Crossing Over: Where Art and Science Meet*, coauthored with photographer Rosamond Wolff Purcell, has just been published by Three Rivers Press. A thousand-page technical tome, *The Structure of Evolutionary Theory*, is forthcoming from Harvard University Press. Readers of *Natural History* can still look forward to occasional contributions by Gould in these pages.
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“If Lars-Eric Lindblad had lived in the year 1000, he probably would have set foot on the North American continent before Leif Ericson. Or, turning eastward, he might have reached China before Marco Polo.” — Roger Tory Peterson

As the fabled American Museum of Natural History celebrates its 100th year, I would like to take this moment to honor my father, who, beginning in 1958, changed the world of travel for us all.

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THE SKY IN DECEMBER AND JANUARY

By Joe Rao

Mercury is not visible during December, arriving at superior conjunction with the Sun on Christmas Day. But it's a different story in January, when the planet emerges from evening twilight around midmonth, shining very low in the southwest just after sunset. A two-day-old crescent Moon hovers well above and to the right of Mercury on the 26th. The planet reaches its greatest eastern elongation (18.4°) on the 28th. On that date, you'll find it far below and to the right of brilliant Venus.

Venus mimics a spectacular "Christmas star" during December, with a dazzling -4.2 magnitude in the southwestern sky at dusk. It sets nearly four hours after sunset. In January the planet reaches its greatest eastern elongation (47.1°) on the 17th and continues to brighten. A crescent Moon is in Venus's general vicinity on December 29 and again on January 28.

Mars rises in the east-southeast between 2:00 and 2:30 A.M. Local Standard Time (LST) during December and between 1:30 and 2:00 A.M. LST during January. It continues to brighten slowly as it approaches Earth. On December 20 a fat crescent Moon slides by Mars.

Jupiter and Saturn are visible through much of the night during both December and January. During the first week of December, Jupiter sets at dawn and can be found low in the west-northwest sky. For the rest of the month and throughout January, the planet sets progressively earlier: by the end of December, at about two hours before sunrise, and by the end of January, at about two hours past midnight. Saturn sets about three-quarters of an hour before Jupiter during both months. The two planets continue to provide fabulous viewing through most telescopes. A waxing gibbous Moon forms a wide triangle with Jupiter and Saturn on December 9 and will approach these two planets again on the nights of January 5 and 6.

The Moon in December is at first quarter on the 3rd at 10:55 P.M. The full Moon appears on December 11 at 4:03 A.M., last quarter on the 17th at 7:41 P.M., and the new Moon on the 25th at 12:22 P.M. In January, first quarter is on the 2nd at 5:31 P.M. The Moon is full on the 9th at 3:24 P.M., at last quarter on the 16th at 7:34 A.M., and new on the 24th at 8:06 A.M.

Earth arrives at perihelion, the point of its orbit that brings it closest to the Sun, on January 4 at 4:00 A.M. Earth will be about 191,402,144 miles from the Sun—only about 3.3 percent less than when it's at the far point of its orbit (aphelion) on July 4.

The Geminid meteor shower, usually one of the best meteor displays of the year, is obscured in December by the bright light of the gibbous Moon. The peak night is December 13, continuing into the morning of the 14th. Although up to seventy-five meteors per hour can often be seen during this display, only the brightest meteors will be visible this time.

The winter solstice occurs on December 21 at 8:37 A.M., when the Sun appears to be farthest south of the celestial equator. Winter begins in the Northern Hemisphere, summer in the Southern Hemisphere.

A Christmas Day eclipse, the final one of the second millennium, will be a partial solar eclipse. This event will be visible over nearly all of North America, with the exception of Alaska and the Canadian Yukon and Northwest Territories in the far north and Panama, Costa Rica, and southern Nicaragua in the south. The eclipse can be seen throughout the continental United States and will be in progress at sunrise on December 25 in all of Washington State, most of Oregon, northernmost California, northern Idaho, and northwestern Montana. It will be visible later in the morning in the Midwest, while observers in the eastern states will see it in the early afternoon. Sky watchers across the Great Lakes, northern New York State, and central and northern New England will see at least 60 percent of the Sun's disk covered. Approximately 40 percent coverage will be visible from the northern plains and the central and eastern states. Viewers in much of the Southwest, the south-central states, and Florida will see roughly 20 percent coverage, while those in southwestern Arizona and central and southern California will see even less than that. Remember never to look directly at the Sun unless you are using an appropriate filter to protect your eyes.

A total eclipse of the Moon is staged for the Eastern Hemisphere on January 9. By the time the Moon comes into view in North America, however, the eclipse will be nearing its end. Those living anywhere to the east of an imaginary line extending roughly from Buffalo, New York, to Norfolk, Virginia, will still be able to see some of Earth's dark umbra shadow, which will slip entirely off the rising Moon by 4:59 P.M.

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Our exceptionally long life span may have influenced the evolution of how we learn and think.

By Jared Diamond

In the course of my nineteen ornithological expeditions to the island of New Guinea, I've been in many unfamiliar situations that initially seemed risky to me. But because my New Guinean field associates are intimately acquainted with the jungle, they're usually unfazed by things that strike me as dangerous. Hence I was very surprised, one night in 1966, to see their terror when I picked a campsite next to a big tree in the Bewani Mountains. My associates feared that the tree might fall on us as we slept. During all my years in the field, though I have heard trees falling far away, I have never been close enough to witness such an event. For a New Guinean, however, falling trees rank as a leading hazard of life in the jungle: while you may see a tree fall only a couple of times a decade, if you're hoping to last seventy years but are not careful, you may well end up crushed under a falling trunk or branch before having lived out your allotted time.

Of all the lessons I've learned in New Guinea, that one about the cumulative odds of rare but recurring dangers is the one that has most affected my outlook. Out there, the penalty for forgetting is severe—you can't call 911 in a life-threatening emergency. But disasters that have recently befallen friends of mine remind me of this lesson's importance for every American who drives a car, climbs a ladder to change a light bulb, or hesitates to call the doctor when feeling faint. Our potential for learning to recognize the riskiness of such mundane acts derives from a trait distinguishing us humans from other animals: our unusually large capacity to modify our behavior in response to acquired information rather than relying solely on instinct. Contrary to assump-
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tions cherished by modern literate societies, I suspect that we still learn best in the way we did during most of our evolutionary history—not by reading but through direct experience. Some limitations on our thinking skills, I believe, stem from our evolutionary history. And although these limitations are not insuperable, we do need to be more aware of them and work harder to overcome them.

Our exceptionally long life span makes us humans unusual among animal species. The Bible tells us that “the days of our years are threescore and ten” or, “by reason of strength,” sometimes fourscore (Psalms 90:10). Nothing about the biology of human aging has changed since biblical times. Even in New Guinean villages, I usually find some people who have reached that biblical age limit. Half of us living in modern Western societies reach it, and a handful of us reach age 100 (the current record is 121). But not even the best medical care, the healthiest lifestyle, or the wealth of Howard Hughes will let you survive longer. Still, by animal standards that’s impressive. Few other

For almost all of our evolutionary history, our repository of knowledge lay in people’s memories, not in books.

warm-blooded vertebrates (the category that includes all mammals and birds), with the notable exception of killer whales, elephants, and albatrosses, are known to rival us in length of life.

Our long lives and our capacity for learning have combined, in traditional nonliterate human societies, to produce many cultural practices that help their members survive rare dangers. A Western visitor who spends only a few years in such a society is very unlikely to appreciate such dangers and hence to understand why some seemingly senseless practices really make sense for such animals don’t have memories that warn them against settling in habitats where climate fluctuations may doom them to die within a few years. Instead, they settle there, breed in great numbers, and end up suffering a population crash when drought or frost strikes. The Carolina wren of the southeastern United States, for example, extends its breeding range northward in years of mild winters, until a harsh winter wipes out all the wrens for hundreds of miles at the northern edge of the range. We moderns also take for granted the availability of written information, which extends our experience far beyond a single human life span. But that’s a relatively new source of infor-
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mation for us. From the origins of the human lineage about 5 million years ago until about 3400 B.C., nobody wrote anything. And mass literacy arose only within the past thousand years. Hence, for almost the whole of our evolutionary history, our repository of knowledge lay in the memories of people, not in books. Therein lies a sad but potent reason for the status of old people being so much lower in many modern, literate societies than in traditional, nonliterate societies: many individuals in literate societies no longer believe that their elders are important repositories of knowledge and thus do not perceive them as valuable. In addition, technology is now changing so quickly that certain kinds of experience are soon outdated, as is made clear to me whenever my eighteen-year-old students watch my sixty-three-year-old eyes glaze over at their efforts to teach me how to use computers.

Human memory, unassisted by the written word, is very good at synthesizing information accumulated over many decades. It’s not nearly so good at accurately transmitting detailed information about rare events over many generations. That’s why traditional societies are effective at anticipating disasters that tend to recur every several decades (such as a flood that every adult is likely to experience at least once in a lifetime) but aren’t effective at anticipating disasters that recur, say, every 200 years. It’s understandable, for example, that the Anasazi Indians toiled to erect huge buildings at Chaco Canyon in New Mexico and then had to abandon the canyon because of a period of severe drought such as had not occurred for hundreds of years. Of course, detailed accounts of those much earlier droughts could not have been passed down.

Are we moderns so different in this respect from traditional peoples? We certainly think so! We have writing but they didn’t, so we’re able to learn from events that happened as far back as the dawn of the written word 5,400 years ago. Archaeologists and paleontologists tell us of much older events, such as an asteroid’s collision with Earth some 65 million years ago. (Some space scientists now urge us to learn from this by monitoring the orbits of all Earth-grazing asteroids.) Our schools require de-
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tailed study of post-Columbian American history. Contemporary isolationist politicians still invoke the advice George Washington gave us 204 years ago, in his farewell address, about the dangers of making permanent alliances with foreign governments. Every year, nearly 2 million Americans visit Gettysburg, Pennsylvania, and imagine in detail the battle that took place there 137 years ago. It would thus seem that the distant past must be vivid to us but not to New Guineans. Can that really be true?

We surely do use writing-based knowledge when we are in a rational mode and have papers spread in front of us. That’s our mode for much of the day, while we are routinely doing our jobs, filling out our tax returns, making the “little” decisions peculiar to civilized life. But are we in that rational mode when making the difficult “big” decisions that we reach by gut feelings rather than by spreading out sheets of paper—decisions that our species has had to make for hundreds of thousands of years, such as whether to get or stay married, go to war, or challenge the chief?

I don’t think so. For us, the lessons that really sink in aren’t always those learned from books, despite what historians and poets would like us to believe. Instead, we absorb most deeply the lessons based on our personal experience, as everybody did 5,400 years ago. Making matters worse, in addition to our limitations stemming from the two traits I’ve already mentioned (our “mere” seventy-year life span and our long evolutionary history without writing), we suffer from a third limitation: we are much less receptive to learning from experience at age sixty than at age ten. Our outlook is shaped especially strongly by early events, and our experiences later in life form only a thin veneer on which we draw during more rational moments. That’s why we find it hard not to feel superior when the elderly cling to an out-of-date perspective. The recent deaths of my parents, at ages ninety-two and ninety-seven, brought me a sad personal example. Clearing out their apartment, my sister and I found that they had kept ragged clothes and old dish towels more appropriate to the poverty in which they had grown up than to the economic comfort they had achieved in their sixties. By then, though, it was too late for them to reprogram their outlook.

The power of events experienced firsthand relatively early in life is particularly clear in the political arena, where the tendency to draw in later years on those experiences may lead to tragedy. The lessons of our youth can be so powerful that they tend to override all subsequent experience to the contrary. For instance, the defining experience of the generation that grew up between 1900 and 1920 was the horror of World War I, and the lesson carried away by the surviving members of that generation was to avoid repeating the particular mistakes that produced that war. With the best of intentions, they applied this lesson under altered conditions in the 1930s to formulate policies of appeasement, isolationism, and inaction, thereby plunging the world into an even more horrifying conflict.

For me, the thinness of our veneer of book learning was brought home by the most vivid political event of my own adult life: President John F. Kennedy’s speech, broadcast on radio
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on the evening of October 22, 1962, about the installation of Soviet missiles on Cuba, our gathering blockade of Cuba, and the risk of all-out nuclear war. That evening I happened to be at a dinner of Harvard University’s Society of Fellows, whose senior members included Nobel laureates and the presidents of the American Historical Association and the American Philosophical Association. If any group in the world was qualified to extract the lessons of history, not just from their own lifetime of experience but from experiences committed to writing over the course of several thousand years, this was the group. The significance of the moment

The lessons of youth can be so powerful that they tend to override all subsequent experience to the contrary.

was clear to us: so far as I know, it was the sole evening in the Society of Fellows’ history when a dinner was postponed in order to turn on the radio. We listened in silence. As Kennedy ended his speech, I waited to hear what the members would suggest as ways of dealing with the world’s most dangerous crisis since 1945.

To my astonishment, the overwhelming reaction of the listeners was to dismiss contemptuously both the danger and Kennedy’s response to it. One of the world’s great modern historians explained that the president was obviously concocting a crisis in an effort to get the public to vote for the Democrats in the congressional elections fifteen days hence. An economist sneered at Kennedy’s announcement that the blockade would intercept Russian shipments of offensive but not defensive weapons to Cuba. How could one legitimately draw a line, said the economist, between offensive and defensive weapons? Someone else said we should leave the whole matter for the United Nations to resolve. Still another person pointed out that we were aiming missiles at Russia from Turkey, so what right did we have to stop the Russians from aiming missiles at us from Cuba?

Entirely absent from the discussion that evening was any sense of the basic lessons that might have been drawn from reading about history: that the leader of a powerful nation is going to defend its interests, that nations cannot count on other nations to behave nicely, that countries often seek to obtain advantages over other countries, and that wars are precipitated by inaction as well as by action. I suspect that several different gut reactions contributed to the thinking of those Harvard professors. Most of them had been born in the decade between 1900 and 1910 and had spent much time in Europe. They may have been sufficiently programmed by the horrors of World War I that not even the mistakes of the 1930s, leading to World War II, could persuade them to favor action over inaction. Some were evidently blaming JFK rather than Nikita Khrushchev for bringing us to the brink of war; others may have come to see anticommunists as more dangerous than communists. Did some of these scholars begin to think differently later, as they watched the situation unfold? Would they have reached different conclusions if they themselves had held responsibility for the world’s fate? Whatever life experiences had brought them to the views they expressed that evening, one thing seems clear to me: their spontaneous reactions showed little influence of a lifetime devoted to reading about history.

Much of our public policy-making today appears to be based on the same type of evidence available to all non-
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literate humans before 3400 B.C.: the firsthand evidence of our senses. We read about what happened in the past and about what will happen in the future if present trends are extrapolated—but we don't incorporate this information deeply into our thinking, let alone into our actions. As Americans look around today, we see that the grass is still green, drinkable water still flows from the faucets, and the supermarkets are still stocked with food. Our conclusion from these observations is that the environment remains in good shape.

The Anasazi at Chaco Canyon may have had a similar reaction to their own environment a mere few decades before their society began to collapse. Much of what we observe directly of the status quo is contradicted by what we learn from reading and then extrapolate into the future. Pleasant environmental conditions won't exist for us, either, a few decades from now if current trends continue. To use the language of mathematics, we look only at functions when we should be looking at their first derivatives.

This magazine, and my own choice of career, are predicated on a belief in the power of the written word. Am I dismissing that power? Do I claim that we are genetically doomed to continue behaving like ancient hunter-gatherers without writing, or to be unable to learn once our teenaged years have passed? Not at all. This magazine instead exemplifies our best grounds for hope: we have the means to learn from what happened to the Anasazi, while they had no means to learn from the fates of prior societies elsewhere in the
world. Often we sweat hard to think rationally and to use what we have learned as adults, and often we get it right. We have now gone fifty-five years without a global war and without anyone dropping an atomic bomb on anyone else. At least Kennedy and his advisors were thinking hard about the lessons of history. Will we attempt now to extend our sphere of rational action and to incorporate into our most important decisions the wisdom to be extracted from 5,400 years of writing? It's our choice.

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Homo Grammaticus

Mathematics has a say about how human language evolved.

By Martin A. Nowak

Whenever I tell my four-year-old a dream, he also tells me a dream. His is often similar to mine. He doesn’t distinguish between a story and a dream. Both my four- and my six-year-old have their own fantasy realms. Sometimes, when a fact proves contrary to their expectation, they hold comfortably to their version of reality in a different world. Their language is limited neither to actual experience nor to the context of this world. We can talk about everything.

Producing the sounds we use in an ordinary conversation is an anatomical feat. The motions of various parts of our vocal tract are coordinated within milliseconds and timed within hundredths of a second. On the receptive end, a listener must process a stream of sounds instantaneously. When it comes to words, a six-year-old has a lexicon, or word store, of about 13,000. The rate of word learning in humans comes to about one word every ninety waking minutes from age one to age seventeen. This leaves a seventeen-year-old with about 50,000 words stored in her mental lexicon. When it comes to grammar, a four-year-old knows how to avoid 95 percent of the mistakes he could make. Children acquire the grammatical rules of their native language spontaneously and without formal education. All they need is the opportunity to talk to someone and to hear examples of sentences.

I could prove to you mathematically that what children do in acquiring language is not possible unless we add a further assumption: children must have a built-in sense of what grammar is. The linguist Noam Chomsky called this innate mechanism universal grammar. It is written in our genes and generated by neuronal circuitry in our brain.

Grammar is the computational system of human language. As used by linguists, the term “grammar” encompasses the patterns inherent in speech sounds, in word forms, and in sentence structures (syntax). All human languages use complex grammar. Grammar is what enables us to produce an infinite number of meaningful sentences, and it is what allows a child to speak sentences he has never heard before. The computations that are necessary for formulating or interpreting sentences cannot, so far, be performed by any computer, but they flow through our brain’s language processor without conscious effort on our part. We can talk and listen without thinking about it.

The aim of my own work on language is to outline the fundamental principles that determine how natural no computer, as yet, can perform the computations that flow through our brain’s language processor effortlessly. We can talk and listen without thinking about it.

Selection shaped animal communication and led from there to human language. The main forces of evolution—mutation and natural selection—can be described by precise mathematical equations. As early as 1906, Oxford zoologist Walter Weldon remarked that “Darwinian evolution is intrinsically a mathematical theory and can only be tested by mathematical and statistical techniques.” Hence, I and my colleagues at the Institute for Advanced Studies in Princeton are using mathematics to find out how language evolved.

Language was the most important evolutionary event in the history of the human species. Indeed, grammatical language defines humanity. The complex vocalizations of mammals such as dolphins and primates have been the subject of many studies, but so far, no natural animal communication appears to have a power of expression that is in any way close to human language. Animal communication can be based on a limited repertoire of calls (for example, warning or territorial calls) or consist of variations on a theme (such as bird-songs) or be a continuous, analog signal (the honeybee’s dance, which transmits information on food sources). But the grammar inherent in human language enables us, in the words of Wilhelm von Humboldt, to “make infinite use of finite means.” Language has changed us and the appearance of the planet and is responsible for the acceleration of cultural evolution during the last few millennia.

Human language originated after our human ancestors diverged from our closest relatives, the chimpanzees, about 5 to 7 million years ago. Since all currently living Homo sapiens have the same language ability, the most recent date for the origin of language would be the time of our last common ancestors, who lived in Africa perhaps 150,000 to 200,000 years ago. Evolution would not have had enough time to build our language ability from scratch but must instead have used ex-
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existing structures that may originally have been employed for other purposes. Neuroanatomists describe certain areas in the brains of monkeys, for instance, that correspond to the human language areas but that are apparently not involved in producing calls or gestures. Monkeys use these brain regions to interpret sounds and control facial muscles. Evolution may have had an easy game here in adopting these structures to generate the neuronal circuits that control speech production and speech interpretation in humans.

Language evolved as a means of communicating information between individuals. In order to communicate on a basic level, a population of individual animals or hominids must discover that specific signals can be associated with specific referents—things being referred to—such as people, objects, actions, places, times, and events. A wolf, for example, may whine, growl, or howl, and this sound (along with extensive body language) can convey certain information to the members of its pack. We can imagine early hominids—perhaps Lucy and her fellow Australopithecus afarensis, who lived 4 million years ago—being capable of making a variety of sounds and transferring information about their world. If a wolf cub fails to learn the sounds and signals of its society, its life may be short. Similarly, hominids that were best able to transmit—and to hear and interpret—specific signals presumably benefited from this trait. They were fitter in the evolutionary sense, surviving longer and having offspring that knew how to communicate.

The computer simulation that I and

Adding signals to a repertoire increases the number of things that can be described but also increases the likelihood of errors.

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my colleagues have been working on moves us from the realm of the presumed to the realm of mathematical analysis. The equations take into account mutation, forces of natural selection, and learning behavior. In the

sen lexical matrices. Then individuals “talk” to each other. Whenever a simulated speaker uses a certain signal to denote a particular referent and the hearer interprets the signal as denoting that referent, they communicate correctly.

Bechuanaland (now Republic of Botswana), 1947

simulation, each individual in a group is characterized by what we call a lexical matrix, which links specific signals to specific referents. In the beginning of our simulation, all individuals are assigned very different, randomly cho-

As the simulation continues, the individuals that are able to communicate well prosper and produce offspring who in turn inherit the genetically encoded mechanism for learning the language. The offspring will use this mechanism to learn the lexical matrix from their parents and others in the population or community. As a consequence of heterogeneity in the group and some errors occurring during language learning, children will not acquire the exact lexical matrix of their parents. Over time, the matrices will change and those individuals that communicate well will increase in abundance.

We have found that over a few generations, each signal tends to become associated with a single referent and that most individuals in the group will use the same signal for the same referent. But to be successful, this evolutionary process depends on conditions that we have quantified and that can also be expressed verbally: communication must contribute to biological fitness, and learners must have a sufficiently reliable lexicon-learning mechanism. Under these conditions, evolution can construct a communication system—but only a simple one.

Our model shows that while adding new signals or sounds to the repertoire may increase the number of things that can be described, such additions also carry a significant cost: a greater possibility of errors. What happens when a signal is misinterpreted, when a hearer misses the message? One monkey shouts “lion,” but the other one understands “banana” and is attacked by the lion. We stretched our basic model by in-
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inclining the possibility of such perceptual errors into our equations. The mathematical analysis revealed an “error limit,” a point at which having too many signals and referents creates confusion and becomes a liability rather than an evolutionary asset. In other words, the monkey might have been better off without a signal for banana that could be mistaken for the signal for lion.

Natural selection, then, prefers limited repertoires of signals. But how did human language overcome the error limit and come to be so vast? Our vocal apparatus can produce a large diversity of sounds. The roughly 6,000 languages on Earth have a total of about 1,000 phonemes—basic sound units, such as the English pronunciation of the letters g, d, p, or t. Still, any one language uses only about 40 phonemes on average, with a range of about 10 to 100. So we use only a small fraction of all possible signals. We generally avoid mistakes among the phonemes that make up our native language but have a hard time with those of other languages.

How do we humans get such linguistic mileage from a small stock of sounds? In something of an evolutionary leap, we have combined them into words. Snippets of sound are spun out and blended into different configurations; the words “God” and “dog” or “top” and “pot” contain the same phonemes but have different referents. Word formation marks a transition from something like an analog (continuous) system to a digital (discrete and combinatorial) system of communication. Our equations show that for a simulated digital language, the error limit is much higher than for a simple analog signal system. Most animal communication, based on a simple system, must operate with a limited repertoire of signals, while human languages consist of more than 10,000 words (English has about 100,000 words).

Words still have to be memorized. Once we have them, however, words can be put into sentences governed by the rules of syntax. Mathematically put, the lexicon of a population cannot exceed the total number of chances an individual has to learn a new word. Syntax makes it possible to generate more sentences than the total number of sentences encountered by a learner. A child, for example, has to memorize the meaning of words but does not have to memorize the meaning of sentences. Syntax enables us to construct and understand an unlimited number of novel sentences.

What we know about animal communication suggests that it is largely nonsyntactic: signals refer to whole events. In contrast, human language is syntactic: signals consist of components that have independent meanings. To find out whether the latter situation confers more of an evolutionary advantage than the former, we built a mathematical model to analyze differences between the two kinds of communication in terms of natural selection. The equations resulting from our mathematical model indicated, fortunately, that syntactic communication is a bright idea, and for two main reasons. Unlike nonsyntactic communication
(for example, the simple system obtained in the beginning of our simulation), syntactic communication not only allows the number of things that can be said to be larger than the number of things that have to be memorized but also enables us to generate messages that refer to novel and rare events—not just "dog bites man" but also "man bites dog."

Nevertheless, the equations reveal some limits: natural selection favors syntax only if there exist a large enough number of events that need to be communicated and only if these events can be broken down efficiently into components with meanings of their own, such as places, times, objects, and actions. We call this point the syntax threshold. Below it, nonsyntactic communication works well; above it, syntactic communication stands the users in better stead. We believe that many animal species have the capacity for a syntactic understanding of the world—monkeys and dogs, for example, perceive that the world consists of components, and they are able to relate the components to one another—but animals did not evolve syntactic communication, because the syntax threshold was not reached.

We can envision the savannas and forests of Africa where, some 100,000 years ago, our young species lived among other mammals, all using their respective ways of transmitting information. For example, vervet monkeys (as shown by biologists Dorothy Cheney and Robert Seyfarth) have a handful of calls they use to denote the presence of potential predators. The call for "leopard" makes the monkeys jump up into a tree, where they can move faster than the cat. The call for "eagle" sends them running under a bush, where they can hide. However, a resident _Homo sapiens_, armed with syntax, can call out—give voice to objects and actions in a sequence—and
Selected for and shaped by evolution, language has, most importantly, led to a new mode of evolution. Information drives evolution. For most of the 4 billion years of life on Earth, the only information that could be used for evolutionary purposes was encoded in gene sequences. Human language gave evolution a new playground. Relatively suddenly, vast amounts of information (at first in the form of orally transmitted ideas, stories, and legends, and later printed in books and journals and transmitted via Internet pages) could be exchanged between individuals and passed on to subsequent generations.

Relatively suddenly (in an evolutionary sense), vast amounts of information could be exchanged between humans and passed on to subsequent generations.

In the small redbrick building opposite my office window, where my four-year-old is at nursery, John von Neumann built the first programmable computer. The Hungarian-born mathematical genius realized that it was not a good idea to rewire a computer every time you wanted to calculate something different. The computer should be a general problem solver. Evolution had the same idea when it came up with a nervous system that allowed animals to learn. Not every task had to be solved by rewriting genetic code: a neuronal problem solver could be more efficient. Language was the next step. It provided an operating system, linked the neuronal problem solvers together, and enabled them to pass on solutions, to work on problems, and to exchange dreams. Language created Homo sapiens.
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I Have Landed

In the final essay of this twenty-seven-year series, the author reflects on continuity—from family history to the branching lineage of terrestrial life.

By Stephen Jay Gould

As a young child, thinking as big as big can be and getting absolutely nowhere for the effort, I would often lie awake at night, pondering the mysteries of infinity and eternity and feeling pure awe (in an inchoate, but intense, boyish way) at my utter inability to comprehend. How could time begin? For even if a God created matter at a definite moment, then who made God? An eternity of spirit seemed just as incomprehensible as a temporal sequence of matter with no beginning. And how could space end? For even if a group of intrepid astronauts encountered a brick wall at the end of the universe, what lay beyond the wall? An infinity of wall seemed just as inconceivable as a never-ending expanse of stars and galaxies.

I will not defend these naive formulations today, but I doubt that I have come one iota closer to a personal solution since these boyhood ruminations so long ago. In my philosophical moments—and not only as an excuse for personal failure, for I see no sign that others have succeeded—I rather suspect that the evolved powers of the human mind may not include the wherewithal for posing such questions in answerable ways (not that we ever would, should, or could halt our inquiries into these ultimates).

However, I confess that in my mature years, I have embraced the Dorothean dictum: yea, though I might roam through the pleasures of eternity and the palaces of infinity (not to mention the valley of the shadow of death), when a body craves contact with the brass tacks of a potentially comprehensible reality, I guess there’s no place like home. And within the smaller, but still tolerably ample, compass of our planetary real estate, I would nominate as most worthy of pure awe—a metaphorical miracle, if you will—an aspect of life that most people have never considered but that strikes me as equal in majesty to our most spiritual projections of infinity.

I would nominate as most worthy of pure awe the continuity of the tree of earthly life for 3.5 billion years, without a single microsecond of disruption.

and eternity, while falling entirely within the domain of our conceptual understanding and empirical grasp: the continuity of etz chayim, the tree of earthly life, for at least 3.5 billion years, without a single microsecond of disruption.

Consider the improbability of such continuity in the conventional terms of ordinary probability: Take any phenomenon that begins with a positive value at its inception 3.5 billion years ago, and let the process regulating its existence proceed through time. A line marked zero runs along below the current value. The probability of the phenomenon’s descent to zero may be almost incalculably low, but throw the dice of the relevant process billions of times and the phenomenon just has to hit the zero line eventually.

For most processes, the prospect of such an improbable crossing bodes no permanent ill, because an unlikely crash (a year, for example, when a healthy Mark McGwire hits no home runs at all) will quickly be reversed, and ordinary residence well above the zero line reestablished. But life represents a different kind of ultimately fragile system, utterly dependent upon unbroken continuity. For life, the zero line designates a permanent end, not a temporary embarrassment. If life had ever touched that line for one fleeting moment at any time during 3.5 billion years of sustained history, neither we nor a million species of beetles would grace this planet today. A single hand-shake with voracious zero dooms all that might have been, forever after.

When we consider the magnitude and complexity of the circumstances required to sustain this continuity for so long—and without exception or forgiveness in each of so many components—well, I may be a rationalist at heart, but if anything in the natural world merits designation as "awesome," I nominate the continuity of the tree of life for 3.5 billion years. Earth experienced severe ice ages but
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never froze completely, not for a single day. Life fluctuated through episodes of global extinction but never crossed the zero line, not for one millisecond. DNA has been working all this time, without an hour of vacation or even a moment of pause to remember the extinct brethren of a billion dead branches shed from an ever growing tree of life.

When Protagoras, speaking inclusively despite the standard translation, defined "man" as "the measure of all things," he captured the ambivalence of our feelings and intellect in his implied contrast of diametrically opposite interpretations: the expansion of humanism versus the parochialism of limitation. Eternity and infinity lie too far from the unavoidable standard of our own bodies to secure our comprehension, but life's continuity stands right at the outer border of ultimate fascination: just close enough for intelligibility by the measure of our bodily size and earthly time but sufficiently far away to inspire maximal awe.

Moreover, we can bring this largest knowable scale further into the circle of our comprehension by comparing the macrocosm of life's tree to the microcosm of our family's genealogy. Our affinity for evolution must originate from the same internal chords of emotion and fascination that drive so many people to trace their bloodlines with such diligence and detail. I do not pretend to know why the documentation of unbroken heredity through generations of forebears brings us so swiftly to tears and to such a secure sense of rightness, definition, membership, and meaning. I simply accept the primal emotional power we feel when we manage to embed ourselves into something so much larger.

And so evolution has anchored this series of essays through 300 uninterrupted issues of Natural History, from January 1974 to this first offering in some people's version of the new millennium, January 2001. (A missing month might not have entailed full extinction, but I did appreciate the practical goad and pure conceit of thinking that I needed to mirror the utterly unforgiving topology of evolutionary continuity!) I called my series "This View of Life" to honor the finale of Darwin's Origin of Species, for the closing sentence of this founding document begins with a justifiably poetic description of evolution: "There is grandeur in this view of life." As one major reason for evolution's enduring popularity among scientific subjects, our minds combine the subject's sheer intellectual fascination with an even stronger emotional affinity rooted in a legitimate comparison between the sense of belonging gained from contemplating family genealogies and the feeling of understanding achieved by locating our tiny little twig on the great tree of life.

Family genealogy is our tiny twig on the great tree of life. Evolution is "roots" writ large.

If continuity so tugs at our heartstrings and so defines our sense of being within the expanding totalities of a personal family, the full human species, and the entire tree of life—and if unbroken continuity defines both the awe of "this view of life" and the conceit of a little literary microcosm also called "This View of Life"—then how else can I end except with a paean to continuity on both scales? Of my decision to hang up the spikes of this particular monthly enterprise, I will only say that when I noted the fortuitous conjunction of my 300th entry with the auspicious date of January 2001, I felt that arbitrary calendrics and numerology must be trying to tell...
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me something. I know that I could persevere until the angel of death makes his most unwelcome, albeit inevitable, intrusion. At least my list of potential topics has never become shorter (my personal criterion, throughout all these years, for a stopping signal that never sounded). But I never witnessed anything sadder than Willie Mays and Mickey Mantle playing far beyond their prime, and I don’t want to risk the possibility of even embarking upon a downhill slope, much less facing, however unawares, an actual entrance into professional dotage. Few old troopers have the gumption to follow what I like to call the “DiMaggio-Jordan principle”: not just to “quit while you’re still ahead” but the more upbeat “quit while they still want you.” I only hope that I have the gumption and that, dear readers, some of you might still want me.

I therefore offer two microcosmal stories of stubborn persistence for my swan song—two analogues or metaphors for this grandest evolutionary theme of absolutely unbroken continuity, the intellectual and emotional center of this view of life. My stories descend in range and importance from a tale about a leader in the founding generation of Darwinism to a story about my grandfather, a Hungarian immigrant who rose from poverty to solvency as a garment worker on the streets of New York City.

Our military services now use the blandishments of commercial jingles to secure their “few good men” (and women) or to entice an unfulfilled soul to “be all that you can be in the army” (emphasize the second syllable of the service, attach a catchy tune, and this enticement even rhymes). In a slight variation, another branch emphasizes external breadth over internal growth: “Join the navy and see the world.”

In days of yore, when reality trumped advertisement, this last slogan often did propel young men to growth and excitement. In particular, budding naturalists without means could attach themselves to scientific naval surveys by signing on as surgeons or just as general gofers and bottle washers. Darwin himself had fledged on the Beagle, largely in South America, between 1831 and 1836, though he sailed (at least initially) as the captain’s gentleman companion rather than as the ship’s official naturalist. Thomas Henry Huxley, a man of similar passions but lesser means, decided to emulate his mentor (Darwin was born in 1809, Huxley in 1825) by signing up as assistant surgeon aboard HMS Rattlesnake for a similar circumnavigation, centered mostly on Australian waters and lasting from 1846 to 1850.

Huxley filled these scientific Wanderjahre with the usual minutiae of technical studies on jellyfishes and grand adventures with the aboriginal peoples of Australia and several Pacific islands. But he also trumped Darwin in one aspect of discovery, with extremely happy and lifelong consequences: he met his future wife in Australia, a brewer’s daughter named Henrietta Anne Heathorn, or Nettie, to the young Hal. They met at a dance. He loved her silky hair, and she revealed in his dark eyes that “had an extraordinary way of flashing when they seemed to be burning—his manner was most fascinating,” as she stated in her diary.

Huxley wrote to his sister in February 1849: “I never met with so sweet a temper, so self-sacrificing and affectionate a disposition.” As Nettie’s only dubious trait, Hal mentioned her potential naiveté in leaving “her happiness in the hands of a man like myself, struggling upwards and certain of nothing.” Nettie waited five years after Hal left in 1850. Then she sailed to London, wed her dashing surgeon and vigorously budding scientist, and enjoyed, by Victorian standards, a happy and successful marriage with an unusually decent and extraordinarily talented man. (Six of their eight children lived into reasonably prosperous maturity, a rarity in these times, even among the élite.) Hal and Nettie, looking back in their old age (Hal died

Henrietta Heathorn’s inscriptions in a volume of poetry given first to her fiancé, Thomas Huxley, and sixty years later to her grandson Julian Huxley

“I never met with so sweet a temper, so self-sacrificing and affectionate a disposition.”

—Thomas H. Huxley, on first meeting Henrietta Heathorn in Australia, 1849
in 1895, Nettie in 1914), might well have epitomized their life together in the words of a later song: “We had a lot of kids, a lot of trouble and pain, but Oh, Lord, we’d do it again.”

The young and intellectually restless Huxley, having mastered German, decided to learn Italian during his long hours of boredom at sea. (He read Dante’s *Inferno* in the original terza rima during a year’s jaunt centered about New Guinea.) Thus, as Huxley prepared to part from his fiancée in April 1849 (he would return for a spell in 1850, before the long five-year drought that preceded Nettie’s antipodal journey to their wedding), Nettie decided to give him a parting gift of remembrance and utility: a five-volume edition, in the original Italian, of course, of *Jerusalemme liberata*, by the great Renaissance poet Torquato Tasso. (This epic, largely describing the conquest of Jerusalem by the First Crusade in 1099, might not be deemed politically correct today, but the power of verse and narrative remains undiminished.)

Nettie presented her gift to Hal as a joint offering from herself, her half-sister Oriana, and Oriana’s husband, her brother-in-law William Fanning. She inscribed the first volume in the young woman’s hand: “T. H. Huxley. A birthday and parting gift in remembrance of three dear friends. May 4th 1849.” For some reason that I have never fathomed but will not question, this set of books sold (to lucky me) for a pittance at a recent auction. (Tasso isn’t big these days, and folks may have missed the catalog entry describing the provenance and context.)

So Nettie Heathorn came to England, married her Hal, raised a large family, and lived out her long and fulfilling life well into the twentieth century. As she had been blessed with accomplished children, she also enjoyed, in later life, the promise of two even more brilliant grandchildren: the writer Aldous Huxley and the biologist Julian Huxley. And now we come to the point of this tale. In 1911, more than sixty years after she had presented the five volumes of Tasso to Hal, Nettie Heathorn, then Henrietta Anne Huxley, and now Granmoo to her grandson Julian, removed the books from such long residence on her shelf and passed them on to the young man who would later carry the family’s intellectual torch with such distinction. In the clear but shaky hand of an old woman, she wrote below her original inscription the missing who and where of the original gift: “Holmwood, Sydney, N.S. Wales. Nettie Heathorn, Oriana Fanning, William Fanning.”

Above her original words, penned in the flower of youth, she then wrote, in a simple statement that needs no explication and that surely lies too deep for tears in its eloquent invocation of life’s persistence: “Julian Sorel Huxley, from his grandmother Henrietta Anne Huxley nee Heathorn ‘Granmoo.’” She then emphasized the sacred theme of continuity by closing her rededication with the same words she had
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“I have landed”': Detail of front page of Papa Joe’s copy of J. M. Greenwood’s Studies in English Grammar

written to Hal so many years before: “In remembrance.” 28th July 1911, Hodeslea, Eastbourne.”

If this tale of three generations watched over by a great woman as she follows life’s passages from dashing bride to doting grandmother doesn’t epitomize the best of humanity, as symbolized by our continuity, then what greater love or beauty can sustain our lives in this vale of tears and fasci-

and Papa Joe to me—loved to read in their adopted language of English. My grandfather even bought a set of The Harvard Classics (the famous “Five Foot Shelf” of Western wisdom) to facilitate his assimilation to American life. I inherited only two of Papa Joe’s books, and nothing of a material nature could be more precious to me. The first bears a stamp of sale: “Carroll’s book store. Old, rare and curious books. Fulton

Irene and Joseph Rosenberg (Grammy and Papa Joe), the author’s maternal grandparents, circa 1950

nation? Bless all the women of this world who nurture our heritage while too many men rush off to kill for ideals that might now be deeply and personally held but will often be viewed as repugnant by later generations.

My maternal grandparents—Irene and Joseph Rosenberg, or Grammy and Pearl Sts. Brooklyn, N.Y.” Perhaps my grandfather obtained this volume from a Landsmann, for I can discern, through erasures on three pages of the book, the common Hungarian name “Imre.” On the front page of this 1892 edition of J. M. Greenwood’s Studies in English Grammar, my grandfather wrote
in ink, in an obviously European hand. "Prop. of Joseph A. Rosenberg, New York." To the side, in pencil, he added the presumed date of his acquisition: "1901, Oct. 25th." Just below, also in pencil, he appended the most eloquent of all conceivable words for this context—even though he used the wrong tense, confusing the compound past of continuing action with an intended simple past to designate a definite and completed event (not bad for a barely fourteen-year-old boy just a month or two off the boat): "I have landed, Sept. 11th 1901."

Of all that I shall miss in closing these columns, I shall feel most keenly the loss of fellowship and interaction with readers. Have we not shared 300 episodes of mutual learning? Early in the series, I began—more as a rhetorical device to highlight a spirit of interaction than as a practical tactic for gaining information—to pose questions to readers when my research failed to resolve a textual byway. (As a longtime worshiper at the altar of detail, nothing niggles me more than a dangling little fact—partly, I confess, from an exaggerated sense of order, but mostly because big oaks do grow from tiny acorns, and one can never know in advance which acorn will reach heaven.)

As the series proceeded, I developed complete faith—not from hope, but from the solid pleasure of invariant success—that any posted question would elicit a host of interesting responses, including the desired factual resolution. How did the Italian word *sque* pass from the rarefied world of classical music into common speech as a synonym for "transition" (resolved by personal testimony of several early radio men, who informed me that in the 1920s they had transferred this term from their musical training to their new gigs as disk jockeys and producers of radio plays)? Why did seventeenth-century engravers of scientific illustrations usually fail to draw snail shells in reverse on their plates—so that the final product, when printed on paper, would depict the snail’s actual direction of coiling—when they obviously understood the principle of inversion and always etched their verbal texts "backward" to ensure printed readability? Who were Mary Roberts, Isabella Duncan, and several other "invisible" women of Victorian science-writing who didn’t even win a line in such standard sources as the *Encyclopædia Britannica* or the *Dictionary of National Biography?*

Thus, after citing my grandfather’s text *en passant* in an earlier essay, I may have wept for joy but could not reign complete surprise when I received the most wonderful of all letters from a reader:

*For years now I have been reading your books, and I think I should really thank you for the pleasure and intellectual stimulation I have received from you. But how to make even a small return for your essays? The answer came to me this week. I am a...*
I think I always knew that I might be able to find the manifest of Papa Joe’s arrival at Ellis Island. I even half intended to make the effort “some day.” But in honest moments of obesiance to the Socratic dictum “Know thyself,” I’m pretty sure that, absent this greatest of all gifts from a reader, I never would have found the time or made the move. (Moreover, I certainly hadn’t cited Papa Joe’s inscription in a lazy and intentional “fishing expedition” for concrete information. I therefore received the letter of resolution with pure exhilaration—as a precious item beyond price, freely given in fellowship, and so gratefully received without any conscious anticipation on my part.)

My grandfather traveled with his mother and two younger sisters on the SS Kensington, an American Line ship (launched in 1894 and scrapped in 1910) that could carry sixty passengers in first class and a thousand more in steerage—a good indication of the economics of travel and transport in these days of easy immigration for European workers, then so badly needed for the factories and sweatshops of a booming economy based on manual labor. The Kensington had sailed from Antwerp on August 31, 1901, and arrived in New York, as Papa Joe accurately recorded, on September 11. My page of the “List or Manifest of Alien Immigrants” includes thirty names, Jewish or Catholic by inference and hailing from Hungary, Russia, Romania, and Croatia. Papa Joe’s mother, Leni, listed as illiterate and thirty-five years of age, appears on line 22, with
The “List or Manifest of Alien Immigrants” of the SS Kensington for September 11, 1901, shows the names of the author’s relatives.

her three children just below: my grandfather, recorded as Joesf and literate at age fourteen, and my dear aunts Regina and Gus, cited as Regine and Gisella (I never knew her real name) at five years and nine months old, respectively. Leni carried $6.50 to start her new life.

I had not previously known that my great-grandfather, Farkas Rosenberg (accented on the first syllable, pronounced “farkash,” and meaning “wolf” in Hungarian), had preceded the rest of his family and now appeared on the manifest as their sponsor, “Wolf Rosenberg, 644 East 6th Street.” I do not remember Farkas, who died during my third year of life, but I greatly value the touching tidbit of information that, for whatever reason, in his initial flurry of assimilation, Farkas had learned and begun to use the English translation of a name that strikes many Americans as curious or even amusing in sound—for he later reverted to Farkas, and no one in my family knew him by any other name.

My kind and diligent reader then bestowed an additional gift upon me by locating Farkas’s manifest as well. He had arrived, along with 800 other passengers in steerage, aboard the Kensington’s sister ship SS Southwark on June 13, 1900, listed as Farkas Rosenberg, illiterate at age thirty-four (although I am fairly sure he could at least read and probably write Hebrew) and sponsored by a cousin named Jos. Weiss (unknown to my family and perhaps an enabling fiction). Farkas, a carpenter by trade, arrived alone, with one dollar in his pocket.

Papa Joe’s later story mirrors the tale of several million poor immigrants to a great land that did not welcome them with open arms (despite Lady Liberty’s famous words) but also did not foreclose the possibility of success if they could prevail by their own wits and unrelenting hard work. And who could, or should, have asked for more in those times? Papa Joe received no further schooling in America, save
what experience provided and internal drive secured. As a young man, he went west for a time, working in the steel mills of Pittsburgh and on a ranch somewhere in the Midwest (not, as I later found out, as the cowboy of my dreams but as an accountant in the front office). His mother, Leni, died young (my mother, Eleanor, bears her name in remembrance), as my second book of his legacy testifies. Papa Joe ended up, along with so many Jewish immigrants, in the garment district of New York City, where, after severing his middle finger in an accident as a cloth cutter, he eventually figured out how to parlay his remarkable, albeit entirely untrained, artistic talents into a better job that provided eventual access to middle-class life (and afforded much titillation to his grandchildren)—as a designer of brassieres and corsets.

He met Irene, also a garment worker, when he lived as a boarder at the home of Irene’s aunt—for she had emigrated alone in 1910 at age fourteen, under her aunt’s sponsorship, after a falling-out with her father. What else can one say for the objective record (and what richness and depth could one not expose, at least in principle and for all people, at the subjective level of human life, passion, and pure perseverance)? Grammy and Papa Joe married young, and their only early portrait together radiates both hope and uncertainty. They raised three sons and a daughter; my mother
alone survives. Two of their children finished college.

Somehow I always knew, although no one ever pressured me directly, that the third generation, with me as the first member thereof, would fulfill the deferred dream of a century, obtain an advanced education, and enter professional life. (My grandmother spoke Hungarian, Yiddish, German, and English but could only write her adopted language phonetically. I will never forget her embarrassment when I inadvertently read a shopping list she had written and realized that she could not spell. I also remember her joy when, invoking her infallible memory and recalling some old information acquired in her study for citizenship, she won $10 on a Yiddish radio quiz for correctly identifying William Howard Taft as our fattest president.)

I loved my grandparents fiercely and reveled in their unconditional blessing and unvarying support—not always deserved, for I really did throw that rock at Harvey.

I loved Grammy and Papa Joe separately. Divorce, however legal and religiously acceptable, did not represent an option in their world. Unlike Hal and Nettie Huxley, I'm not at all sure they would have done it again. But they stuck together and prevailed, at least in peace, respect, and toleration, perhaps even in fondness. Had they not done so, I would not be here—and for this particular twig of evolutionary continuity, I could not be more profoundly grateful, in the most immediate of all conceivable ways. I also loved them fiercely, and I reveled in the absolute certainty of their unconditional blessing and unvarying support (not always deserved, of course, for I really did throw that rock at Harvey, even though Grammy slammed our front door on Harvey's father, after delivering a volley of Yiddish curses amidst proclamations that her Steve would never do such a thing, while knowing perfectly well that I surely could).

The tree of all life and the genealogy of each family share the same topology and the same secret of success in blending two apparently contradictory themes of continuity without a single hair's breadth of breakage, and change without even a moment's loss of a potential that need not be exploited in all episodes but must remain forever at the ready. These properties may seem minimal, even derisory, in a universe of such stunning complexity (whatever its inexplicable eternity or infinity). But this very complexity exalts pure staying power (and the liability that facilitates such continuity). Showy statues of Ozymandias quickly become lifeless legs in the desert; bacteria have scuttled around all the slings and arrows.

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rows of outrageous fortune for 3.5 billion years and counting.

I believe in the grandeur of this view of life, the continuity of family lines, and the poignancy of our stories—of Nettie Heathorn, grown old as Granmoo and passing Tasso's torch two generations after her initial lighting; of Papa Joe's ungrammatical landing as a stranger in a strange land, and my prayer that, in some sense, he might see my work as a worthy continuation, also two generations later, of a hope that he fulfilled in a different way during his own lifetime. I suspect we feel the poignancy in such continuity because we know that our small realization of an unstated family promise somehow mirrors the larger way of all life and, by this affirmation of totality,
becomes “right” in a sense too deep for either words or tears. I can therefore say goodbye to this particular forum because I know that I will never run out of unkept promises or miles to walk and that I may even continue to sprinkle the journey remaining before sleep with a new idea or two. This view of life continues, flowing ever forward, while the current patriarch of one tiny and insignificant twig pauses to honor the twig’s centennial in a new land by commemorating the first recorded words of a fourteen-year-old forebear.

I can say goodbye to this particular forum because I know that I will never run out of unkept promises or miles to walk.

Dear Papa Joe, I have been faithful to your dream of persistence and attentive to a hope that the increments of each worthy generation may buttress the continuity of evolution. You could write those wondrous words right at the beginning of your journey, amidst all the joy and terror of inception. I dared not repeat them until I could fulfill my own childhood dream—something that once seemed so mysteriously beyond any hope of realization to an insecure little boy in a garden apartment in Queens—to become a scientist and to make, by my own effort, even the tiniest addition to human knowledge of evolution and the history of life. But now, with my 300, so fortuitously coincident with the world’s new 1,000 and your own 100, perhaps I have finally won the right to restate your noble words and to tell you that their inspiration still lights my journey: I have landed. But I also can’t help wondering what comes next!
A Cosmic Muse

At the dawn of the new century, an astrophysicist looks at popular culture and detects signs that the arts and sciences are headed toward fusion.

By Neil de Grasse Tyson

Science and art are profoundly similar in many ways. Both emerge from the deepest regions of human creativity, nurtured by an individual's passion for and commitment to a discipline. In everyday conversation, we are as likely to hear (or to say ourselves) "She's got it down to a science" as to hear "He's raised it to an art."

In other ways, though, science and art are profoundly different. Each of the most important scientific theories of all time came from the minds of undeniably great scientists but would eventually have been discovered by other scientists. Occasionally an important theory or discovery has been rushed to publication due to the author's fear of being scooped by someone else. Leonardo da Vinci, however, didn't have to "rush paint" his Mona Lisa for fear that somebody else would create an identical portrait. And if Ludwig van Beethoven had never been born, nothing remotely approximating his famous Ninth Symphony would ever have been written by anybody, anywhere, at any time.

Art can be described as an expression of the beauty, the tragedy, and the complexity of the human condition. Central to expressing this complexity is the need to explore our sense of place and purpose in the world. If the discoveries of science are viewed by the layperson as detached from this calling, then one would never expect science to inspire an artist's creativity—or, more specifically, one would never expect an artist to be attracted to scientific themes.

For much of the twentieth century, science fiction's image of scientists was of the lab-coat-wearing, test-tube-holding, unkempt-looking, wild-haired, antisocial variety. But what mattered more than this stereotype was that most scientists conducted their work within the confines of laboratories and rarely communicated their findings to the general public unless the results had direct implications for a nation's health or defense. Even then, these outcomes were only occasionally presented by the scientists themselves.

True, the great physicists Galileo, Newton, Laplace, Faraday, Eddington, Jeans, and Einstein all wrote popular accounts of their work. But they were exceptions. Within the past decade or so, it's become expected (and even common) for scientists, as well as traditional science writers, to communicate discoveries to the public through magazines, books, television, and public lectures. Nowadays, during any week of your choosing, a dozen science programs appear on PBS and cable TV channels, and multiple science stories make headlines in the daily newspapers.

Take a recent two-month stretch in my own life: I saw the Tony Award-winning play *Copenhagen* on Broadway, and the audience was transfixed by the retelling of important episodes in the history of particle physics in connection with the making of the first atomic bomb. I noted that Brian Greene's *Elegant Universe*, a book on the search for a theory of everything, was still high on best-seller lists. I attended a dance performance entitled *Elements*, which featured four dancers (Earth, Air, Fire, and Water, of course) and was inspired by modern geology and geophysics. And I attended another dance performance, called *Strings*, which was inspired by string theory and the major tenets of the big bang theory. I also read about a new play that explored mathematical theorems. Its title? Proof.

These new domains for the creative voice surely reflect a broader movement in society at large. If artists' choice of subject matter is any indication, the public has embraced science as never before—not as something cold and distant but as something vibrant and within reach. People are beginning to feel that the cosmic discoveries made by members of our own species—from the mysteries of the big bang to the stellar origin of the chemical elements of life and the mapping of the human genome—belong to us all. People see, perhaps for the first time, that they are no longer bystanders in the scientific enterprise but vicarious participants.

As *Natural History*'s new century begins, I wonder whether the discoveries of modern science—those of astrophysics in particular—are numerous enough and accessible enough to warrant the declaration that we are entering a new era of artistic inspiration. Like the religious and mythological sources that so influenced art before and during the Renaissance, the cosmos has become a thematic source for the arts of our own day. I'd bet that the theories and discoveries of modern science have a limitless capacity to awaken human emotion and trigger unbridled wonder. If so, artists can now count among their many muses the secrets of the universe.
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A Hundred Years of Missing Links

So many fossil hominids have been discovered since 1900 that they now constitute an embarrassment of riches.

By Ian Tattersall

The first 100 years of Natural History correspond almost exactly to the period within which we Homo sapiens finally began to acquire a reliable perspective on how we fit into the living world. At the beginning of the twentieth century, philosophers still regarded humans as unique and assumed that a wide gulf separated us from the animal kingdom. Sure, Charles Darwin had hinted as early as 1859 that the origins of humanity might be sought within the rest of nature. And at about the same time, the first fossil of an early human—the Neanderthal from Germany’s Feldhofer Cave—had been recognized as a phenomenon requiring explanation. But during the nineteenth century, there was no established framework for interpreting the sparse evidence of human origins. Even Thomas Henry Huxley, Darwin’s vocal defender and an advocate of the theory that nature “does sometimes make jumps,” dismissed the Feldhofer fossil (consisting of a skullcap and some limb bones) as a primitive variant of humanity, rather than allowing for the existence of another species close to the human lineage. This viewpoint remained dominant throughout the rest of Darwin’s century, although the Irish anatomist William King did go against the flow and assigned the Feldhofer individual to a separate species, Homo neanderthalensis, for the splendidly nineteenth-century reason that “the thoughts and desires that once dwelled within [the skullcap] never soared beyond those of the brute.”

It was left to the scientists of the twentieth century to develop a larger notion of our evolutionary past that could incorporate the gradually expanding human fossil record. Among the early additions were the Pithecanthropus (Homo erectus) fossils (the so-called Java man) from a human-sized hominid with heavy brow ridges and a brain of intermediate size. Their discovery in 1891 by Eugène Dubois began to reshape anthropology’s view of human origins. If critics of Darwin had complained of the “missing link” between humans and other primates, the Java fossils were the first of what would eventually be so many links that no one knew quite what to do with them all.

The prevailing scholarly influence in the early years of Natural History’s existence—when it was a skinny pamphlet entitled The American Museum Journal—was exerted by a coterie of British paleoanthropologists who were still in thrall to the set of archaic influences dating back to the origins of biological anthropology in the eighteenth century. At that time, the discipline’s primary concern was to categorize and explain the variety of humans that Europeans were encountering in their explorations of the globe. And with Europeans as the observers, it was hardly surprising that a racist tradition rapidly developed, with supposedly primitive humans such as Australian Aborigines and Africans at the bottom of the heap and Europeans (specifically the Brits) at the top. Unfortunately, this unpromising framework imposed itself on the interpretation of the growing human fossil record, and shaking it off required most of the century.

One great obstacle was that, in 1912, the “earliest Englishman,” the big-brained and putatively ancient (but of course fraudulent) Piltdown fossil, was accepted as a lineal human ancestor. As a result, the Australopithecus skull found in Taung, South Africa, in 1924—pointing to the existence of a four-foot-tall, upright hominid with a chimp-sized brain—was dismissed as belonging to an extinct side branch. It took until 1953 for Piltdown to be conclusively revealed as a hoax and for the initially snubbed Taung skull to be recognized as one of the keys to understanding the human past. The Asian Homo erectus fossils Pithecanthropus and Sinanthropus (Java man and Peking man) were also shunted aside during the 1930s, and the large-brained European Neanderthals, too, were considered an unsuccessful side branch that had left no descendants. The net effect of such interpretations was to produce a human family “bush” with multiple branchings and terminal twigs.

The dominant voice in Natural History from about 1908 until 1935 was, unsurprisingly, that of the Museum’s powerful president, Henry Fairfield Osborn. Osborn followed his colleague W. D. Matthew in placing human origins in central Asia, where he believed the “Dawn Men” had evolved in the “invigorating . . . atmosphere of the . . . dry uplands.” This notion fit nicely with his desire to distance humans as

Henry Fairfield Osborn chose to ignore Darwin’s correct guess that Africa was the cradle of mankind.

Homo ergaster as reconstructed by British artist John Holmes for the Museum’s Hall of Human Biology and Evolution
far as possible from the African apes—hence, his dismissal of the significance of the Taung skull. Osborn chose to ignore Darwin’s correct guess that because Africa was where gorillas and chimps lived, the cradle of mankind would be found there. While it appalled the British, who were convinced that the purported Dawn Men arose some twenty-five miles from Charles Darwin’s home in Kent, Osborn’s Asian theory also suited Davidson Black, head of the laboratory in Beijing (then called Peking) where the newly discovered Peking man fossils were under study during the 1930s. A Canadian, Black had gone to Beijing expressly to be near the hominin homeland.

With Black’s premature death in 1934 and his replacement by the German anatomist Franz Weidenreich, the picture changed again. Weidenreich, who was of Jewish descent, had personally experienced Nazi racism, and this doubtless affected, or at least reinforced, his perceptions of human evolution. Weidenreich rejected the then-conventional wisdom that regarded each new human fossil as “a side branch of the main stem.” Instead, he saw continuity as the main message of the human fossil record. While acknowledging the differences among the geographic varieties of modern and fossil humans, he concluded that interbreeding was, and always had been, an integrating factor among human populations worldwide.

Weidenreich came to the Museum in 1941, just before the Japanese invaded Beijing and his beloved Peking man fossils were lost in the shuffle (although the plaster casts he had sent to New York survived). Weidenreich’s views proved congenial to his new colleagues. This was the moment when curators Ernst Mayr and George Simpson, along with their Columbia University colleague Theodosius Dobzhansky, were putting the finishing touches on what became known as the synthetic theory of evolution: an integration of paleontology, systematics (classification), and population genetics that was to dominate biologists’ view of evolution for decades to come.

According to the purest version of the synthetic theory, virtually all evolutionary phenomena could be boiled down to gradual genetic changes in individual lineages of organisms, taking place over vast periods of time and under the benign guidance of natural selection. Here was a view of the evolutionary process supremely well suited to Weidenreich’s gradualist, fossil-based scheme, although Weidenreich himself continued to hew to older—and outdated— notions of how evolution occurred, including the idea that evolution somehow proceeded toward a predetermined goal. And such was the influence of the synthetic theory and its highly vocal advocates that by the early 1950s, previous interpretations of human evolution had been swept away, replaced by a linear view beguiling in its simplicity: the small-brained Australopithecus gave rise to the medium-brained Homo erectus, which in turn begat the large-brained Homo sapiens.

Such simplicity was too good to last, especially when a flood of hominin fossil finds in the 1960s and 1970s showed that a substantial variety of extinct, humanlike creatures had walked on Earth. Among them were the so-called robust australopithecines and Homo habilis, found by Louis and Mary Leakey at Olduvai Gorge, Tanzania, and Australopithecus afarensis (best known in the form of the Lucy skeleton), found by Donald Johanson in Ethiopia. Still, anthropologists’ vigorous attempts to fit them all into a linear scheme continued right into the 1970s—and indeed, some anthropologists today honor Weidenreich as the father of the
Skeletons of our nearest extant primate relatives.

"multiregional hypothesis," which contends that despite regional variation, Homo erectus was a single population that evolved throughout the world into Homo sapiens. But the new fossils, together with fresh developments in evolutionary theory, eventually produced a widespread recognition that multiple hominid species coexisted in the past.

Recent evidence indicates, for instance, that Homo erectus overlapped in time with Homo sapiens and that robust australopithecines (large-boned hominids with enormous jaws, huge teeth, and smallish brains) coexisted with early Homo in southern and eastern Africa. These hominids competed with each other as well as with other kinds of organisms. What this dynamic picture has taught us, above all, is that Homo sapiens is very unusual in being the lone hominid on Earth today. Just because this is the situation we happen to be familiar with does not mean it is a typical state of affairs—and our elimination of the competition should make us think hard about the kind of creature we are.

As ever, and as readers of Natural History well know, it was events at the American Museum of Natural History, home of the new synthetic theory and a perennial source of new ideas in evolution, that provided the theoretical component for a reappraisal of the hominid fossil record. In 1972 curator Niles Eldredge and Harvard paleontologist Stephen Jay Gould (who had done research at the Museum during graduate school) published a paper in which they accounted for the predominant pattern in the fossil record of all kinds of organisms—a pattern of discontinuity, not of continuity. Species tend to make rather sudden appearances in the record, persist relatively unchanged for varying and often long periods of time, and then disappear, to be succeeded by other species. This pattern of "punctuated equilibrium" described by Eldredge and Gould corresponded exactly to what the rapidly expanding hominid fossil record had been suggesting in the dozen years since Louis and Mary Leakey had begun to make their discoveries at Olduvai Gorge.

Once again, it began to appear that our species, Homo sapiens, far from occupying the splendid summit of the tall, slender, minimally branching human family tree favored by the proponents of the synthetic theory, was no more than the single surviving terminal twig among the many that had existed over the eons. And regular additions to the fossil record continue to reinforce this sobering conclusion. I recently received an e-mail from China that inquired, rather worriedly, whether it was true that I believed that at least seventeen species are represented in the known hominid fossil record. That sounds like a lot, and it had me worried too for a moment, but a quick tally rapidly confirmed it. And because of this multiplicity of species, the human family tree is, ironically, beginning to look—superficially, thank goodness—rather like the earlier constructs that Franz Weidenreich so disliked. But this time, the picture is based on sound biological reasoning rather than on arrogance and prejudice.

The latter half of the twentieth century also saw physics and chemistry produce some remarkable tools that could be applied to anthropology. Molecular biology, for instance, revolutionized the methods of determining how closely animals are related to one another. Using a "molecular clock," Berkeley biochemist Vincent Sarich calculated that humans, chimps, and gorillas share a common ancestor about 5 million years ago—much more recently than the 15 to 20 million years ago that "bone" paleontologists had previously believed. Researchers have even recovered DNA from Neanderthal remains and concluded that it is significantly different from human DNA. Some have applied molecular techniques to establishing that all of humanity is traceable to a small population that lived in Africa a few hundred thousand years ago.

So Natural History's century has been an eventful time in the history of human evolutionary studies, reminding us how complex scientific belief is and how subject to rapid change. Paleoanthropology today bears little resemblance to the field in which I began to work nearly forty years ago, and there is no reason to believe that today's version will be any more recognizable a century hence. Fortunately, however, Natural History will be around to record the changes as they happen.
Reading Nature’s Tea Leaves

Our ideas about nature reveal as much about ourselves and our cultures as they do about the world around us.

By Frans de Waal

A journalist once told of being sent into the office of Konrad Lorenz, the famous Austrian ethologist, with assurances that he was expecting her. His office appeared to be empty. Asking around, however, she was told that Lorenz had never left. Eventually she discovered the Nobelist partially submerged in an enormous aquarium that was built into the office wall.

This is how we like our biologists: as close to their animals as possible. Our expectations go with their special status as society’s high priests of nature, the intermediaries between us and where we came from. Mathematicians, chemists, and astronomers can be greatly admired, yet the task of putting us in touch with our creaturely past and reflecting on the human condition falls to the biologist. It is an ancient function once fulfilled by stories such as the fables of Aesop and La Fontaine. Moralizing accounts are still with us, but scientists are gaining the upper hand because they supposedly tell us the unvarnished truth about the animal world and, by extension, about ourselves.

It would be naive, though, to think there is no connection between a scientist’s social, cultural, or moral outlook and the way he or she sees nature. As has been pointed out many times, Darwinism, with its premise that competition drives the evolutionary process, arose while English society was moving toward capitalism. Similarly, in the early part of the last century, both postrevolutionary Russia and the United States—two cultures with faith in the ability of humans to control their own future—emphasized the power of learning and behavioral modification of the sort championed by Ivan Pavlov and B. F. Skinner. At about the same time, in more conformist Europe, ethologists such as Lorenz became enamored of the concept of instinct and the behavioral constancy it implied.

Even those who view people as fundamentally distinct from animals—claiming, for example, that animals are enslaved by instinct whereas humans are entirely driven by culture—are themselves projecting cultural prejudices onto nature. In reality, the relationship between nature and culture is much like the situation of the elephant and the mouse walking side by side over a rickety wooden bridge. Above the noise, the mouse shouts, “Hey, listen to us stamping together!” People who claim that humans have left behind their biology suffer from the same delusions of grandeur as the mouse. They barely realize they are walking next to human nature, the elephant that sets the tone of everything we do and are. Consequently, naturalists’ contribution to humanity’s “Know thyself” mission can be understood only in the context of the tinted glasses through which each one stares into nature’s mirror. Removing these glasses is next to impossible, so the next best thing is to compare the view through an alternative pair.

A little-known but telling example is that Western and

Moralizing about human nature is a task once fulfilled by animal stories, such as the fables of Aesop and La Fontaine.
Eastern scientists once held contrasting views about our closest animal relatives, the great apes. The Western view was Rousseauian: like noble savages, apes were seen as self-sufficient—free of social ties and obligations. To field biologists who encountered them in the forest, the parties of chimpanzees traveling in apparently haphazard combinations from one fruit tree to the next seemed to confirm the lack of a coherent group life.

In the 1960s, however—at the same time that Jane Goodall, working in the Gombe Stream Reserve in Tanzania, speculated that females and their dependent offspring might be the only bonded units in chimpanzee society—a Japanese team studying chimpanzees a mere eighty miles away was operating under a quite different assumption: that these apes, which supposedly filled the gap between ourselves and other animals, must have a complex social life.

Much Eastern art reveals a great sensitivity to animal behavior, as in this late-twelfth-century Chinese fan painting of gibbons raiding an egret's nest.
Eventually, through persistent field observations, the team, led by primatologist Junichiro Itani, showed that chimpanzees do in fact live in large communities with stable memberships. Today the communal life of the chimpanzee is taken for granted—we have abundant evidence for territorial warfare between different communities and for group-specific social traditions—but the initial finding came out of a conviction on the part of Japanese researchers that chimpanzees could not be as individualistic as Western science had made them out to be. Their own culture’s emphasis on the individual as part of the group had put Japanese researchers on the right track for making this discovery.

My goal here is not to propose some sort of cultural relativism of knowledge, as if everything depends on the investigator’s background. The beauty of science is that it has rules of evidence that allow us to sort through various perspectives until we find the one most consistent with the data. Conflicting ways of looking at nature enrich this process: culturally or even ideologically charged theories are fine so long as they can be tested against reality. This is what distinguishes science from storytelling.

Within the Western tradition, the greatest contrast in outlook has been between those who accept and those who reject the natural condition. Take, for example, England’s two Terrible Toms, who were convinced that nature is not to be trusted. Thomas Hobbes, the seventeenth-century philosopher, depicted us as acting like wolves toward one another: Homo hominim lupus. In a single move, he managed to deny humanity’s talent for group living and to misrepresent a carnivore marked by an extraordinary degree of cooperation. Hobbes claimed that, left to their own devices, people are not fit for civil society; they need to be controlled and educated so as to overcome their basic impulses.

Darwin’s fiercest advocate, Thomas Henry Huxley, dressed the same view in evolutionary terms, claiming that because natural selection was such a harsh process, it could not possibly have produced kindness and morality. If we occasionally find these gentler tendencies in human society, he asserted, they must be culturally imposed. For most of his life, unable to imagine evolutionary advantages to altruism and cooperation, Huxley saw nature as an unruly garden, kept under control by a hardworking gardener.

Darwin himself had made it clear in the Descent of Man that there was plenty of room for the evolution of ethics. Believing that animals share our kindest inclinations (“many animals certainly sympathize with each other’s distress or danger”), he proposed that any animal endowed with well-defined social instincts would inevitably acquire a moral sense if its intellectual powers became more developed. But it was Huxley’s view of humans as a species at war with itself that became the cornerstone of Sigmund Freud’s Civilization and Its Discontents and that is still recognizable in the statements of some of today’s biologists, such as the British evolutionaryist Richard Dawkins, who in a 1997 interview endorsed Huxley thus: “What I am saying, along with many other people, among them T. H. Huxley, is that in our political and social life we are entitled to throw out Darwinism, to say we don’t want to live in a Darwinian world.”

The pessimists have not ruled unopposed, however. For example, the Russian anarchist Peter Kropotkin pointed out in his 1902 book Mutual Aid that many animals survive through cooperation. Sometimes depicted as a romantic, Kropotkin was far from naive when he asked whether animals hostile to one another are fitter than those seeking one another’s company and support. Inspired by animals in a Siberian environment so unforgiving that outcompeting
others could hardly be the primary issue, he saw cooperation as behavior born of necessity: "It is not love, and not even sympathy . . . which induces a herd of ruminants or of horses to form a ring in order to resist an attack of wolves."

At about the same time, the American philosopher and educator John Dewey criticized Huxley for imagining that a gardener could go against nature. The successful gardener, said Dewey, achieves his ends by creating conditions that "fall within the wont and use of nature as a whole."

In their emphasis on humanity's social nature, both Dewey and Kropotkin were more Darwinian than was Huxley, who acted entirely on his own when he kicked morality outside the evolutionary framework. As noted by his biographer Adrian Desmond, "Huxley was forcing his ethical Ark against the Darwinian current which had brought him so far." Clearly, the Darwinian world seems far more livable than Huxley's, which has little to offer by way of amelioration other than an artificial civility.

Both ways of looking at nature—as something we need to subjugate or as the source of everything we are, both good and bad—have coexisted for centuries, and not only in the West. In fourth century B.C. China, the Confucian philosopher Mencius postulated that humans tend toward the good as naturally as water flows downhill. He disagreed with a fellow philosopher who, defending a view not unlike Huxley's gardener-and-garden metaphor, stated that making human nature righteous is like fashioning a wooden cup or bowl out of a willow. Mencius replied, "Can you, leaving untouched the nature of the willow, make with it cups and bowls? You must do violence and injury to the willow before you can make cups and bowls with it. If you must do violence and injury to the willow in order to make cups and bowls with it, on your principles you must in the same way do violence and injury to humanity in order to fashion from it benevolence and righteousness! Your words alas! would certainly lead all men on to reckon benevolence and righteousness to be calamities."

A thirteenth-century Chinese handscroll depicts renowned calligrapher Wang Hsi-chih deriving inspiration for his writing from the movement of geese on a lake.

In this portrait by eighteenth-century British painter Thomas Gainsborough, humans dominate an agricultural landscape.

And so the question of how the study of nature has shaped our self-image inevitably invokes the observation that the causal relationship between the two is hard to figure out. We tend to see what we want to see, what we have been conditioned to see. In his 1997 book The Origins of Virtue, for example, biologist and science writer Matt Ridley cites the opinions of Margaret Thatcher ("There is no
such thing as society. There are individual men and women, and there are families”) and Newt Gingrich to make the point that political conservatism is in line with the me-first side of evolution. He argues that we are doomed if we keep denying our species’ inherent opportunism and egoism. By contrast, Francis Fukuyama, in *The Great Disruption* (1999), uses the latest insights into primate behavior to make the point that our societies have drifted away from the conditions that cause us to form groups in the first place: “We’re programmed to cooperate in groups, to be joiners, to feel accepted.” Fukuyama, a professor of public policy at George Mason University, stresses how being surrounded by a tightly knit community—such as an old city neighborhood where everybody knows everybody—enables young women to walk the streets at night without fear and permits store owners to trust passersby. Thus, whereas Ridley advocates a devolution of centralized power in order to set the individual free, Fukuyama speaks of social capital and civic duty and of the importance of social networks.

We should always be suspicious of simple lessons drawn from nature, however. There is no domain with more contradictions and diversity. Both Ridley and Fukuyama have a point, and both rightly feel they have biology on their side. If such contrasting views can coexist within a single culture, one can imagine the differences that can exist between cultures. Again, comparisons of East and West are instructive. Western culture is marked by an enduring belief that humans are special, different from other animals. Even today—with all we have learned about our genetic relatedness to the other great apes and about their remarkable social and emotional lives—certain topics in animal behavior are still considered taboo. When a gorilla at Illinois’s Brookfield Zoo rescued a child who had fallen into her enclosure, for example, some scientists saw this as a sign of sympathy (much as Darwin might have), while others considered such an interpretation far too anthropomorphic. Yet from an evolutionary perspective, the most conservative view is that if an animal closely related to us acts like us, the emotional and cognitive underpinnings of the action must be similar, too.

I found myself reflecting on this recently while on sabbatical in China and Japan, doing research for a new book on the possibility that animals have culture. In the West, the concept of the Great Chain of Being—derived from the ideas of Plato and Aristotle—has had a spectacularly long and influential life. The essence of this notion is that all forms of life have their proper place on a ladder, with the humblest organisms at the bottom and divine beings at the top. Humans sit high up on the ladder, above all other animals. Nearly 2,000 years after this idea was put forth, and more than a century after Darwin provided an explanation for the evolutionary connectedness of all organisms, the concept—modified and in modern dress—often still colors the way Westerners (biologists and laypersons alike) think about humanity’s place in nature. The idea of such a hierarchical chain of life is, however, alien to Eastern philosophy, which maintains that all living things are spiritually connected and that the human soul—or any other soul—can be reincarnated in many shapes and forms. A man can become a fish, and a fish can turn into a god. The presence in Asia of indigenous primates has served to strengthen the idea of continuity. Eastern folktales and poetry are laced with references to monkeys, and the three wise men of the Bible are matched in the East by the three wise macaques of Tendai Buddhism (“see no evil, hear no evil, speak no evil”).

If the soul can move from monkey to human and back again, there are no grounds to resist the idea that we are historically as well as spiritually connected. Not surprisingly, the idea of evolution was never controversial in the East; it was considered a logical and welcome thought. According to Junichito Itani, “Japanese culture does not emphasize the difference between people and animals and so is relatively free from the spell of anti-anthropomorphism—we feel that this has led to many important discoveries.” Japanese scientists, assuming that every animal had a distinct personality, identified and named each individual. The initial response of many Western scientists was to ridicule their Japanese counterparts for humanizing their subjects.
It was in this climate that in 1952 Kinji Imanishi, the father of Japanese primatology, wrote a book that criticized the view of animals as automatons driven by instinct. Included in the book was an imaginary debate among a wasp, a monkey, an evolutionist, and a layman about the possibility that animals other than ourselves might have culture. Imanishi, convinced that they might, outlined a simple principle: if individuals belonging to a group learn from one another, their behavior may, over time, become different from the behavior found in other groups of the same species, thus forming a characteristic culture—in other words, behavior and customs that are transmitted socially rather than genetically.

Imanishi's views inspired other Japanese scientists and set the stage for the discovery of a host of culturally transmitted behaviors, beginning with the exciting finding, now familiar to schoolchildren around the world, that between 1952 and 1958 the macaques of Koshima Island picked up from one another the habit of washing sweet potatoes before eating them. Increasingly, Western scientists have followed the lead of their Japanese colleagues, and we now know that cultural learning is widespread in the animal kingdom—from young birds learning to sing and chimpanzees mastering the use of termite-fishing twigs and nut-cracking stones, to whales adopting unusual hunting techniques. Orcas living in the waters off Argentina, for example, sometimes hurl themselves onto a beach and grab one of the seals breeding there. This is a hazardous technique that, if performed incorrectly, may lead to the standing and death of the whale. Adult orcas have been seen encouraging their young, pushing them onto a "practice" beach where no seals are present. If the young get stuck on the sand, the adults help them out by creating waves. At the San Diego Zoo—and as far as we know, only at this zoo—bonobos regularly alternate grooming a partner with clapping their hands (or feet) together. Newcomers to the colony may adopt the habit within a couple of years.

Even though symbolic communication and education undeniably make human culture far more complex, the way people learn from one another doesn't seem fundamentally different from the way animals do. But in the West, the idea that animals might have culture still meets with resistance. Here, the social sciences and humanities have accorded culture the status previously reserved for the soul—that is, as the attribute distinguishing us from all other life forms—and this leads to the assertion, repeated so often as to be trite, that culture is what makes us human. Not surprisingly, it fell to non-Western scientists, untrained in such sharp dualisms, to come up with the concept of animal culture.

Reading the tea leaves of nature cannot be left to a single priesthood. Each culture is too wrapped up in its own relationshio with nature to step back and see it as it is. To gain a full picture requires all kinds of scientists, who together take on a task equivalent to comparing the images in a range of fun-house mirrors. Somewhere in that heavily distorted information resides the truth about the reflected object.
The Laughing Species

A familiar vocal act reveals its evolutionary past.

By Robert R. Provine

Among friends, we voice our instinctive social call of “ha-ha-ha,” a sound more like the cries and songs of wild animals than like human speech. And when we hear laughter, we often bark back “ha-ha-ha,” joining fellow Homo sapiens in a bizarre, contagious chorus. Our brains have a built-in laugh detector, which, once triggered, activates a neural circuit that produces the movement we ultimately hear as laughter. Somehow, all members of our species usually manage to laugh at just the right times, without consciously understanding what they are doing. A universal human signal, laughter is generated and recognized by people of all cultures, yet it has only recently come under scientific scrutiny.

I began my study of laughter a decade ago, in the course of a thirty-year search for the neurological bases of behav-

Contagion of a happy sort unites a group of playmates.
ioral development and evolution, which I studied in stages ranging from embryo to adulthood. I was particularly interested in “behavioral fossils,” such as the neurological vestiges of flight in living flightless birds. No ostrichlike bird I tested (emu, rhea, ostrich, cassowary) manifested any behavioral trace of its flighted past, never flapping under any circumstances. Ravens, by contrast, flap their way underwater, though in air they are flightless and have lost the neurobehavioral mechanism that triggers flapping in flighted birds when they fall from a height. In pursuit of bigger game, I began searching for similar archaic behavior in humans, focusing on the apparently primitive vocalization of laughter.

My choice was partly tactical. When a researcher is investigating a neurological mechanism, it’s best if everyone has it; besides, the neuromuscular basis of “ha-ha” is more easily understood than that of complicated vocalizations such as speech. To my surprise, little was known about the act of laughter. Most of what I found concerned humor—speculations about what makes jokes funny, or frothy tracts about “laughing your way to health.” So in the tradition of an anthropological field study, three undergraduate research assistants and I set out to observe laughing people in their natural habitats, from the university student union to suburban malls and city sidewalks.

Whenever we heard laughter, we noted what had been said immediately before it occurred, the gender of the speaker and the audience (the person addressed), and whether it was the speaker or the audience who laughed. Our collection of 1,200 cases of natural laughter yielded several findings so unexpected that initially I did not believe them. Most laughter was not a response to jokes or other formal attempts at humor; the typical pre-laugh comments, such as “I’ve got to go now” or “Look, it’s Andre,” were hardly knee-sappers. And unlike the scenario of comedy performance, speakers laughed almost 50 percent more often than their audiences.

The critical stimulus for laughter was the presence of another person, not the cracking of a joke—or, for that matter, a sight gag, comic gesture, or other visual cue (plenty of laughter is present in telephone conversations, a purely auditory mode of communication). This requirement was confirmed in a study in which a group of my students kept a diary of the circumstances of their own laughter. When the students were by themselves and the sources of vicarious social stimulation were removed (television, radio, cinema, reading), laughter almost totally disappeared. Even when we are very happy, we seldom laugh when alone. The canned laughter added to television shows taps another social aspect of laughter: its potent tendency to trigger laughter in those who hear it, synchronizing the response of an entire group. Although Time magazine included laugh tracks in its “100 Worst Ideas of the Century,” viewers do react to them by laughing more and by rating jokes as funnier.

The response to tickling probably evolved from an ancient reflex defense mechanism against predators or external parasites.

In her best-selling book You Just Don’t Understand, linguist Deborah Tannen described gender differences in speech. The gender differences in laughter may be even more pronounced. In our 1,200 cases, we found that while both sexes laughed a lot, females laughed the most, especially when conversing with males. In contrast, men may yuk it up with their male pals but fall strangely silent in the presence of women—in fact, a male speaking to a female was the only gender combination that produced less speaker laughter than audience laughter. In general, women are the leading laughers, while men are the best laugh-getters. This pattern develops early in life: think back to your high-school class clown—most likely it was a guy.

Women may use their laughter as an unconscious vocal display of compliance with or subservience to a more dominant, usually male, group member. In many societies, from the Tamil of southern India to the Tzeltal of southeastern Mexico, laughter is a self-effacing behavior of both males and females who occupy subordinate positions. It offers a revealing probe into hierarchical social relations because it’s not consciously controlled and is relatively uncensored. By contrast, we exercise more control over word selection in speech.
If you doubt the involuntary nature of laughter, ask a friend to laugh. Some people may produce a burst of genuine laughter at your unusual request, but even they will report that they can’t “laugh on command” and will fail to produce convincing voluntary laughter. We are better at intentionally inhibiting than at intentionally producing laughter. (Crying, another emotional signal, is even more difficult to control.)

Tickling is the most reliable stimulus for laughter. The neurological basis for the response to tickling probably evolved from a reflex defense mechanism that protected our body’s surface from external, moving stimuli—most often, predators or parasites. The original reflex actions may have ranged from brushing away an invader to ever more energetic attempts to break free. The response to tickling is still somewhat like a reflex (we laugh uncontrollably when tickled, struggle to escape the tickler, push away the tickling hand). Beyond that, however, tickling is yet another social context for laughter. One of our surveys indicated that people tickle and are tickled by friends, family, and lovers and that the rationale given most often for tickling someone is to show affection. Our nervous system conspires to enforce this sociality of tickling: we can’t tickle ourselves.

Tickle battles, the most benign form of human conflict, bind us together in a laugh-filled give-and-take. The ticklee may push away the tickler’s hand and, if necessary, run away, only to return and renew the interaction. For infants who can’t yet talk, tickling, along with the associated laughter, is an entrée into social relationships. Laughter signals “I like it; do it again!” while crying and fending off the other person signal that the game has gone too far. Tickling games, we found in surveys, are not confined to children. In adults, such tactile friskiness is commonly part of sex play. Tickling is also the source of what may be the most ancient joke, the feigned tickle of the “I’m going to get you” game, a ruse that works even with our hairy cousins the chimpanzees.

Women are the leading laughers, while men are the best laugh-getters. Think back: most likely, your high-school class clown was a guy.
Chimpanzees (and other great apes) also produce a laughlike sound when tickled or during play, a fact noted by Charles Darwin in *The Expression of the Emotions in Man and Animals* (1872). But in important details, chimp laughter differs from that of humans. Laughing humans chop an outward breath into a series of short (1/15 second), vowel-like blasts (“ha,” “ho,” or “he”) that repeat about every 1/5 second, with a decrescendo as the lungs run out of air. The sounds have a marked harmonic structure, consisting of a fundamental frequency and its overtones. Chimpanzee laughter, however, is breathy—lacking the voiced, vowel-like sounds, the harmonic structure, and the clean onset and termination of the human “ha.” The chimp utterances are produced at about twice the human rate, with one sound generated during each outward and inward breath.

This breathy huffing and puffing (or “ah” grunting, if intense) is the chimpanzee and orangutan “laughing” and “chuckling” referred to by Darwin and others, and the gorilla “chuckles” reported by Dian Fossey. It mimics the heavy breathing of vigorous play but signals playful intent, not physical exertion. To those unfamiliar with it, audio recordings of chimpanzee laughter do not sound laughlike. When I asked students in my classes to identify a mystery sound, only 2 of 119 thought it was laughter. The most common description (offered by 36 students) was “panting,” usually that of a dog. Some even described it in terms of mechanical acts such as “sawing” or “sanding.” However, if given the opportunity to engage a chimp in a bit of rough-and-tumble, most would have recognized the sound as laughter—the context of tickle and play and the chimp's
cheerful “playface” (mouth open, upper teeth covered, lower teeth exposed) would have tipped them off. We are, don’t forget, each other’s closest relatives.

The characteristics of laughter in chimpanzees point to a critical constraint on the evolution of speech and language in the great apes. After all, how much vocal facility is available to an animal limited to one syllable per breath? Chimps are captives of an inflexible neuromuscular system that is still closely tied to the ancient and essential labor of breathing. They share this characteristic with other four-legged animals, whose breathing and running are closely synchronized (one stride per breath) so as to brace the thorax for forelimb impacts. This respiratory pattern was probably more limiting to the emergence of speech than was the structure of the tongue and vocal tract.

The evolution of bipedalism in humans allowed for greater flexibility in the coordination of breathing and locomotion. A human runner, for example, may employ a variety of patterns: the ratio of strides per breath can be 4:1, 3:1, 5:2, 2:1, 3:2, or 1:1, with 2:1 being the most common. Breaking the rigid link between stride and breath allowed our early ancestors to evolve a system of vocalization in which individual sounds were no longer tied to single breaths, permitting the emergence of speech as we know it and, incidentally, of our species’ characteristic laugh.

Although the vocal mechanism that permits the human laugh is necessary for speech, it must be remembered that spontaneous laughter is not a matter of speaking “ha-ha-ha.” Spinal injuries that cause various degrees of quadriplegia, thus affecting breath control, may eliminate normal laughter but spare speech. Conversely, brain-injured individuals who can neither produce nor comprehend speech may still laugh at jokes, responding to nonlinguistic vocal and gestural cues. Constraints on the mechanism of laugh production are apparent in the difficulty we experience producing certain ses.

Bipedalism gave humans greater flexibility in breathing, permitting the emergence of speech and of our species’ characteristic laugh.

People unconsciously synchronize their laughing.

Evidence that laughter is “hardwired” into our brains is found in the behavior of people suffering from various neurological disorders. Inappropriate, excessive laughter is an early symptom of kuru, a degenerative disease of the brain akin to “mad cow disease.” This fatal malady, caused by an infectious protein called a prion, was observed in the Fore people of New Guinea, who, during the ritual cannibalism of dead relatives, sometimes consumed the infected brain tissue of the deceased. As in most cases of inappropriate laughter, the symptom probably results from the failure of some mechanism that inhibits laughter rather than from the direct activation of a laugh center in the brain.

Other disorders in which laughter may be a symptom include manganese poisoning, Wilson disease (a disorder caused by a recessive gene that leads to the accumulation of copper in the brain), some types of epilepsy, Alzheimer disease and the somewhat similar Pick disease, Rett disorder (a condition affecting only girls, in whom a common symptom
Chasing and tickling games are a primeval source of laughter.

is solitary, nocturnal laughter), Angelman disorder (a genetic condition whose unfortunate victims were once dubbed “happy puppets”), Williams disorder (a genetic but not hereditary illness in which frequent laughter is part of an abnormally gregarious nature), and some kinds of schizophrenia. The symptom is also sometimes seen in lobotomy patients and other sufferers of frontal lobe damage and in victims of amyotrophic lateral sclerosis (Lou Gehrig’s disease) and multiple sclerosis. In many of these pathologies, the laughter is not connected with feelings of mirth—the patient is as baffled and horrified as everyone else is when the errant brain causes him or her to bark out an emotionless sound. Curiously, laughter is not a symptom of Tourette’s disorder, otherwise known for tics and vocal outbursts.

Laughter may be primed through the use of drugs such as marijuana or laughing gas (nitrous oxide), which can make things seem funnier, or stimulated by group conditions favoring mass hysteria or religious fervor. Some aspects of a person’s style or frequency of laughing, if not his or her taste in humor, may even be inherited, as in the case of the “giggle twins”—female identical twins who were separated at birth, raised by relatively sober families, and reunited forty years later. Both had a similar predisposition to laughter.

One of the pleasures of my quest to understand laughter has been to escape from my windowless neurophysiology laboratory to seek laughing in all its contexts—bars, zoos, comedy clubs, acting classes, neurology clinics, city sidewalks, operas, TV laugh tracks, Pentecostal services, tickle wars. The study of laughter requires a catch-as-catch-can interdisciplinary approach and entails grappling with some of science’s knottiest problems—the interrelationship of nature and nurture and the evolution of speech, language, and social behavior. Above all, studying laughter provides new insights into what it means to be and act human.
Common Ground

Studies of the social and emotional lives of forest apes reveal the evolutionary roots of human nature.

By Barbara Smuts

What sort of species are we, and how did we come to be this way? When scientists attempt to answer these questions, they tend to emphasize our upright stance, large brains, manual dexterity, complex use of tools, hunting ability, and capacity for spoken language and abstract reasoning—all ways in which we differ from other animals. When scientists focus on human social and emotional tendencies, however, they uncover striking resemblances between ourselves and the great apes. Any full definition of what it means to be human must include the traits we share with our closest living primate relatives.

Recognition of our profound kinship with great apes began 141 years ago, when Charles Darwin startled the world with the implication that humans had evolved from an apelike ancestor. Yet serious study of apes in the wild did not begin until a century after the publication of the Origin of Species, and only in the past decade have scientists reached a consensus about the evolutionary relationships between humans and great apes. DNA evidence indicates that we last shared a common ancestor with the orangutan roughly 15 million years ago, with the gorilla roughly 8 million years ago, and with chimpanzees and bonobos (the latter sometimes known as pygmy chimps) about 5 million to 7 million years ago. These molecular data not only confirm that chimps and bonobos are our evolutionary kin but also show that they are more closely related to us than they are to gorillas. (Because the DNA evidence also implies that humans are a kind of great ape, I refer to the others as forest apes.)

In several early issues of Natural History, in articles written before scientific behaviorism made the study of animal emotion unfashionable, authors described captive apes raised in association with humans, usually as pets or as circus performers. A good example is Henry Sheak’s “Anthropoid Apes I Have Known,” published in 1923. Sheak, a lecturer at the Museum, gave a detailed account of how affectionate some chimps could be. He told of their suffering when their favorite ape or human companions went away, of the enthusiasm with which they greeted returning friends, and how they shared food. Most remarkable to Sheak was that the chimpanzee “understands how to express affection and gratitude by hugging and kissing without being taught. This can only mean that these modes of expression are very, very old in the primate group.”

Sheak’s conclusion anticipated discoveries made decades later, when field studies revealed that many aspects of human emotional expression, including hugging, kissing, begging, and bowing, are homologous with those of chimpanzees. To understand these and other emotional similarities between forest apes and humans, we need to look at how natural selection has shaped the apes’ (and ultimately our own) social tendencies.

Orangutans, which live in Southeast Asia, are largely solitary, but the other forest apes, of Africa, live in complex societies that revolve around long-term bonds between particular individuals. African apes are strongly motivated to form such relationships. Among the chimpanzees of Gombe Stream National Park in Tanzania studied by primatologist Jane Goodall, the strength of the mother-infant bond can

The joy and comfort of companionship are reflected in two human pals and a pair of young orangutans.
determine whether or not the infant survives. Similarly, the degree of trust between two allied males can influence each one’s ability to obtain status in the group and to father young. Among bonobos, a male’s position in the community and probably also his mating success depend in part on his maintaining a close bond, even as an adult, with his mother. A mountain gorilla female can raise an infant only if she has a close association with a particular silverback male, and a male gorilla’s success in siring offspring reflects his ability to woo females and keep their loyalty over the course of many years. Bonobo females rely on strong friendships with other females to gain access to the best foods and
to prevent males from bullying them and their young.

Forest ape relationships are often long term, based on a history of interaction, and intensely personal. Because each ape’s social success depends on what other group members are up to, natural selection has favored the capacity for social maneuvers and counterploys, as illustrated by primatologist Frans de Waal’s accounts of Machiavellian power struggles among male chimpanzees at Arnhem Zoo in the Netherlands. Selection has also promoted the ability to influence the relationships of others. Witness Mama, the most influential female in the colony that de Waal studied. If two males failed to reconcile after a tense encounter, Mama would sometimes make contact with one of them and then go sit next to the other, pulling the first male by the arm if he failed to follow her. Both males would then groom her, and when she melted away, the males would find themselves placidly grooming each other. Chimps and bonobos appear to place value on maintaining good relations, renewing friendly contact after a fight. Bonobos reconcile by having sex; chimps literally kiss and make up.

The parent-infant bonds of mountain gorillas, like those of humans, are vital for the social development of the young.

Life in African ape societies possesses all the essential ingredients of first-rate soap operas: convoluted plots, passion, lots of sex and politics, surprise endings, and a cast of distinct characters skilled in conveying a wide range of emotions. In chimps and bonobos, in particular, emotional expression is uninhibited, at least from the point of view of staid human observers. When two groups meet after a separation of days or even hours, it is as if they have not seen one another in ages. Animals rush into each other’s arms, jump up and down, and shriek with delight. Everyone greets everyone else, and after they have calmed down enough to sit still, they will often groom together for an hour or more.

As Sheak noted, captive chimpls and bonobos show enthusiasm when greeting friendly humans. Cognitive psychologist Sue Savage-Rumbaugh describes her first meeting with Kanzi, an infant bonobo. Kanzi’s adoptive mother, Matata, knew Savage-Rumbaugh well, but Kanzi had never before touched or smelled a person: “Without warning, he emitted an electrifying scream and propelled himself from Matata’s arms to mine . . . threw both arms and legs around
Emotion can peak when an event is of significance to everyone in the group. Soon after I began fieldwork with wild chimps, the female I was following joined a large, mixed-sex group. They traveled for a while and then, without warning, broke into loud screams and, with their hair standing on end, hugged one another. I feared that a chimp had been killed by a leopard. After several minutes of chaos, the chimps settled down to feed in a tree full of ripe figs, and I realized that what had struck me as hysteria was simply their way of expressing joy when they discovered a delicious and ample food supply. Equally bizarre, when one first sees it, is the tendency of male allies, upon hearing the pant hoots (long-distance calls) of enemy males from a neighboring community, to grasp each other’s penises in a show of fraternal solidarity. In a similar vein, a “waa” bark, which announces danger, will stimulate nearby chimps to embrace or grasp hands. The power of such communal reassurance was brought home to me when the Gombe alpha male, Wilkie, headed my way during an impressive charging display that posed a danger to anyone in his path. As Wilkie thundered past, I leaped away and fell backward into some bushes. When I regained my wits, I found myself holding hands with a young male researcher I had not yet met. Though embarrassed, I soon felt vindicated when I glanced around and saw several chimps clinging to one another. I have no doubt that all of us were responding to an atavistic impulse to clasp someone when we felt threatened.

Emotional attachments have a downside, as humans well know. Forest apes are extremely vulnerable in the face of loss, particularly when it involves infants. Ape mothers nurse their babies for several years, and during this period they are protective and attentive to the point of indulgence. They hold, caress, and groom their young, play with them, and gaze into their faces. If separated in the forest, both mother and infant call and search for each other. If an infant dies, the mother appears disoriented and may continue to carry the body for a few days. Among chimpanzees, if a mother dies, the infant often perishes too, even if it is already weaned. Jane Goodall tells the story of Flint, who sank into a depression after losing his mother, Flo, and died three weeks later. Chimp orphans who survive may suffer from stunted growth or emotional immaturity.

While fieldwork helps us understand the selective advantages of ape sociality, captive studies have provided unique insights into what apes know and feel. In the early 1970s psychologist Gordon Gallup showed that chimpanzees recognize themselves in mirrors. We now know that bonobos, orangutans, and possibly gorillas do also. Many cognitive psychologists believe that such self-recognition allows individuals to make inferences about the emotions and intentions of others, and in experiments chimpanzees did indeed make inferences. For example, chimps (but not monkeys) know that when food is placed under a cup, a person who did not see the placement will not know where the food is. In addition, chimps apparently attribute motives to others. In one experiment, human actors brought juice to a female chimp. One actor would “accidentally” spill the juice. The other would deliberately throw it on the floor. The chimp threatened only the seemingly angry actor, and when allowed to choose who would bring her juice next time, the chimp opted for the person she judged as clumsy but well-meaning.
The other side of the inference coin is active deception. When chimps know the location of food but a human does not, chimps will point out where the food is if the human has shared with them in the past. If the person has not shared or is disliked, the chimp may not only refuse to divulge the location of the food but may mislead the human by pointing in the wrong direction. De Waal observed similar reciprocity in a captive group of chimps. Individuals remembered who had, and who had not, shared in the past; they were generous with sharers and aggressive toward the stingy. These and other studies in both the lab and the field indicate that chimps understand the dynamics of cooperation and the importance of punishing cheaters.

Over the past thirty years, members of all four forest-ape species have learned signs in various systems of symbolic communication—such as American Sign Language—that help them communicate preferences, feelings, and thoughts in ways humans can understand. Washoe, the first ape to learn signs, lives with several other signing chimps. Their conversations among themselves and with humans concern mostly play, reassurance, daily routines, or favorite foods. Kanzi uses a keyboard of symbols to tell his human caregivers what he likes best on TV (his favorite programs include Tarzan movies and other films about ape-men). Kanzi and his chimpanzee friend Austin also spend hours in front of mirrors, making faces, putting on makeup, and admiring themselves in new apparel.

Through spontaneous play, captive apes living in relatively stimulating environments demonstrate a capacity to imagine and pretend. Kanzi puts on a monster mask and playacts biting someone. When someone else dons the mask, he screams in mock fear. Kanzi also likes to place imaginary food on the floor and then snatch it away when someone tries to take it. Captive apes play with dolls and toy animals as if they were babies and, via signs, request pets such as kittens, dogs, and rabbits, which they care for tenderly. They grieve when they lose a companion and use signs or symbols for “sad,” “cry,” and “lonely.” Their memories are long: when reunited with a favored human, even after many years of separation, they recognize the old friend instantly and are quick to resume long-interrupted games.

All the chimps and bonobos that have learned symbolic communication use it to talk to themselves. Their trainers note that “self talk” is apparently a very private affair, as indicated by the apes’ consistent efforts to hide what they say from others. Perhaps, like us, forest apes have an inner world and need some time just to be alone and think.

In the wild, apes often need to determine quickly whether the intentions of another ape are benign or hostile; in captivity, they apparently transfer these skills into “reading” humans, which they do with a speed and accuracy some humans would be hard put to match. Researchers Jane Goodall, Roger Fouts, Sue Savage-Rumbaugh, and Birute Galdikas, all of whom have lived with apes for years, report similar experiences of instant acceptance by apes normally wary of strangers. My first up-close meeting with a wild ape revealed the important role of eye contact in such encounters. The Gombe female Melissa, who had never seen me before, was feeding in a tree when I approached and sat down quietly about forty yards away. She immediately ceased eating and stared at me, obviously annoyed. Still glaring, she climbed down the tree and moved purposefully in my direction. When Melissa reached me, she grabbed my opaque sunglasses off my face, threw them to the ground, and stared into my eyes. Apparently satisfied, she returned to her food tree. I never wore those glasses around chimps again.
On a later occasion, I felt redeemed by an up-close encounter with one of the mountain gorillas studied by Dian Fossey. While following a peaceful cohort of females and young in a group habituated to humans, I noticed an adolescent female staring at me in a friendly way.

She was utterly beautiful, so I beamed back. Suddenly she was right in front of me, pressing her nose against my face so that her breath fogged up my (clear) glasses. A moment later, she wrapped her impossibly long gorilla arms around me and held me in a gentle embrace. Then she returned to her spot, as if hugging strange women was an everyday occurrence (Fossey later told me it was not). When I first met the gorilla Koko on the Stanford University campus, she gazed into my eyes, as well as tasted the inside of my ear, before falling into my arms.

Creatures great and small: Koko envelopes a pet kitten.

Such experiences have brought me face to face with the fact that we share this planet with other beings whose essential nature is the same as ours. Like us, forest apes are capable of deceit, manipulation, and aggression. But our mutual heritage also includes a capacity for intimacy, empathy, and love. Like them, we realize our full potential in the crucible of relationships.

From a scientific perspective, the survival of wild great apes is critical because of the insights they provide into our own nature. Science aside, however, their future matters because of their intrinsic worth as sentient beings. A recent survey of forest ape populations by primatologist Richard Wrangham and his colleagues indicates that if current trends continue, all four species will be extinct in the wild before Natural History's next centennial, and many populations will succumb way before then. Orangutans and bonobos will be the first to go, then gorillas, and finally chimpanzees.

Perhaps we are capable of extending our evolutionary legacy of caring and empathy to include our closest living relatives, ensuring that they will be around for eons to come. I can think of no greater gift to pass on to their descendants—and ours.
Birth of the Arts

What lies behind the human urge to elaborate, to embellish, to make the ordinary extraordinary?

By Ellen Dissanayake

One of my most unforgettable experiences was being handed a stone tool made by an archaic *Homo sapiens* and being told by the distinguished paleontologist Kenneth Oakley that it was probably about 250,000 years old. I held it in my palm with what surely resembled the feeling of a religious devotee who has been allowed to touch a holy relic—a sense of privilege, humility, and wonder.

Almost exactly the shape and size of the inside of my open hand and made from a piece of army-jeep brownish green flint, the tool was what is called a hand ax. Long before the invention of agriculture, someone not so different from me had taken up a large cobble, assessed it, and fashioned this very tool. Of course, he (or she?) could not have imagined the room or city or time in which someone like me would one day come to hold this item and wonder about the life and being of the person who had made and used it. That asymmetry was one of countless others between us. And yet, holding the hand ax like a talisman, I felt a connection to its maker that I can still retrieve (even if, just as with the person who touches a relic, whether of a saint or a famous athlete, the feeling has as much to do with me as with the material object or its owner).

In any event, I was interested to read, much later, an account that the naturalist Loren Eiseley wrote of his thoughts and emotions while he, too, held a flint tool shaped by human hands. Admiring its purposefulness, he noticed something he found even more remarkable:

As I clasped and unclasped the stone, running my fingers down its edges, I began to perceive the ghostly emanations from a long-vanished mind, the kind of mind which, once having shaped an object of any sort, leaves an individual trace behind it which speaks to others across the barriers of time and language. It was not the practical experimental aspect of this mind that startled me, but rather that the fellow had wasted time.

In an incalculably brutish and dangerous world he had both shaped an instrument of practical application and then,
with a virtuoso's elegance, proceeded to embellish his product. He had not been content to produce a plain, utilitarian implement. . . . This archaic creature had lingered over his handiwork.

Eiseley's embellished hand ax was not a singular example. Oakley had shown me photographs of two Paleolithic hand axes that had been deliberately fashioned so that a marine fossil embedded in the stone appeared in a central position, almost like an insignia. Years later I saw a similarly worked tool—a scraper—in a museum in France.

The French anthropologist Claude Lévi-Strauss titled a
famous volume *The Raw and the Cooked* to describe the universal human imperative to transform “nature” into usable “culture.” Such transformations characterize humans everywhere—from present-day subsistence farmers, such as the Yekuna Indians from the upper Orinoco River in Venezuela, converting raw, poisonous cassava tubers into a processed and cooked staple food, to early toolmakers working flints into implements or modern technocrats turning silicon into microchips.

Herbert Cole, an American anthropologist, has given the Lévi-Strauss phrase additional explanatory bite by referring to the raw, the cooked, and the *gourmet*, thereby calling attention to the unusual fact about our species that Eiseley recognized in the embellished hand ax: for humans, transforming nature into culture may not always be enough. For the Yekuna, studied by Tufts University anthropologist David Guss, it is insufficient simply to plant, to reap, to set out in a canoe, to treat a wound or illness, to kill an animal, to begin to menstruate, to marry, or to die. As in many other traditional societies, these are all occasions for elaboration in both word and action.

Evolutionary biologists often overlook this penchant of humans to “linger over their handiwork,” to “embellish” or elaborate, to make the ordinary implement (or material, movement, sound, utterance, motif, story, or idea) extraordinary. They assume it is a cultural overlay, a superfluous side effect of some ability (such as curiosity) that evolved for an adaptive purpose, or simply the product of a lone individual with time on his or her hands. To the unsentimental gaze of a scientist looking for the “selective value” of an activity, elaborating is truly perplexing, for it is an axiom of evolutionary theory that successful creatures expend their resources on survival-related ends: finding food, protecting themselves from harm, putting provisions aside for a rainy day, seeking mates and mating, caring for offspring, and, after all these are attended to, conserving their energy. Toolmaking clearly contributes to survival. Continuing to work on a hand ax after it is “finished,” however, would appear to interfere with fitness, not to enhance it.

Yet there we are, in every society—people adorning themselves, their artifacts, and their surroundings; making music, dancing, dramatizing, and poeticizing; and often spending vast quantities of time, energy, and material resources doing so. When evolutionary explanations for such extravagant behaviors as performing dances and making art are given, they often center on the suggestion that displays of creativity, physical skill, strength, and stamina improve reproductive success, especially that of males. By singing, by dancing, by speaking well, by skillful building, goes this idea, males draw attention to the superior qualities that set them apart from less talented or tireless males, thereby impressing and attracting mating-minded ladies. The animal world has visual, architectural, musical, and terpsichorean analogues to our own species’ male theatrics: the peacock’s splendid tail, the bowerbird’s *chambre d’amour*, the thrush’s territorial warbles, and the great bustard’s acrobatic dances all either repel rivals or seduce females, or both.

As for the human realm, while we all know about the proverbial allure of the sweet talker, the sexy dancer, the master builder, and the king whose power is evident in the palaces and monuments he is able to command, sheer male competition seems to be only part of the explanation for elaborating. While some activities are the province of males or prominently feature the talents and stamina of individual men, I do not think male competition alone can adequately account, for example, for the cave paintings or megaliths of prehistoric Europe; the temple of Kailasa at Ellora in south-central India; the Gothic cathedrals of Europe, built over
centuries by whole communities; or such practices as *mbuni*, in which the Owerri Igbo of Nigeria spend a year or more constructing a ceremonial house of anthill mud, adorning it with dozens of life-size sculpted and painted mud figures, and then, after a week of ceremonial dancing and feasting, leave it to disintegrate. Nor does male competition explain the custom, prevalent in many cultures, for all the participants in a group to make art the same way, as in the Walbiri men of central Australia incising identical designs on bullroarers to represent the ceremonial grounds and paraphernalia of Dreamtime heroes.

Also (and importantly, I think), male competition cannot account for the arts of females, which may—as in the case of the ubiquitous *bilum*, or looped string bag, of Papua New Guinea—be less spectacular and arduous than the arts of males but are as evident throughout human history. Nor can it account for the arts of men and women older than prime reproductive age—who may in fact be the master elaborators in their society (Yekuana males, for example, devote their later years to making baskets as a disciplined means of understanding and expressing complex cultural symbols)—or for the obvious fact that the arts, even when they also serve competitive interests, are frequently co-created and performed by more than one individual. This last is especially true for pre-modern societies, in which the arts transmit valued systems and stories and serve to unite individuals in social groups.

So what does lie behind the apparently universal human urge to elaborate, an urge that to a modern, bottom-line
One clue emerges when we realize that far from being frivolous, all this extraordinary care and attention are expended in the arena of biologically important concerns—finding food, assuring prosperity and safety, curing illness, preventing harm—and serve to relieve anxiety about the attainment and preservation of life’s necessities. These special efforts of body and mind express people’s emotional investment in assuring good outcomes for important ventures and generally address the uncertainty inherent in the human condition. Most often, these efforts take the form of what we call ritual or ceremony, and this is where we find the bulk of the arts in premodern societies.

Indeed, “ceremony” is a one-word term for what is really an assembly of elaborations (words, voices, actions, body- ies, surroundings, and paraphernalia), a collection of arts (chant, song, poetic language, dance, mime, and drama, along with considered and even spectacular visual display). Such extravagant displays of beauty and skill, as well as other evidence of the expenditure of time, thought, and effort—sometimes including fanatical demonstrations of endurance—demonstrate a people’s belief that nonhuman powers will thereby be attracted and their assistance procured.

In its excessiveness, such behavior may seem maladaptive, given the modern, capitalistic attitude that espouses minimum effort for maximum return on investment. But I suggest that this was not the case as humans were evolving. Despite the negative cost-benefit calculations of many evolutionists (or recent U.S. congressional representatives arguing against spending public money on the arts), I maintain that what we today call the arts, the shaping and elaborating of behavior and of the material world, has been necessary to the maintenance and continuity of human societies.

The artful (special, exaggerated, compelling) features of rituals not only draw attention to important concerns. By reinforcing a group’s like-mindedness and one-heartedness, they also help persuade people to devote themselves to ideals that transcend narrow individual self-interest: loyalty, generosity, hard work, unselfishness, patriotism, and even the sacrifice of one’s life. At the same time that the Gèlèdè masquerade of the Yoruba in Nigeria entertains the general public with dazzling costume and dance, for ex-
ample, its fundamental message of honoring female power sensitizes onlookers to the virtues of social stability and good citizenship.

Even if an ancestral ceremony failed to achieve its ostensible, immediate purpose of success in hunting, warfare, or healing, it benefited the participants, since the debilitating physiological effects of stress are known to be reduced when individuals have some sense of control over uncertain circumstances. "Doing something" to address uncertainty, as in a ritual enacted with the reinforcement and collaboration of one's fellows, is arguably more adaptive than not doing anything or acting alone. Archaeologists studying such diverse vanished human groups as the Mimbres and the Dorset of North America and the prehistoric inhabitants of Europe and of Arnhem Land in Australia have noted an increase in indications of ritual activity (Paleolithic cave art production in Europe, art on rock shelter walls and ceilings in Australia) at times of environmental stress, such as when the climate changed or an invasion by outsiders threatened a group's control over resources.

Ceremonies and the collection of arts they comprise may have been important and adaptive for early humans. But where did this urge to elaborate first come from? My own view may surprise some people. I trace the origin of the arts to a source almost the opposite of male competition and display—that is, to the early communicative interchanges between mothers and infants.

Human infants come into the world ready to engage with others. During their first year, before being able to do much of anything else, they are exquisitely sensitive to certain kinds of sounds, facial expressions, and head and body movements that others present to them through the common behavior often dismissively referred to as baby talk. In all cultures, people of both sexes behave differently with infants than with adults or even older children. An adult who catches the eye of a cute baby in a supermarket checkout line or airport waiting area typically goes through a striking sequence of head movements and facial expressions. The head tilts sharply backward as the eyes widen and the mouth opens. Then the head drops and nods as the tongue clicks. This solicitation is repeated until the baby smiles, which brings about an answering broad and sustained smile accompanied by raised eyebrows and a high-pitched, exaggeratedly undulant vocalization—perhaps something like "Hiiiin!". These expressions, sounds, and movements, as well as the associated rhythmic touching, stroking, and patting, are all exaggerations and elaborations of the ordinary expressions of connection and readiness for contact that we use when we are with other adults. (Think of the quick eyebrow flash with which we acknowledge an associate who enters a meeting late or the smile we produce when introduced to a new neighbor.)

Rather than our teaching infants to prefer these peculiar antics, babies train us to produce them by responding to baby talk (though not to ordinary adult conversation) with unmistakable and irresistible signs of pleasure and delight. Painstaking frame-by-frame analysis of videotaped interactions between mothers and babies as young as eight weeks of age show the pair to be in remarkable synchrony, responding to each other in subtle yet precise ways. The mother varies her pace and rhythm in order to fit in with the baby's emotional state and—as necessary—gradually move it toward greater calm or excitement. The baby, in turn, responds to the mother's signals with kicks, hand and arm movements, facial expressions, head movements, and vocalizations of its own—often appearing to be participating in a mutually ne-

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Video stills show some of the expressions mothers and infants display while interacting. In the first shot, top left, the mother registers concern that her baby may have been alarmed by loud noise. In the second, she has moved her head back and opened her mouth wide as part of an attempt to engage the infant in a mutually pleasurable exchange.
gotiated rhythmic “beat.” The pair engage and disengage, synchronize and alternate, practicing their “attunement” over the first five or six months of the infant’s life. Such interactions are not just pleasurable but are also known to contribute to babies’ linguistic, intellectual, and social development and to benefit their neurophysiological, immunological, and endocrine systems.

The sense of intimate engagement, or mutuality, that arises out of mother-infant interactions predisposes us to develop the feeling of belonging to a social group. This occurs naturally in contemporary hunter-gatherer societies, in which a child moves from physical as well as emotional attachment to its mother to gradually increasing social embeddedness within a group of children of different ages who then grow up together, sharing the same experiences, knowing the same people, and eventually reinforcing their bonds more formally in art-saturated rituals.

**Traditionally the arts have been a response to age-old vital concerns and have addressed the uncertainty inherent in the human condition.**

Significantly, the components of these crucial earliest interactions between mother and infant are fundamentally aesthetic. In baby talk, mothers simplify and formalize their behavior. With face, voice, head, and body they repeat, exaggerate in time and space, use dynamic variation (changing between faster and slower, louder and softer, larger and smaller), embellish or elaborate themes, and create and satisfy expectations—all in collaboration with the infant’s sounds and movements. Like mothers, artists working in all media use these same aesthetic features to gain attention and to provoke and manipulate emotional responses.

I suggest that when ancestral humans began to create ceremonies, they drew upon their evolved sensitivities to the emotionally evocative and compelling features of mother-infant interaction and elaborated them further, into what we now call the arts. These became efficient means of arousing interest, compelling attention, synchronizing bodily rhythms and movements, conveying culturally important messages memorably and with conviction, and ultimately indoctrinating and reinforcing “right” attitudes and behavior within the group.

Through being especially riveting, beautiful, rare, painstaking, and astonishing, a people’s arts are emblems to themselves of how much they care about the sacred beliefs that bind and preserve them. As the duet of mutuality synchronizes a mother-infant pair, so does ceremonial partici-

- pation instill general coordination, cooperation, and feelings of affiliation among members of a group, further enhancing the well-being of individuals. One can justifiably claim that the traits that enable mutuality are as fundamental to human nature as are self-interest and competition.

In subsistence societies, everyone participates in the arts; in most of the world today, the arts are produced by specialists—artists—most often working on their own. Nevertheless, our arts do retain traces of their origins. Although we may tend to purchase art rather than make or perform it ourselves, we still take special pains on occasions that are important to us, such as a party, a holiday, a wedding, or a big date. In addition, we adorn our bodies and surroundings—homes, office spaces, and even cars—so that they will not be “ordinary.”

The objects from other times and places that fill our museums and are customarily called art—sculptures, paintings, fine textiles—largely served religion and empire and were, like the ritual performances enacted in subsistence societies, judged by aesthetic standards of uncommon (that is, extraordinary) beauty, perfection, grandeur, sacredness, and seriousness. Today the reverse of such standards often seems to hold. The ancient urge to take time and care in excess of practical requirements is still there, but some contemporary artists make art that is excessively banal or trivial, excessively esoteric or cryptic, excessively vulgar, or even excessively and intentionally boring or meaningless.

- As does contemporary society itself, contemporary popular arts tend to serve
not God but Mammon, and thus the collective excesses on
which time, thought, and effort are expended and with
which modern societies are most engaged are the elabora-
tions and spectacles of rock concerts, blockbuster films, tele-
vision extravaganzas, and athletic contests. And advertise-
ments, together with the events or products they enhance,
have become the ceremonies on which our extraordinary
communal—creative and financial—efforts are lavished.
Do these examples of today’s art seem unrelated to an
embellished hand ax, a painted rock wall, or a spirited cere-
mony in celebration of a successful yam harvest? Each pro-
duces its emotional effects by transforming what is ordinary
and expected into something extraordinary and astonishing,
and each is still, at root, a response to age-old vital interests
and concerns. And if I am right, all art, whether new or old
and whether it promotes competition or conjoinment,
emerges from the same aesthetic components that give rise
to the oldest bond of all: that of a mother and her baby. □

A Buddhist monk paints a prayer on a rock in Nepal.
Before the invention of photography in 1839, explorers such as Alexander von Humboldt and Captain James Cook brought watercolor artists along with them to document the world's plants and animals. By the mid-nineteenth century, however, a world without photographs was quickly becoming unimaginable, and every scientific expedition was accompanied by at least one photographer.

True, many of the early photographers' "wildlife" pictures were of explorers posing with the animals they had just shot. But some of these hardy souls became hooked on photographing living animals in the wild, whatever the effort or risk involved in capturing the images. A. R. Dugmore, an exemplary pioneer, once stood his ground against a charging rhinoceros while clutching a massive twenty-pound reflex camera. (Roll film was invented only in the 1880s, flashbulbs in the 1930s, and lightweight telephoto lenses and electronic cameras during the past few decades.)

Photographers As Naturalists

Carl Akeley, best remembered for creating the Museum's Hall of African Mammals, was one of the great explorer-naturalists whose photographs appeared regularly in the pages of Natural History seventy-five years ago. Akeley made the first motion pictures of gorillas in their native forests and invented a special panoramic camera for field photography. During the 1920s and 1930s, the stylish husband-and-wife team of Martin and Osa Johnson also made wildlife movies in Africa and shot stills of rarely seen creatures for this magazine.

Right from the start, photographs were popularly believed to be more objective than sketches and paintings, since they seemed to be produced solely by light and chemicals rather than the human hand and eye. Although photographs were widely taken for reflections of reality, not a few photographers found they could build successful careers by using ingenious tricks to manipulate their images. Some simply moved a stone or log to get a better view of a flock of flamingos, while others tethered snakes and mongooses together, hoping to stage a dramatic-looking death match. Just a few years ago, a photographer stirred controversy by using a computer to add a few dozen zebras to a herd. But is fakery the important issue in these cases, or do photographers, like other visual artists, have a right to please their aesthetic sense by taking advantage of new tools?

Perhaps the most problematic aspect of contemporary nature photography is what is not in the frame. Are there telephone poles just beyond the loping giraffes in the photograph? Does a town or farm lie behind the foraging gorillas? Commercial images of wild animals and displays such as the Museum's dioramas tend to depict a timeless Eden, where humans are literally out of the picture.

Over the past half century, a growing sense of urgency about documenting the world's most threatened ecosystems before they are gone has energized a new breed of dedicated wildlife photographer. Some work primarily as artists, others as scientists, and a few as both, with a bit of the journalist and environmental partisan thrown in. Perhaps their greatest influence came from the resurgence of field biology in the twentieth century.

Documenting the natural behavior of animals, however, requires more than scientific knowledge and technical skill. One also has to be ready to spend thousands of hours trekking, setting up, and sitting patiently day after day in heat, cold, snow, or rain—prolonged self-abnegation that must be based on a deep love of the wilderness and its creatures.
I was born in Belgium but raised in the Galápagos Islands, where, at the age of twelve, I vowed to compile a complete photographic record of the habits and life cycles of all the native bird species of the islands, not realizing that a lifetime would probably be insufficient for this task.

After shooting thousands of images in the enchanted isles of my childhood, I yearned to travel widely and photograph other creatures in other lands. I photographed emperor penguins under a bloodred midnight sun in Antarctica and polar bears on Spitsbergen’s shifting sea ice, condors in high Andean canyons and hornbills in the Indonesian rainforest. Eight years ago, with my partner, photographer Mark Jones, I moved to New Zealand, where I took on the challenge of photographing the nocturnal, endangered kiwi.

This past year, I decided to return to the Galápagos for an intense four-month photo session among old friends such as giant tortoises, marine iguanas, and blue-footed boobies. I saw the subtleties of the light more clearly, the animals' behavior more dramatically. Combining my heightened awareness with improved techniques honed around the world enabled me to reach another level of intimacy with animals I already knew so well.

I shot one sequence of a small female tortoise foiling a large male’s mating attempts by quickly spinning around under his huge shell—a behavior I’d seen many times but never before captured. Above all, I savored more than ever the magical experience of immersing myself in the lives of the islands’ animals, which are uniquely trusting of humans.
I've always assumed that making images of the natural world, especially of wild animals, is a primal experience, if not second nature, for us two-leggeds. Take the earliest evidence of humankind's attempts at recording a thought or conveying a notion: an image of an animal scratched or drawn on the cold walls of dark sanctuaries. Is my inserting a roll of film into the camera and producing an image of a wolf much different from a Cro-Magnon man's dipping his finger into a swirl of red ocher pigment and painting a lion on the wall of Chauvet Cave 30,000 years ago? What were his motivations? What are mine? And can one really connect these two experiences, so far apart in time?

After thirty years of pondering this question, I've concluded that whether one regards the early artists' skillful depictions as simply documentation of what they saw or as profound, prayerful ritual, the same range of perception and motivation is found in my own "nature art." To try one's hand at producing pictures of animals is, I think, profoundly and uniquely human. I believe that inspiration born of untold numbers of human-animal encounters over countless generations is deeply implanted in our marrow.

Today I pay homage to the animal subjects themselves and to that ancient human tradition as I attempt to conjure what I hope is a similar sympathetic magic. The tool may be a stick of charcoal or a camera, but the desire to become one with the animal world comes from the same place.

Above: Two common loons at sunset, Moose Lake, northern Minnesota

Top right: Bison herd running on a ranch near the Missouri River, South Dakota

Right: Adult arctic wolf on an iceberg, Ellesmere Island, the Arctic
While I was studying to become a marine biologist, I thought of photography more as a communication tool than as an art form. I remember being surprised by people’s reactions to my early underwater photography. They seemed stunned. The novelty of the creatures captivated them, for sure, but they also noticed a certain “look.” That I could create an image that people would react to with emotion, not just intellect, excited me and changed my life. So I traded in the microscope for a macro lens and the telescope for a telephoto.

My latest project, Wild Orphans, is my most ambitious and includes a series of books, a Web site, magazine articles, and a lecture tour. The project is an attempt to deepen environmental awareness and encourage conservation by documenting orphaned wild animals. I am focusing not just on the environmental conditions and human factors that resulted in the orphaning of these young creatures but also on the extraordinary efforts of people around the world who are dedicating their lives to rescuing and rehabilitating them. African elephants dominate the first phase of the project. Learning about their biology, culture, and ecology has given me a different perspective on these creatures and is crucial to my ability to say something significant about their future. The next phase, on the orangutans of Borneo, will bring me back to an earlier passion—the great apes.

The art of photography means much more to me now than it did at the beginning of my career. I have come to realize that it’s not the science of nature, but rather the beauty of nature, that moves people. But I believe science and art can share the same palette.
I usually stay close to home. By concentrating my efforts in my own backyard, I can be near my family while gaining an intimate knowledge of local wildlife. Of course, as backyards go, I've been fortunate. After having spent twenty years in Yellowstone National Park, we now have an even larger backyard, sprawling toward the massive, ice-covered peaks and volcanoes of Alaska's Wrangell–Saint Elias National Park, the largest in the nation.

I have always had a fondness for predators, both birds and mammals. Their beauty and savage nature is fascinating to watch and photograph. Some of my most cherished memories as a wildlife photographer have come from working on extended projects with raptors. I spent two or three years photographing the great gray owl and the northern goshawk. Despite my constant presence, the shy but aggressive goshawks went about their vital business of rearing a family.

The picture above was taken in the dead of a very harsh Yellowstone winter while I was photographing ravens. They were feeding on an elk carcass but keeping a watchful eye out for returning coyotes.

To see nature in this raw manner is like a dream. To be able to share what I see through my viewfinder is a dream come true.

Michael Quinton
I love to night dive. It allows me to get close to certain animals and to see nocturnal creatures I would miss during the day. One evening when I was moving along at a snail’s pace underwater on a coral reef in the Red Sea, searching for small subjects for my macro lens, I spotted a lovely sea anemone of a kind I had not seen before. I trained my camera on it but was disconcerted to notice that I had only three frames left on the roll. (We pros look good because we take thousands of shots and publish only the one that comes out great!)

I had been in the water for more than two hours, and perhaps my concentration was beginning to fade. I decided to focus on the base of the anemone, where the tentacles are attached. After shooting the three frames in rapid succession, I headed back to the boat. Studying the images a month later, I was amazed to discover that a tiny symbiotic shrimp, which I had not seen when taking the picture, had been perched on the anemone. I realized I had captured a special picture. It won first place in BBC Wildlife’s annual photography contest. Now, that is my definition of luck!
I cannot resist a challenge. The more difficult, the more enjoyable. To photograph the black-faced lion tamarin, one of the world’s rarest and most elusive primates, I went to the Atlantic coast rainforest of Paraná State in southern Brazil. Although these beautiful diminutive monkeys live in a region inhabited by Europeans since the sixteenth century, they have been known to science for only ten years. How was I to find them? My ace in the hole was primatologist Fabiana Prado, who had been following a group of them for years. I would simply follow her.

Within a few days Prado located the group, and we watched the tamarins bed down for the night in a tree hollow close to the ground. At dawn I stood before their “sleeping tree” with my feet in a puddle of water, camera on tripod, strobe on, and mosquitoes all around. To pass the time and forget the stinging swarms, I kept wondering, “Why am I here?” My wife put her finger on the answer: I’m a nature addict. I am filled with wonder and a sense of fulfillment in the forest. I need to be here, alone, in contact with different forms of life, away from ordinary human concerns and egos. Here I feel vitally alive, ready to react to the moment. The heightened experience is full compensation for the physical discomfort. Spending long periods in the wilderness is as crucial to me as life itself.
One of us (Michael) began as an Oxford University ornithologist studying birds in Sarawak, Malaysia, while the other (Patricia) is a mammalogist who originally specialized in bats. We still tend to think like scientists and occasionally publish papers in scientific journals. For the past twenty years we have lived in a mountaintop home next to the Monteverde Cloud Forest Reserve in Costa Rica.

We’re most interested in documenting animal ecology and behavior—the ways in which animals feed, reproduce, and escape predators and how they interact with plants to their mutual advantage. We did one project on rainforest snakes, covering everything from constrictors to vipers. Snakes are specialized feeders. Many predators will take a wide variety of prey, but some species of snakes feed exclusively on other snakes, others want only rodents, and still others concentrate on snails or scorpions.

Another project concerned the reproductive strategies of frogs. Most people think of them as tied to water, but a great many frogs are independent of water. Some lay their eggs in damp leaf litter, some create nests of foam, and some even carry their eggs or tadpoles in pouches on their backs. Many have evolved elaborate forms of parental care.

Currently we are photographing hummingbirds and their flowers. Everyone knows that the exchange of nectar for pollination benefits both bird and flower, but the myriad adaptations that enhance the relationship are a never-ending source of wonder.

We are naturalists first and photographers second. We love nothing better than to wander in the forest without cameras and just watch what’s going on without having to worry about photography. In fact, some people are shocked to find that we don’t particularly like taking pictures.
Mark Moffett

Anyone can have an adventure. What nature photographers have is a whole lifetime of adventures. Just off the top of my head, I clearly remember: in Peru, backing a jeep a quarter mile down an obscenely narrow mountain road flanked by a drop-off of hundreds of feet after meeting a vehicle that was too wide for me to pass . . . accidentally sitting on the New World’s most deadly snake, the fer-de-lance, again in Peru . . . crawling a hundred yards on hands and knees while tracking an ant column in Thailand, to suddenly realize I had accidentally sneaked up on a bull elephant that loomed overhead . . . being among the first to visit one of Venezuela’s flat-topped tepui mountains (subject of Sir Arthur Conan Doyle’s Lost World) . . . crouching out of view in the back of a taxi to get past protesters burning American flags in the southern Philippines the day Benigno Aquino was shot . . . vaulting the front steps of a cheap Australian hotel to avoid the amazing hordes of leaping fleas that hung out there . . . for a photo, persuading a girlfriend to provoke a huge spider into throwing its toxic hairs at her at night while we waded in a crocodile-infested swamp in Guinea . . . watching an ape climb down from the trees to unbutton another girlfriend’s dress in Malaysia (she had made the mistake of wearing “orangutan orange”) . . . using tribal blowguns for self-defense against smugglers in Colombia . . . being driven out of a tree by a spectacled bear, again in Colombia . . . searching a Montana cave for ice-loving beetles on Christmas Day . . . hunting the world’s largest tarantula for dinner with a shaman in the Orinoco basin . . . tagging behind two Texan spelunkers to stumble upon an Aztec burial chamber in a cave inhabited by giant spiders . . . having my helicopter dive down into the trees of a rainforest interior to avoid a severe storm in Brazil . . . being caught in stampedes of both Asian and African elephants in the same week . . .
attempting to concentrate on insects at a topless beach resort, the only place my colleague and I could find to stay for a night in Mauritius . . . having a tent washed from around me by a nocturnal flash flood in Chile . . . being surprised by a tiger in Nepal that leaped out of the forest in front of us to kill a spotted deer . . . realizing a companion had collapsed from heat exposure as the temperature hit 132°F in Paraguay . . . in Namibia, learning it is right to be suspicious when a !Kung bushman says something is within “walking distance” . . . discovering two new ant species while on a tour of a Balinese temple . . . having a tethered horse killed and eaten by lions in Kenya . . . watching the cook flay live snakes at a restaurant in Vietnam . . . eating scorpions in China, rats in Africa, and beetle larvae on five continents . . . arguing with Iranian militia at 3:00 A.M. while chasing scorpions near the Afghan border . . .

descending with a flashlight into tombs in Egypt’s Valley of the Kings to photograph hieroglyphs . . . sitting in Darwin’s writing chair to study his beetle collection at his house in Downe, England . . . remaining motionless for a painful seven-hour stretch, arms furry with mosquitoes, hardly daring to breathe while waiting for a caterpillar to stalk an aphid in a swamp in Japan . . . seeing a centipede in Trinidad that was so huge it yanked stones out of the roadbed during its death throes after our jeep ran over it . . . having my safety harness snap open while climbing a hundred feet up a rope in a tree to photograph biologist (and doctoral mentor) Edward O. Wilson in Panama . . . tracking down the world’s largest dung beetle in South Africa, largest frog in Cameroon, and largest cricket in New Zealand . . . living in India for six months on a $100 traveler’s check . . . and, along with my teammates, being the first to ascend the world’s loftiest tree, a California redwood 365 feet tall . . . and managing somehow to never be sick along the way and to keep my total lifetime excess baggage expenses below $500. . . . But I’ve rambled on so long there’s probably no room left for any of my pictures.
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Michio Hoshino

In a 1992 interview with Douglas Yates, the late Michio Hoshino, a native of Tokyo, spoke about photographing the wilderness of his adopted land, Alaska:

On photography: “The very best picture is one that provides meaning and variation to as many different people as possible. It must speak to the child as well as the elder who has seen a full life. . . . Conveying real information is the path. . . . Front lighting usually doesn’t have the impact of dramatic backlighting, but it provides more information. It can be appreciated longer, approached and understood more successfully.”

On bears: “Wherever we go in Alaska we must think of the bear. This is the underlying tension and pressure of all our considerations while camping in the bush. The lesson of the bear teaches us to be aware of the unpredictability of the natural world. . . . I’ve learned it is good to be frightened. Bears scare me, but then I become more humble, so this tension is a necessary thing.”

On August 6, 1996, in northeastern Russia, Hoshino was killed by a grizzly bear that entered his tent.

Above: Polar bears on ice field, Alaska

Left: Resting grizzly, Kamchatka Peninsula, Russia
For more than an hour, I had been swimming hard, struggling to position myself to capture images of a feeding gray whale. Finally, nearly out of film and all but exhausted, I settled on the bottom and watched the whale swim away. Suddenly it turned and swam slowly toward me. When it was five feet away, it stopped and settled on the sand right in front of me. I had worn myself out trying to get this kind of head-on proximity, and now, when I had only a few frames left, the whale seemed to be begging for a close-up.

Moving carefully, I crawled over to look into the tennis-ball-sized eye. It was looking back. The whale raised its nose toward me, and I could see barnacles on it, with their feathery legs straining the water. I looked into that great eye, and a long moment passed. I was certain that if I scratched the whale's nose, it would not be upset. Slowly I reached out and touched the rubbery hide. Gently I scratched. Mesmerized by the close contact with this magnificent creature, I continued to scratch for about thirty seconds. Then I decided I'd had enough, and stopped.

Have you ever scratched the snout of a dog and then, after stopping, had the dog put its nose back under your hand and nudge it for more? Well, that's what the whale did. Problem was that the whale weighed fifteen tons, and when it bumped me with its snout I went flying.

Rolling across the sand like a peanut, I looked up just in time for the whale to whack me with its nose again. I went head over heels. I rolled across the bottom like a football bouncing downhill. My mask filled with water, and I had just managed to get it about half-clear when I went spinning a third time. The game had ceased to be fun. I was in danger of losing my camera if not my mouthpiece. After clearing my mask for the second time, I found myself several feet off the bottom, with the whale moving in for another affectionate blow. I twisted away just in time and went rolling down the whale's flank.

Then it was over. The whale slowly drifted away and vanished from sight. I now know there are two reasons not to scratch a whale on the nose: one, the whale might not like it; two, the whale might like it very much.

Howard Hall
I really enjoy being out in the wilderness; a bad day in the field is better than a good day in the office. Animals change me. They communicate a lot with body language and thus are very sensitive to what others are demonstrating with their bodies. I go to great lengths to illustrate relevant connections between people and animals, be they positive or negative. I live eye to eye with them and witness not only their ordinary lives but also their most intimate and most desperate moments. Often there is danger, such as the time I was photographing in the midst of male elephant seals, some weighing as much as three tons, on a California beach, or the time I followed East African lions, living as an auxiliary member of the pride. They accepted me to a point at which it became possible to get within a few feet of them at night, and I spent hours taking shots of the lions as they devoured a giraffe’s carcass.

I try to control situations only to a certain extent, leaving the door open to chance by allowing the animals choices or leeway, which forces me to improvise and react. It becomes more of an interaction than a one-way street. My pictures also show the context within which these animals live—not just the totemic large animals but the little critters, too, which are often overlooked. All are expressions of vital ecosystems.

When I was a child, I had a favorite book about a boy who is shrunk by a magician and joins a flock of wild geese. The leader shows him how animals have been hunted and persecuted by humans. “Go back as our ambassador,” he tells the boy, “and tell people that animals, too, are entitled to their place in the world.” That story hit a deep chord in me. I became a mediator who stays with wild animals, then reports back to my own species through my photographs.
Left: Mounted extinct Tasmanian wolf, downtown Sydney, Australia

Below: Eastern gray kangaroos, Murrarang National Park, Australia
When I was growing up in the suburbs of Seattle in the 1950s and 1960s, nature was all around me. My earliest memories are of playing in local woodlots, collecting frogs, and watching birds. I moved on to hiking in the nearby Cascade Range and Olympic Mountains. But over the years, all those magical woodlots of my youth have been devoured by development, and the air and water degraded.

My latest project, *The Living Wild*, is my forty-second book. To complete it, I embarked on a three-year odyssey to photograph the world's iconic animals—those that best represent their ecosystems. I wanted to help report on the state of Earth's wildlife today—to show what we have left, what we still have time to save. I ended the book with a photograph of an emperor penguin chick from the Antarctic. To me, it's an image of hope from a place that is threatened by the effects of global warming but that many nations have been working together to preserve.

I feel very lucky to be alive now, when we still have time to act, enough knowledge to act correctly, and the collective will to do so. Our role as nature photographers should always be to make sure humankind knows firsthand what's at stake and never stops trying to make a difference.
Above: South American marbled tree frog, Tambopata River, Peru

Above left: Greater Indian rhinoceros, Royal Chitwan National Park, Nepal

Left: Emperor penguin chick, Weddell Sea, Antarctica
Jack Dykinga

Fresh out of school and working for a Chicago newspaper, I specialized in gritty black-and-white shots of human tragedy and despair. In 1971 my images of institutionalized people with mental retardation landed me a Pulitzer Prize at age twenty-seven. But when I climbed Mount Rainier in pursuit of a photoessay about a middle-aged man’s attempt to fulfill his dream, a new way of seeing opened up to me. The combination of severity and beauty, the experience of empty places with no need of people and their baggage, caused me to look inward.

My family and I soon moved to Tucson, Arizona, where I worked for another five years as a newspaperman—but finally allowed myself to fall in love with the beauty of the nearby Sonoran Desert. I have embraced it with my heart and my photography. Now I’m working on a book to promote the creation of a Sonoran Desert national park. I can only hope that if I can capture the spirit of the place on film, other hearts will sing, too.
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<tr>
<th>Month</th>
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<tr>
<td>JANUARY</td>
<td>The Galapagos Islands: Aboard the Isabela II</td>
<td>January 14 - 24, 2001</td>
<td>$4,495</td>
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<td>exploring Antarctica &amp; the Falkland Islands: Aboard the Harun-Seaic</td>
<td>January 14 - 29, 2001</td>
<td>$7,975 - $15,475</td>
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<td>Cuba: Image and Reality Aboard the Panorama</td>
<td>January 18 - 28, 2001</td>
<td>$5,595 - $6,495</td>
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<td>Indochina Unveiled: Laos, Vietnam, and Cambodia</td>
<td>January 26 - February 11, 2001</td>
<td>$7,280**</td>
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<td>February 8 - March 4, 2001</td>
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<td>Bhutan &amp; Northern India: Aboard the Royal Orient</td>
<td>January 29 - February 15, 2001</td>
<td>$7,950</td>
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<td>Tumbukt and the Rivers of West Africa: Mali, Senegal, and the Gambia Aboard the Halcyon</td>
<td>January 7 - 20, February 4 - 17, 2001</td>
<td>$6,595 - $6,495</td>
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<td>Mexico: Mayan Ruins and Exquisite Haciendas</td>
<td>February 9 - 21, 2001</td>
<td>$9,690</td>
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<td>Big Cats of the Serengeti: Biodiversity and the Role of Carnivores in Ecosystem</td>
<td>February 19 - March 4, 2001</td>
<td>$8,190</td>
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<td>Inside Saudi Arabia: Interpreting the Islamic World</td>
<td>February 22 - March 8, 2001</td>
<td>$7,850**</td>
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<td>The Amazon: Discovering its Natural Wonders Aboard the Amazon</td>
<td>February 24 - March 4, 2001</td>
<td>$7,950 - $11,690</td>
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<td>March 10 - 18, March 3 - 11, March 17 - 25, March 24 - April 1, 2001</td>
<td>$3,198**</td>
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<td>MARCH</td>
<td>The Lost Islands of Tahiti: Exploring French Polynesia Aboard the Paul Gauguin</td>
<td>March 1 - 11, 2001</td>
<td>$5,340 - $9,760</td>
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<td>Belize &amp; Tikal: Rainforests, Reefs, and Ruins</td>
<td>March 9 - 18, November 2 - 11, 2001</td>
<td>$3,450</td>
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<td>Indian Ocean Odyssey: South Africa, Madagascar, and the Seychelles Aboard the Hanseatic</td>
<td>March 17 - April 4, 2001</td>
<td>$9,975 - $17,475</td>
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<td>China for Families: Beijing, Xi'an, Yangtze River, Shanghai</td>
<td>June 19 - July 3, 2001</td>
<td>$4,990 - $5,850</td>
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<td>North America's Great Lakes: From Chicago to Toronto Aboard Le Levant</td>
<td>June 24 - July 2, 2001</td>
<td>$3,890 - $5,390</td>
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<td>Wildlife of the Galapagos Islands: A Family Adventure Aboard the Santa Cruz</td>
<td>June 30 - July 10, 2001</td>
<td>$2,790 - $5,790</td>
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<td>Family Dinosaur Discovery: In the Grand Valley of the Colorado River</td>
<td>July 7 - 13, August 18-24, 2001</td>
<td>$1,350 - $2,650</td>
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<td>Inside Iceland: Discovering Vikings &amp; Volcanoes</td>
<td>July 9 - 18, 2001</td>
<td>$4,275</td>
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EVENTS

DECEMBER 1
7:00 P.M. Claire Dunne, author of a new biography of Carl Jung, gives a talk on the pioneering psychologist and screens a documentary about Jung’s disciple Helen M. Luke.

DECEMBER 2
2:00 P.M. George Plimpton and Dmitri Nabokov read correspondence between Edmund Wilson and Vladimir Nabokov, in Terry Quinn’s play Dear Bunny, Dear Volodya.

DECEMBER 5
7:00 P.M. For the last talk presented in conjunction with the exhibition "Iceland, Land of the Vikings,” an exhibition of photographs by Páll Stefánsson, continues in the Museum’s Akeley Gallery through January 14.


DECEMBER 6
7:00 P.M. In a symposium coinciding with the Viking exhibition, scholars discuss the first Norse contacts in North America.

DECEMBER 7
7:00 P.M. Robert Pollack, director of the Center for the Study of Science and Religion at Columbia University, gives a talk entitled “The Faith of Biology and the Biology of Faith.”

DECEMBER 9
1:30 P.M. “How the Ocean Got That Way,” a talk by geophysicist Karl Turekian, is the third in a series on Earth and its water resources.

DECEMBER 11
7:30 P.M. As part of the “Frontiers in Astrophysics” series, Bryan Gaensler, of MIT, discusses supernovas and their smoke rings. Neil de Grasse Tyson, director of the Hayden Planetarium, will give a brief sky show using the Zeiss Mark IX projector.

DECEMBER 12
7:00 P.M. In conjunction with the live butterfly exhibition, Eric L. Quinter talks about lepidopterology.

7:00 P.M. Maraleen Manos-Jones speaks about the butterfly as symbol.

DECEMBER 16
10:30 A.M. A free day-long program entitled “Viking Living History” takes place on the fourth floor and includes demonstrations of various crafts.
2:00 P.M. The Vikings 2000, a NOVA/WGBH film about the Vikings as colonizers, merchants, shipbuilders, and artisans, is shown in the Kaufmann Theater.

DECEMBER 18
7:30 P.M. As part of the “Distinguished Authors in Astronomy” series, Virginia Trimble gives a talk entitled “Astronomy From A.D. 1001 to 2000: The Millennium in Review.”
DECEMBER 30
The African American holiday Kwanzaa is celebrated all day in the Hall of Ocean Life.

JANUARY 13
*Ocean Oasis*, a film on the biodiversity of the Baja California peninsula, opens in the IMAX Theater.

JANUARY 20
1:30 P.M. “Hot Water in the Earth: The Genesis of Mineral Deposits,” the fourth in a series of talks on Earth and its water resources, is given by geologist Philip Candela.

JANUARY 22
7:30 P.M. As part of the “Frontiers in Astrophysics” series, David Helfand, of Columbia University, gives a talk entitled “Chandra: The X-Ray Universe Revealed.”

DURING DECEMBER AND JANUARY
The Museum’s Origami Holiday Tree, decorated with 1,500 folded-paper animals, is on display in the Theodore Roosevelt Memorial Hall.

A 220-million-year-old fossil of the small gliding reptile *Ichnosaurus* is on display in the Rotunda. Recently donated to the Museum, the Triassic fossil was discovered in 1960 in northern New Jersey.

The Department of Education presents free weekend multicultural programs on the theme “Of Earth and Sky: Stories of Our Environment.” Call (212) 769-5315 for information.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100 or visit the Museum’s Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online.
Endnote on a New Beginning

By Stephen Jay Gould

Dr. Johnson, invoking the sexism of the ages to disparage an incipient form of eighteenth-century feminism, compared a woman preacher to a dog walking on its hind legs. The marvel, he stated, consisted not in doing it well but rather in doing it at all. At the dawn of a new millennium, we might repeat this cynical judgment and praise this magazine, at its centennial, merely for its continuity through a time of maximal peril and change. Indeed, in simply staying the course, Natural History has achieved something quite self-referentially wonderful, for our magazine has displayed the defining criterion for success in its central subject of evolutionary biology: the unbroken continuity of genealogical persistence. Human institutions, however, unlike their morally neutral analogues in factual nature, also demand judgment in conceptual, aesthetic, and ethical terms. And here, on these distinctively human grounds, Natural History may truly celebrate the inception of its second century in transcending Dr. Johnson’s image by doing its appointed task so very well and with such uncompromising integrity.

Sometimes we win a less taxing form of integrity by alloying ourselves to a just principle and then sticking to it through thick and thin, pain and loss. But the more complex mode that has been the hallmark of this magazine for 100 years seeks to craft a dynamic midground between simplistic endpoints that can only spell destruction at their extremes. Should Natural History promote an idealized concept of pure “wilderness” without human presence, or should a magazine published in a great city always stress the importance of intelligent human use? Should Natural History be written as a “house organ” for the committed or as glossy fluff, striving for the goods of proselytization by using the bads of commercial blandishment and the frantically empty prose of sound bites and simplicities?

Natural History found the golden mean for both these contrasts—and many others. Art can be nature’s true partner, as Frederick Law Olmsted showed us in Central Park and as this magazine learned in regarding a human presence as intrinsic to nature’s current evolutionary state. And Natural History can span the full intellectual depth and aesthetic beauty of evolution by relying mainly on active scientists with a lifelong feel for their subject and a passionate commitment that inspired their professional choice—not primarily on writers who, despite exemplary skills in conveying the work of others, must miss a hundred subtleties of truly divine minutiae.

As I read previous anniversary issues to prepare these thoughts, I realized that Natural History did not drift into these balances passively; rather, this optimal place has been discovered by change, experiment, and historical struggle. Issue Number 1 of The American Museum Journal (April 1900) reported Museum business to the cognoscenti without any sense of intellectual excitement and with certainty about the superiority of those who observed over those on display, as in this report about some Far Eastern folk: “As with most barbarous peoples, conduct is restricted by many superstitious conventionalities, such as the supposed shocking impropriety of a man’s ever seeing his mother-in-law’s face.”

In the semicentennial issue of 1950, and for entirely understandable reasons in the wake of World War II, the Museum’s curators exaggerated nature’s potential role as the source of ethical solutions for an erring humanity that had embraced cities and technological destruction, and now needed a correction. None other than former president Herbert Hoover advocated, in our pages, “the primaeval joy... of getting back to nature—for recreation and to wash one’s soul of the complexities of modern life.” One curator predicted that by the year 2000, our global population of 3 billion would be eating yeast steak and algal butter. Meanwhile, the same Mr. Hoover feared no technological competition from other lands, because, as a consequence of cultural background, not intrinsic limitation, the “peoples of Asia... imitate and fumble with [machines]”. I have great faith in our capacity to correct and overcome the inevitable fallibilities of human judgment and therefore do not fear permanent harm from such transient misbalancing of the relative worth between natural and cultural life.

Sic erat in principio et nunc et semper et in saecula saeculorum. This doxology (“as it was in the beginning, is now, and ever shall be, world without end”) purports to describe a form of divine immanence but should also apply to nature—for we need her shrinking presence more than ever—in a universe that at least enjoys geological expanse if not true eternity. Saecula saeculorum refers literally, in one meaning, to centuries of centuries.” And so, as this great magazine begins its second saeculum, may we continue to keep its subject healthy and in vibrant partnership with our cultures right on through times that only a geologist can comprehend.
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An Expedition Notebook, 1900-2000
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To the Ends of the Earth

By Michael J. Novacek  First established 131 years ago in the old arsenal on Fifth Avenue in New York City, the American Museum of Natural History was the repository for an odd assortment of items—the bones of an extinct dodo, 4,000 seashells, four skeletons of sea otters—whose provenance could be attributed more to circumstance than to any particular acquisition strategy. Soon the arsenal began to fill, still in this rather haphazard way, with bird skins, beetles, mastodon teeth, crocodile skins, and other exotica. When the Museum opened at its present site on Central Park West in 1877, it was clear that some changes were in order. Fortunately, Morris K. Jesup, the Museum’s first president, inaugurated a worldwide effort in exploration, one that would yield collections based on sound scientific research as well as spectacular discovery. Jesup and his successors brought the Museum full tilt into the so-called golden age of exploration, from about 1880 to 1930, when it organized expeditions to the North Pole, Siberia, the Gobi Desert of Mongolia, and the Congo basin in Africa.

Those years of discovery laid the foundation for the Museum’s fieldwork in later decades. Expeditions continued to flourish, and collections and exhibits grew accordingly, whether drawn from voyages to the Pacific Islands or from excavations of the fossil terrain of Patagonia. Today the Museum remains committed to exploration, launching more than a hundred expeditions and field projects each year. The rewards of such massive efforts past and present are notable: some of the world’s largest and most important col-

Of the thousands of expeditions that the Museum has supported, thirty-six are highlighted in this supplement. The photographs and excerpts we have chosen are a small fraction of the many memorable moments, observations, and adventures described in the pages of Natural History in the course of our 100 years of publication.

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collections of dinosaurs, fossil mammals, wasps, butterflies, spiders, mollusks, birds, reptiles, and amphibians, as well as gems and minerals and Northwest Coast Indian art.

Modern field research is sensitive to the limitations on the collecting of certain animals and cultural artifacts. At the same time, new kinds of materials have become important scientific evidence—frozen tissues for DNA studies, microorganisms from sulfide chambers rooted to the ocean bottom well over a mile below the sea’s surface, digital data on stars and galaxies. But Museum expeditions still depend on the collection of objects and certain data necessary for understanding our natural world and its past. Such missions are indeed critical, despite—or rather, because of—the shrinking natural resources of our planet. Whereas we have an exhaustive accounting of mammals and birds in many regions, we have barely begun a sufficient census of Earth’s dominant biological species: insects, soil organisms, and microbes. Since these poorly known biological groups are the key to maintaining ecosystems, the Museum’s tradition of exploration and discovery has never been more relevant or more exciting.

Every summer since 1990, Michael J. Novacek, senior vice president and provost of science at the American Museum of Natural History and curator in the Division of Paleontology, has led a Museum team to Mongolia’s Gobi Desert in search of fossils. His book Dinosaurs of the Flaming Cliffs (Anchor, 1997) chronicles the extraordinary fossil finds of the Gobi Desert.

**Natural History** celebrates 100 years of Museum work in the field.
Australia and the Pacific

1921–23 First Australian Expedition

Concerned about escalating extinctions, curator of comparative anatomy (and first editor of Natural History) William K. Gregory organized an expedition to collect Australian and Tasmanian mammals. At the time, Museum president Henry Fairfield Osborn planned to build a hall devoted to the continent’s animal and plant life and human inhabitants. Although the Australian hall was never completed, a preliminary sketch of its diorama centerpiece was made by Charles R. Knight, America’s most influential painter of the prehistoric world. Knight, whose many depictions of animal life were based on the Museum’s collections, began visiting its galleries as a young boy in the 1880s to gaze on what he called “a galaxy of treasures in the form of mounted animals, birds, skins of various kinds, and plaster casts of dead specimens.” Gregory describes the proposed diorama:

“The background will be the Australian ‘bush’ (or open forest) of eucalypt trees, with the sunlight streaming through the thin foliage. In the foreground a dingo, or wild dog, has just bounded into view and is hurling himself at the nearest kangaroo, an old male. Two of the females, one of them with a large young one in her pouch, are leaping frantically in different directions. A little way back, still another kangaroo is raising its head in a startled way, and in the distance a few are feeding quietly.” (Natural History, January–February 1924)

1920–41

Ornithologist Rollo Beck led the first segment of what became a twenty-year survey of marine and land birds of Micronesia, Melanesia, and Polynesia. Thousands of specimens were brought back to the Museum to be displayed and stored in the Whitney Memorial Hall of Oceanic Birds. Beck also documented the life of islanders. At Rapa Island in Polynesia, he was “astonished at the performance of the boat crews” but was perhaps most impressed with the boat-handling skills of the women. (Natural History, January–February 1922)
1938–39 Lerner Australia–New Zealand Expedition

Wealthy patrons Michael and Helen Lerner, both practitioners of big-game fishing, funded and led five expeditions to different parts of the world to gather data about the so-called giants of the mackerel tribe—marlin, tuna, sailfish, and broadbill swordfish—that shared a common ancestor at least 60 million years ago. The trip to Australia and New Zealand focused particularly on collecting marlin. While the Lerners were fishing, William K. Gregory searched among steep rocks and tidal pools for seashells that would encapsulate the geological history of the Southern Hemisphere’s island continent:

“A living limpet is of high interest to the student of the evolution of the shell-bearing mollusks, because his earliest known fossil ancestors are found in the rocks of the Cambrian period and are probably more than 400 million years old. But the limpet himself, as he clings tightly to his rock, exhibits only a strong negative interest in the activities of an amateur conchologist. And unless he can be suddenly caught off guard, it is almost useless to try to pull or push him off his firm base. The best way to dislodge him is to push the edge of a sheath-knife suddenly under his shell and break the suction exerted by his powerful oval base or ‘foot.’ This general type of broad, clinging foot is shared by thousands of other kinds of mollusks and it is so typical of them that this great class of mollusks has been named gastropoda (belly-foot).” (Natural History, November 1939)

1950 New Guinea Expedition

On several trips to what is now known as Papua New Guinea, ornithologist E. Thomas Gilliard collected material for the Whitney Memorial Hall of Oceanic Birds. On the south slope of Mount Hagen, in a subtropical forest 7,500 feet above sea level, Gilliard witnessed a striking courtship dance:

“The male King of Saxony elevated the head plumes in a wide V until they tilted forward like slender horns and drooped to a point level with the feet . . . Then the bird began a rhythmic dance, which consisted chiefly of an undulating or bouncing of the body. This took place some 50 feet above the ground on a thin horizontal perch, perhaps of finger thickness. Clasping the perch tightly, the male made crouching movements that caused the slender limb to spring rapidly up and down some six inches to a bounce. As the tempo increased . . . the bird bowed his head a number of times in a manner that caused the spectacular twin-occipital plumes to be cast forward and down like the tines of a great fork.

“While this activity was under way, the dancer emitted a spurring, hissing noise, which sounded like steam . . . The female . . . seemed drawn to the side of the dancing male as iron filings are to a magnet . . .

“At the moment of highest excitement, when the male’s gorgeous crown plumes undulated so close to her as to almost touch her head, the male and probably also the female leaped suddenly upward some 18 to 24 inches. Quite appropriately, the climactic explosive call ‘Kis-sa-ba’ marked this peak of emotion. After the spasmodic leap, I saw two birds as they flew directly overhead. Side by side against the sky, one of the pair was clearly seen to have two long blue streamers trailing behind.”

(Natural History, June 1953)
1949 Palau Islands Expedition

Marine biologist Eugenie Clark went to Palau, a group of islands in the southwestern Pacific, to study and collect fish under the auspices of the Museum and the Office of Naval Research’s Pacific Science Board. Palau’s most esteemed spearfisherman, Siakong, served as Clark’s guide in exploring the coral reefs and collecting fish in Malakal Harbor, where, Clark wrote, “we could look deep into the clear water and see sunken battleships from the war days”:

“One of Siakong’s remarkably simple methods of spearing fish underwater was literally ‘breath-taking.’ He would find a reef well populated with fishes and then dive calmly to a depth of about 10 or 20 feet, sometimes weighting himself with a rock so that he could sink without swimming. He’d get a firm grip on the reef with his legs or free arm, poise his spear in readiness, and then—wait for the fish to come to him! . . . I’ve never measured how deep I can dive, but I know that at more than 20 feet under, my face mask cuts into my head, and my ears and nose feel uncomfortable. Usually I don’t go much deeper, for I have always found enough activity in the top 20 feet to keep me occupied and satisfied.

“As my weeks in the Palaus came to an end, Siakong asked when I would be back again. ‘Perhaps many years later,’ I said because I hated to tell him ‘Probably never.’ ‘That’s O.K., Nechan. I’ll still be a good spear-fisherman when I’m 80.’ And he might have, too; but that was not in the cards for Siakong. . . . After being released from a long stretch in jail, Siakong went on a fishing trip, took a deep dive after a turtle, and never came up again. The area was combed by other divers, but they couldn’t find a sign of him or a clue to his disappearance.

“Perhaps with his great skill in the water, Siakong found a way to stay alive underwater indefinitely and just decided not to bother coming back to a world that was constantly throwing him into the calaboose. Let us imagine him still happily swimming around those reefs that he loved so much, playing with the turtles and fishes.” (Natural History, May 1953)
1928–75 Beginning in 1928, anthropologist Margaret Mead did periodic fieldwork on Manus, an island in the Admiralty group north of Papua New Guinea. When Mead returned to Manus in 1975, she found that the society as a whole was being revitalized: “The extreme emphasis on modernization and rejection of the characteristics of an earlier period were now gone. The society was still distinctively Manus, but with a new sense of identity, ready to combine the old and the new. I realized how little we had been able to learn when we used to study a people only once, and how illuminating and unique was this opportunity to follow the same population—a microcosm of the world—for forty-seven years, as they fanned out into the wider world, but retained the core of their culture at home.” (Natural History, June–July 1976)

1998 Black Smoker Expedition

Exploring the hydrothermal vents along the Juan de Fuca Ridge (200 miles off the coast of Seattle), a remotely operated vehicle worked at a depth of 7,200 feet to raise three sulfide chimneys, called black smokers, for display in the Museum’s Gottesman Hall of Planet Earth. Science writer Peter Tyson describes the delicate operation aboard ship to secure the live chimney that the team named Roane:

“We raced outside. The gauge read fifteen thousand pounds and was falling fast... Live chimneys, being more porous, lack the solidity of dead chimneys, and Roane might have crumbled away when it was wrenched free of the seabed....

“An hour later, Roane reared out of the ocean on the end of the line and was lifted safely aboard. It had split horizontally and was missing its top portion, but what we had was solid as a redwood and festooned with drinking-straw-like tube worms. Seconds after it had touched down on the fantail, Delaney and Kelley rushed forward and thrust a temperature probe into Roane’s still-steaming central ‘flue,’ a fist-sized opening that glittered with black crystals.... The temperature read 194°F; and that was after an hour in 35°F seawater. I stuck my hand into the hole; it felt like a sauna.” (Natural History, June 1999)
Asia

1897–1902 The relationship between the peoples of northeastern Asia and northwestern North America was explored in the Jesup North Pacific Expeditions. For ethnologist Waldemar Jochelson and his wife, Dina, who took photographs and collected ethnographic artifacts, archaeological materials, and zoological specimens, field conditions were extremely difficult: "Bogs, mountain torrents, rocky passes and thick forests combined to hinder our progress. . . . Heavy rain . . . caused the provisions to rot. Therefore we had to cut down our rations from the very beginning. After crossing the passes . . . we reached the upper courses of the Korkodon River." (Natural History, March 1988)

1916–17

Asiatic Zoological Expedition

In one year, expedition leader Roy Chapman Andrews and his photographer wife, Yvette Bonip Andrews, traveled 2,000 miles by horseback through China's Yunnan province, whose topography Andrews likened to "the surface of the ocean in a furious gale, for the greater part has been thrown into vast mountain waves which divide and cross one another in hopeless confusion." He took a particular interest in gorals and serows, the so-called goat antelopes that are found only in Asia. He described coming upon a goral on Snow Mountain:

"I have seen a goral run at full speed down the face of a cliff which appeared to be almost perpendicular, and where the dogs dared not venture. As the animal landed on a projecting rock it would bounce off as though made of rubber, and leap eight or ten feet to a narrow ledge which did not seem large enough to support a rabbit . . . They are vicious fighters, and frequently back up to a cliff, turn on the dogs, and fight the pack." (Natural History, December 1917)
Over the course of a decade, Roy Chapman Andrews organized five expeditions to the Gobi Desert, where Museum scientists found dinosaur fossils dating back 80 million years. Henry Fairfield Osborn, creator of the Department of Vertebrate Paleontology and Museum president from 1908 to 1933, joined the first Central Asiatic Expedition in 1922. He reports on the two outstanding discoveries of the expedition, whose object was to test his theory that the mammals of Europe and America originated in central Asia:

“First, the discovery of a hitherto unknown and extremely ancient continental surface of Gobia right in the heart of Asia, where the conditions were highly favorable for the origin and evolution of all forms of continental life over a period of time variously estimated as from ten millions to sixty millions of years in duration; second, the discovery that this inland continent lay at the very center of a series of great life-zone belts which extended around the Eastern and Western Hemispheres along the lines of the fortieth and forty-fifth parallels. Hitherto we have known only the eastern and western ends of these great broad bands of life; now we are exploring in the very center of these life zones.” (Natural History, March–April 1924)
1926 Komodo, one of the Lesser Sunda Islands in Indonesia, is distinguished by pinnacles of igneous rock overlooking low country covered with long grass and sago palms. Capturing the giant lizards unique to the island became the focus of the Burden East Indian Expedition. Douglas Burden describes one Komodo dragon: “He looked black as ink. His bony armor was scarred and blistered. Half his tail had been lost in battle. His eyes, deep set in their sockets, looked out from underneath overhanging brows. Now his footsteps were plainly audible. . . . Then, of a sudden, it happened. He walked straight up to the opening, stepped through the noose, and seized the bait. I pulled the release, and the great dragon was catapulted into the air. . . . Then it was a contest of strength between him and the tree, which began to crack noisily with the strain as he clawed at the ground, tugging at the rope which was tightened about his middle.” (Natural History, January–February 1927)

1990–present After Mongolia’s Soviet-backed regime fell in 1990, the new government invited Museum scientists to resume fossil excavations (suspended in 1928) at various sites in a 500,000-square-mile area of the Gobi Desert. Every summer since 1990, in collaboration with the Mongolian Academy of Sciences, a Museum team headed by paleontologists Malcolm McKenna, Michael Novacek, and Mark Norell has traveled to the Gobi, identifying fossils and amassing a wealth of information about the locomotion, feeding, and sensory systems of a broad spectrum of ancient vertebrates. “How can a scientist make sense of all these data?” writes Mark Norell, discussing the interpretation of an oviraptorid embryo found at Ukhaa Tolgod. “Oviraptorids were small, bipedal dinosaurs closely related to birds. . . . In the Ukhaa Tolgod and other oviraptorid nests, the eggs are arranged in a circular pattern, with the large end of the eggs facing inward. This indicates that, like modern birds, oviraptorids manipulated their eggs in the nest. More broadly, such evidence tells us that many of the behaviors that we think of as unique to birds have deep roots. They evolved far back within the history of the group, with the extinct nonavian dinosaurs.” (Natural History, June 1995)
1926–29 Vernay-Faunthorpe Expedition

Arthur S. Vernay and Colonel John C. Faunthorpe organized expeditions to India, Myanmar, Angola, and parts of East Africa to obtain the mammal specimens and other materials needed to construct dioramas for such habitat groups as those centered around the Sumatran rhinoceros and the Indian leopard. Preparator Albert E. Butler describes the work of collecting and preparing materials to create the setting for a habitat group:

“Any grasses required, for instance, are collected and packed carefully so as not to become broken in shipment, for such material can be preserved, recolored, and actually utilized in the group. Leaves and twigs of the plants selected are carefully packed in tanks containing a formalin solution—tanks for this purpose having been specially made and included in the field outfit. Plaster molds in series are made from leaves of each plant form, and similar molds are made from flowers in much the same manner. Color sketches are also made in order that the artificial reproductions may closely imitate nature, and if time permits, wax reproductions are sometimes made on the spot and colored in imitation of the freshly growing plants. Samples of rocks and sections of tree bark usually are all that is necessary of such material, for these can be faultlessly imitated in the work shops of the Museum where paper maché and plaster take their place.” (Natural History, November–December 1928)
THE GREATEST RISK IS NOT TAKING ONE.

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Africa

1909–15 American Museum Congo Expedition

Zoologist Herbert Lang and eighteen-year-old Columbia University student James Chapin spent six years in the Belgian Congo (now the Democratic Republic of the Congo). They returned to the United States with fifty-four tons of diverse flora, fauna, artifacts, and ethnographic data. After the expedition, Chapin completed his studies at Columbia University and joined the Museum as a curator in the ornithology department. In 1960, in a series of oral reminiscences, he described his extraordinary travels some fifty years earlier:

“I can never forget the noise that an African caravan used to make in those days. There was a capita, a head man who wasn’t carrying anything. He had good lungs and he would yell, ‘B-r-r-r-r, makata mia; b-r-r-r-r, makata mia-mia.’ At each ‘makata mia’ the whole caravan was supposed to yell, ‘Wow!’ Then when they got on a bit, sometimes I would hear him say, ‘Makata mia,’ and then ask a question: ‘B-r-r-r-r, makata mia; nachoka?’ (Are you tired?) And the whole caravan was supposed to reply, ’Wapi’ (Where?), the strongest negative they could think of. Then they would sing, too: ‘Tulala wapi? Tulala wapi?’ ‘Tulala na bandaholio.’ That song said, ‘Where are we going to sleep?’ Then would follow the name of the village where they expected to sleep in some big shed, or bandaholi. . . .

“In 1913, Lang and I parted in Avakubi. . . . I, with three Azande carpenters, began to repair packing boxes, make new ones, and prepare all our collections for the three weeks’ overland safari down to Stanleyville, where, at last, they could be put on a river steamer. I figure that during that year—between 1913 and 1914—I rearranged loads for about one thousand men at sixty pounds per box.” (Natural History, November 1990)

1930 On a survey of southern Africa’s Kalahari Desert funded by Arthur S. Vernay and led by zoologist Herbert Lang, the team traveled in five one-and-a-half-ton trucks. Three were equipped with wire sides that could be let down to make beds for six people. Vernay was intrigued by the desert people and wrote that “the Bushman has a most amazing faculty, an extraordinary quickness of perception in seeing the spoor; he goes along at a jog-trot on the spoor, and in this way can actually run fifty miles a day. We ascertained quite definitely that they can run down such animals as steinbok and duiker by keeping on the spoor hour after hour, until eventually the animal is tired out and becomes their prey.” (Natural History, May-June 1931)
Carl E. Akeley, the Museum preparator who revolutionized the field of taxidermy, envisioned a hall displaying African wildlife. On the third of six visits to Africa, he went to Lake Kivu at the eastern edge of the Belgian Congo to collect gorillas and study their habitat. Well ahead of his time, Akeley was deeply concerned about disappearing wilderness and wildlife, as well as about misconceptions regarding particular creatures:

“Had the American Museum undertaken to prepare a gorilla group five years ago, using skins which could be purchased in the open market, and planning the group as carefully as possible in accordance with the accumulated data of the past seventy-five years, I have an idea that that group would have had a much greater appeal to a public thirsting for excitement and sensation, than the group which will result from the knowledge recently acquired. Such an imaginary group would of necessity have shown the gorilla as a ferocious creature in a setting of gloomy forest or mysterious jungle. There would have been one specimen in a tree, another walking erect with a staff or club in one hand, and perhaps a third beating its breast with its fists and opening its cavernous mouth as though roaring with rage. . . . Taking the records literally, there would have been justification for depicting an old male in the act of crushing with his teeth the barrel of a hunter’s gun. . . .

“The gorilla group in Roosevelt African hall will be a great disappointment to that portion of the public which has expected and would prefer to see the gorilla made as human and as horrible as the imagination has painted him, for it will show the gorilla as a great amiable creature in a setting of extraordinary beauty.” (Natural History, September–October 1923)
1924–28 Martin Johnson  
African Expedition

With the backing of George Eastman, of the Eastman Kodak Company, and a group of Museum trustees, photographer and filmmaker Martin Johnson and his wife, Osa, were enlisted to document African wildlife. Their work was used to generate interest in and funds for Carl Akeley’s African Hall. Martin Johnson describes the difficulties of capturing on camera the wild animals they encountered throughout East Africa:

“I doubt very much whether any one who has not tried it has any conception of the difficulties connected with making wild-animal pictures. The screen pictures of the veldt, showing all kinds of wild game roving about, seemingly unaware of the presence of the camera and the camera man, often delude the audience into thinking that after all it is rather easy to photograph them. Herein art and skill defeat themselves. The better an animal picture is made, the less exciting it appears to be. The easiest thing to do is to shoot an animal with a high-power rifle at a comfortable and safe distance, or to run it down with a motor car, picturing the process and its excitements. The hardest thing is to picture that same animal in a calm, undisturbed state of nature. But that is the most important thing that the camera can attain.” *(Natural History, September–October 1927)*

1996 A team of twenty scientists, preparators, designers, and audiovisual technicians spent five weeks in the Central African Republic’s Dzanga-Sangha rainforest collecting materials that became the centerpiece of the Museum’s Hall of Biodiversity. Scientists on the expedition identified about a hundred species of mammals, three hundred of birds, hundreds of trees, and thousands of ants, termites, beetles, and butterflies. *(Natural History, July–August 1997)*
1953 Morden African Expedition

William J. Morden, assisted by his wife, Irene, spent eight months in what was then called South-West Africa (now Namibia). The team covered more than 11,000 miles, including the Kaokoveld, a desert area in the northwest corner of the country, and the Skeleton Coast, “a desert strewn with electric light bulbs and automobile tires—the remains of ships that ventured too close to shore.” Upon crossing the Namib Desert to the Hottentot Reserve near the oasis town of Sesfontein, the expedition members met four beach dwellers (called Strandlopers in Afrikaans):

“They are not pygmies. Perhaps they are an offshoot of the Bushmen, who are considered the oldest existing group of aboriginals in Africa, or they may even have predated the Bushmen. In any event, the little Strandlopers used to travel up and down their lonely ways subsisting on fish, sea birds, lizards, seeds, and the fruit of the ///ara// [the / indicates a clicking sound], or wild cucumber. . . . The Strandlopers were permitted to reside on the reservation, but amid the Hottentots’ many dome-shaped and matting-covered huts, their modest shelters were a thing apart. Built of bark, grass, and the leaves of the mopane tree, their homes were entirely and characteristically different. On the coast, the framework could have been of whale bones, we were told, but here they were of branches.” (Natural History, February 1955)

1996–present From references in whalers’ logs, Howard Rosenbaum, a research fellow in the Museum’s Molecular Systematics Laboratory, suspected that the shallow Antongil Bay along the northeast coast of Madagascar was a wintering ground for humpback whales. When he finally visited the bay, he “almost immediately spotted the tall, distinctive, bushy ‘blow’ of a humpback. . . . On that first morning, we saw about 20 of these leviathans.” Rosenbaum is now assembling a database of the approximately 250 humpbacks and other marine mammals in the area. (Natural History, July–August 1998)
**The Americas**

**1934–37 American Museum—Sinclair Dinosaur Expedition**

Logging 20,000 miles, paleontologist Barnum Brown conducted an aerial survey of the Rocky Mountain states from the Diplodocus, an airplane owned by the Sinclair Refining Company, and discovered many promising fossil areas in Triassic, Jurassic, and Cretaceous strata. Brown’s wife Lilian, who served as aide-de-camp, reports on the excavation at Howe Quarry, Wyoming, in 1934:

“So delicate is the work after the bones are uncovered, that the final cleaning is done with small paint brushes and awls, after which the uppermost bones are shellacked and hardened to keep them from breaking.

“The blocks are then braced with wooden splints, and covered with strips of burlap that have been soaked in plaster. When this hardens, the entire block is turned over, and the same process applied to the other side; thus, when it is ready for shipment, the whole specimen is encased in a protective cast. “Before the bones are removed, the entire collection is elaborately charted, sketched, and numbered, so that when the bones are unpacked, they can be definitely placed in their exact relationship as they were found in the quarry, and parts of detached animals can be associated. Some of these blocks weigh one thousand pounds.”

*(Natural History, February 1936)*

**1923-24** The expedition to the coral reefs of Andros Island in the Bahamas yielded materials for the Hall of Ocean Life. Roy Waldo Miner, curator of lower invertebrates, describes the view from a submarine tube, a device that allowed scientists to observe life on the seabed: “Great trees of the reef-forming coral *Acropora palmata* rose from the reef platform constituting a veritable stone forest with closely interlacing branches, a marble jungle which melted into the pearly blue haze of the watery atmosphere, the wide branches often breaking the surface of the water at low tide, especially on the side toward the lagoon.” *(Natural History, September–October 1924)*
1955  An ancient settlement at Poverty Point, Louisiana, was discovered after anthropologist James A. Ford examined aerial photographs taken by the U.S. Army Corps of Engineers. Ford organized an expedition and excavated the area, which Native Americans had settled in about 800 B.C., creating dome-shaped mounds as tombs for the dead, stone tools that were ground rather than chipped, pottery, and techniques of working copper. The ridges that revealed the configuration of the settlement, Ford wrote, "are from five to ten feet high and were built of earth taken from the swales that lie between them. The dwellings were evidently situated along the tops of the ridges. This we knew because it was along the flanks that we found the greatest concentration of black soil stained with charcoal from cooking fires, as well as most of the broken and worn-out utensils." (Natural History, October 1955)

1915, 1998–present
Mission San Marcos Archaeological Project

San Marcos, just southwest of Santa Fe, New Mexico, is the site of the largest ancient Indian pueblo in the United States. David Hurst Thomas, curator of North American archaeology, has been studying the settlement with ground-penetrating radar, magnetometry, soil resistivity analysis, and other noninvasive techniques. The site was first excavated in 1915 by Museum archaeologist Nels Nelson, one of the pioneers of stratigraphic excavation in the United States. He describes the task of an archaeologist:

"Archaeological field work, like other branches of research, offers its moments of exultation. In a way the excavation of ruins is like prospecting for ore—you always expect a strike and you are reasonably sure of getting it. But... the real mission of archaeology is to make the unknown past live again or, in other words, to write history.

"Some may question the possibility of stating anything of permanent historical value about the times lying beyond the invention of writing, or concerning any people who have not left us some written records. But if history is to be essentially a record of the general organic life and growth of the world's inhabitants, then archaeology is in a position of advantage. A stone axe or a necklace of sea shells is an incontrovertible document, in certain respects worth more than any written document whatsoever." (American Museum Journal, February 1917)
1922 Santo Domingo Expedition

The Hall of Reptile and Amphibian Life, completed in 1927, was developed by herpetologist G. Kingsley Noble, who was interested in skeletal, neurological, endocrinological, and biochemical differences among species. Noble tells of his nighttime pursuit of the giant tree frog Hyla vasta in the mountainous northern rainforest on one of several collecting expeditions to the Dominican Republic:

“As I stepped nearer, there took shape against the velvety blackness of the night a tree frog so large that it seemed unreal. Its four immense feet were flattened out against the plantain stalk but its head, with staring orbs, slowly turned as if contemplating in which direction to leap. . . . I dropped everything, slipped out of my coat, and stealthily moved nearer. With both hands free I could not miss! . . . With both hands I clutched. Something squishy slipped in my fingers. Without daring to look, I dropped the frog into the bag which Juan stretched toward me. . . . We opened the bag cautiously; a penetrating odor like that of burning mustard, though more acrid and sickening, streamed forth. I looked more closely at my hands. To the red swellings was adhering some of the mucus from the frog’s skin. In a moment it was clear to me—the skin of the giant frog had badly poisoned me.” (Natural History, March–April 1923)

1930–31 During a paleontological expedition to Patagonia, George Gaylord Simpson took time from fossil excavations to observe living fauna. “The guanaco is a most improbable creature, apparently put together in haphazard fashion and in questionable taste. Zoologically he is a camel, but to most laymen he suggests more a misshapen and hornless deer, lacking the hump that we think of as characteristic of camels and having a rather deerlike head. . . . The guanaco’s eyes are large, liquid, appealing, and utterly stupid, the hairy, flexible lips admirably adapted to the vulgar habit of spitting enthusiastically at all comers.” (Natural History, March–April 1932)

1975–80 Anthropologist Craig Morris surveyed, mapped, and excavated about 300 of the nearly 4,000 structures in the Inca city of Huánuco Pampa. Located in the Peruvian highlands more than 12,000 feet above sea level, the city was, writes Morris, part of a “meticulously planned network” connected by thousands of miles of roads. (Natural History, December 1976)
1925 On an expedition to collect and film birds along the coasts of Ecuador and Peru, ornithologist Robert Cushman Murphy used a forty-pound motion picture camera that Museum preparer Carl E. Akeley had patented in 1916. Murphy observed “the dramatic accompaniments” to the abrupt arrival of El Niño, “the warm current from the north” that flows along the western coast of South America sometime between December and April of every year. “The first . . . was the rise in ocean temperature, amounting to an increase of 10° F within forty-eight hours, and a subsequent rise of at least six degrees more which endured throughout the winter. No less remarkable . . . was the replacement of the reliable southerly winds, upon which seafarers have banked from immemorial time, by fitful and yet recurrent rain-bearing winds from the north. And finally, most impressive of all, were the changes in the oceanic life . . . the immigrating cohorts of hammerheads, the jumping mantas or giant rays, the schools of large flying fish pursued by equally alien tropical dolphins.” (Natural History, September–October 1925)

1943–44 Paricutín Expedition

One year after a volcanic eruption created Paricutín, an approximately 1,300-foot-high mountain in southwestern Mexico, a Museum team led by mineralogist and volcanologist Frederick H. Pough went to the site to study the volcano. As the team climbed up the mountain’s slopes with cameras, a radiation pyrometer, and an egg to be cooked on a fragment of hot lava, Pough realized that all was not quiet on Paricutín:

“The vents began to throw out fragments and . . . fluid lava welled up in their mouths and started to pour forth. The nearest mouth, that harmless little gas vent, soon started throwing fragments high in the air, and lava rose higher and higher, starting to sweep down the trough before us, as tremendous bubbles of glowing lava rose in the air and shattered with great ‘plops’ into a thousand fragments. . . . The lava from the many vents merged into a single rapidly advancing flow, which was coming across our path of escape. . . . The lava blocks were falling within a few feet of the tripod, and our borrowed pyrometer was in danger of sharing the fate of the now certainly well done egg.” (Natural History, October 1944)

1993–present At the Tilcajete Project in Mexico’s Oaxaca valley, anthropologists Charles S. Spencer and Elsa M. Redmond have been excavating second- and third-century B.C. temples and palaces of the early Zapotec state, which represented the first urban culture to appear in ancient Mexico. (Natural History, March 1999)
1908–12 Stefansson-Anderson Arctic Expedition

This expedition to the Cape Parry–Coppermine River region of the Arctic aimed to study Eskimo (Inuit) life, make zoological surveys and collections, and map unexplored coasts. The expedition’s leaders, anthropologist Vilhjalmur Stefansson and zoologist Rudolph M. Anderson, wore Inuit clothes that enabled them “to sit comfortably on a block of snow, with back to the wind, fishing through a hole in the ice, the temperature being −50°F, and to feel the cold nowhere but on the face.” Even so, members of the expedition had to struggle to survive a fifteen-day blizzard in November 1909. Stefansson describes the ordeal:

“On the whole trip we killed five ptarmigan and not a single rabbit. . . . The sun was gone and so the daylight was meagre, besides it blew a blizzard every day. The whale tongue was very bad eating, it had little to it but dry fibres and was strongly impregnated with sea salts (other than NaCl). When we had finished this we were really better off for the stuff seemed to make us sick. We then ate sealskin, some deerskin we had along for sole leather and our snowshoe lashings, in fact every edible thing except clothes. Fortunately we had seal oil. With about a cupful of oil a day one does not feel in the least hungry but lazy, sleepy and weak. All of us found it a little difficult to take the oil straight. We soaked it up in tea leaves, deerskin with long hair on it and ptarmigan feathers.” (American Museum Journal, November 1910)

1969–71 Vertebrate paleontologist Edwin H. Colbert (right) accompanied an expedition to Antarctica. The team’s discovery of labyrinthodont amphibians and a skull belonging to the reptilian genus Lystrosaurus showed that “the same animals roamed southern Africa and Antarctica 200 million years ago, more evidence that the southern continents were once a single land mass.” (Natural History, January 1972)

1998 Museum mammalogist Ross MacPhee, with a team that included research assistant Clare Flemming and scientists from the Russian Academy of Sciences, collected woolly mammoth specimens on Wrangel Island in the Arctic Ocean, northeast of the Bering Strait. Through molecular analysis of the samples, the scientists are now testing their hypothesis that “as human populations expanded and colonized new landmasses during the Pleistocene, they brought with them virulent pathogens that wiped out native animals.” (Natural History, December 1998–January 1999)

Clare Flemming with a mammoth tusk
1912–13 Ornithologist Robert Cushman Murphy discovered his lifelong fascination with birds while leading the South Georgia Island Expedition. He wrote of the venture: "The greater part of our stay at South Georgia was spent at the lonesome Bay of Isles, and at Possession Bay where in 1775 Captain James Cook set up his colors and claimed the dreary land for his king." (American Museum Journal, October 1913)

1913–17 Crocker Land Expedition

The last extensive Arctic dog-sled expedition was undertaken to investigate unknown areas of the Polar Sea and to find "Crocker Land," which polar explorer Robert Peary had reported seeing west of Cape Columbia in 1906. Crocker Land was never found. Fitzhugh Green, an engineer and physicist who was on the expedition, wrote to his parents in January 1914:

"I know that you care not the snap of your fingers whether we find Crocker Land or not. I realize that I must come back to you. But even that cannot change the everlasting desire inside of me, the passion to travel, to fight the cold, and the wind and the nights, to be hungry and kill game. Unless the Devil himself gets into my luck and lays me up early with a frozen foot or the like..."

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