NATURAL HISTORY

4/04

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NATURAL HISTORY

APRIL 2004 VOLUME 113 NUMBER 3

FEATURES

ON THE COVER: *"Dolichos palmatilobus" (Pachyrhizus erosus),* from the Royal Scientific Expedition to New Spain, 1787–99

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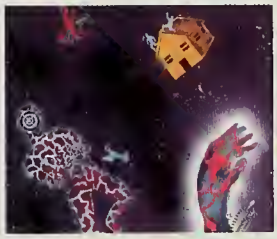
DEPARTMENTS


80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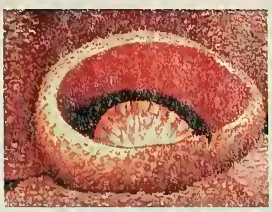
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CREDITS: Page 8


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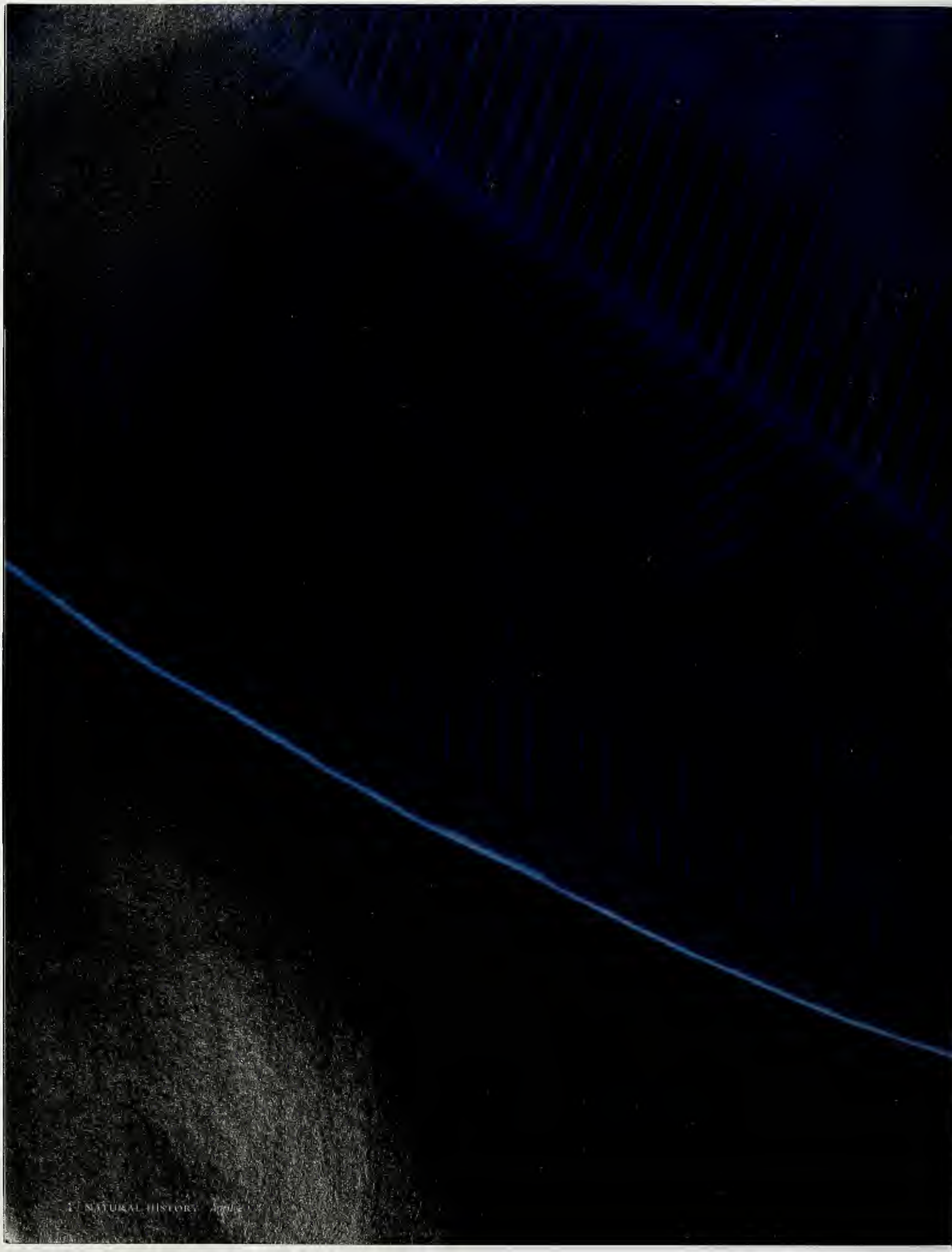
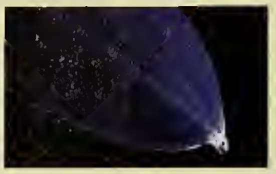


Disappearing Act

Photograph by Peter Herring

THE NATURAL MOMENT

◄ *See preceding pages*



Juvenile eels, though far from microscopic, are nearly invisible. The leptocephalus, or eel larva, pictured here measured about eight inches long, two inches high, and a few millimeters thick. Peter Herring, a marine biologist based in Southampton, England, noticed this leaf-shaped dainty while sorting through a slithering mass of aquatic animals brought to the surface of the western Pacific Ocean. He first saw what he describes as a three-dimensional, mobile "space" among the other deep-sea feeders caught in the trawl. Then he spotted an eye. He quickly photographed the pellucid larva as it was turning opaque in the open air.

An eel larva's transparent qualities—the ultimate camouflage—depend on a host of physiological features. Being paper-thin helps, as does having a body made mostly of gelatinous material. The muscle cells, seen here as vertical wavy lines, help minimize the amount of light that might be reflected from the eel to a predator's eye. The eel's gut, curving along the bottom of the larva, is harder to disguise, especially after a meal. Some eel larvae trail an external gut behind them as a makeshift solution.

Eels are slippery things to study, and not just because of their remarkable transparency early in life. Adults—even freshwater eels—spawn in the ocean, and soon die. And the hatchlings, which in certain species can grow for years before metamorphosing, often have no known adult counterpart. Such is the case with the larva in the photograph, tentatively identified by several ichthyologists as *Thalassenchelys coheni*. —*Erin Espelie*

UP FRONT

For the Sake of the Kids

For some people, April is the month of fools and showers and cruelty; for me, it will always be the month of a kids' game. Never mind that this year's calendar moves baseball's opening day into late March; April is the real beginning of the Major League season, not to mention the month when the grass seeded in the fall gets its first real trial by cleats, and the shouts of children stir winter's lethargy out of the diamonds.

Baseball is a game of biomechanics, which makes it fair game for our regular columnist Adam Summers ("A Fly in the Curveball," page 36). Received wisdom, Summers says, has it that even if a batter is lucky enough to smash a curveball in the sweet spot, the fly will never outdistance a similarly hit fastball. According to my seventeen-year-old son, Robinson, though, "everybody knows" that's nonsense: an incoming curveball has the proper spin to get an extra kick in the same direction from a slight undercut by the bat. How satisfying to have Summers report that Robinson's intuition is just right: the spin on a well-hit curveball can lift it out of a ballpark, whereas a fastball, tagged with the same optimum swing, could get caught.

Space travel is another game for kids as well as for grownups—though the kids get to enjoy it as a simple fantasy, without having to worry about the opportunity costs on Earth. Following President Bush's announcement of revisions to the space program, Neil deGrasse Tyson felt compelled to weigh in on the question of "robots vs. humans" in space ("Launching the Right Stuff," page 16). His conclusion: robots should be sent to do science, but human explorers will be essential to get kids excited about becoming scientists.

Most of the time I'm no fan of "virtual reality," but for interstellar travel, virtual may be the only way to go. Several months ago a few of us at *Natural History* attended a preview of the Digital Universe at the American Museum of Natural History, a stunning re-envisioning of our three-dimensional place in space, for kids of every age. Brian Abbott, Carter Emmart, and Ryan Wyatt describe this breakthrough educational tool in "Virtual Universe" (page 44); here's a project done "for the sake of the kids" that benefits us all.

• • •

Two of our regular contributors have earned special recognition for their work. Adam Summers has won a kind of Oscar-by-proxy for his work as a scientific consultant on the movie *Finding Nemo,* which won this year's Oscar for Best Animated Feature Film. "If you stay to the very, very end of *Nemo,*" Summers told me, "you will see your biomechanics columnist credited. I . . . am very pleased with how it came out. The Pixar [Animation Studios] folks are truly interested in using scientific truth as a backdrop for their stories."

Neil Tyson, when he isn't sharing his enthusiasm about the cosmos, will be helping NASA determine its long-term priorities in space. He was recently appointed to serve on President Bush's Commission on Implementation of United States Space Exploration Policy.

—Peter Brown

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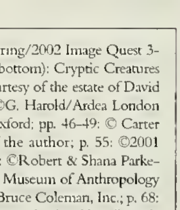
CONTRIBUTORS

Aboard the German research vessel *Sonne,* PETER HERRING and his colleagues were examining a haul trawled from the Pacific Ocean off the coast of Hawai'i, when they spied the eerie creature featured this month in "The Natural Moment" (page 4). A marine biologist and recently retired professor at the Southampton Oceanography Centre in England, the aptly named Dr. Herring studies the physiology and ecology of deep-sea animals, with an emphasis on methods for improving their live capture and collection. His most recent book, *The Biology of the Deep Ocean,* was published by Oxford University Press in 2002.

MARTEN SØRENSEN ("Supercrop," page 38) has spent twenty years investigating the history, adaptability, and economic potential of yam beans, indigenous Latin American tubers of the genus *Pachyrhizus,* of which the best known species is the jicama. Sorensen is the founder and project coordinator of the Yam Bean Project, and head of the Botanical Section of the Department of Ecology at the Royal Veterinary and Agricultural University, in the municipality of Frederiksberg in Copenhagen, Denmark.

"Virtual Universe" (page 44) is a product of teamwork, much like the Digital Universe atlas, the project the authors helped develop for the Rose Center for Earth and Space, at the American Museum of Natural History (AMNH) in New York City. BRIAN ABBOTT (far left), a data analyst in the Department of Astrophysics and Hayden Planetarium, oversees the development and distribution of the atlas. CARTER EMMART (center left) is a member of the original NASA-funded Digital Galaxy Project, which redefined AMNH's science presentations for the public. He is now the Rose Center's Director of Astrovisualization for Production and Education. RYAN WYATT worked on planetarium productions for more than a dozen years before becoming the Rose Center's Science Visualizer.

A second-generation Japanese American born and raised in Chicago, TAKEYUKI TSUDA ("No Place to Call Home," page 50) traveled both to South America and Asia to learn about the lives of the 280,000 Japanese Brazilians who work in Japan. That fieldwork was the basis for Tsuda's doctoral dissertation in anthropology, as well as for his book *Strangers in the Ethnic Homeland: Japanese Brazilian Return Migration in Transnational Perspective* (Columbia University Press, 2003). Tsuda is associate director of the Center for Comparative Immigration Studies at the University of California, San Diego, in La Jolla. He is currently documenting the struggle of immigrants for rights and social services in Japan, Korea, and Spain.



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Natural History (ISSN 0028-0712) is published monthly, except for combined issues in July/August and December/January, by Natural History Magazine, Inc., in affiliation with the American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024. E-mail: nhmag@naturalhistorymag.com. Natural History Magazine, Inc., is solely responsible for editorial content and publishing practices. Subscriptions: $30.00 a year; for Canada and all other countries: $40.00 a year. Periodicals postage paid at New York, NY, and at additional mailing offices. Canada Publications Mail No. 40030827. If you would like to contact us regarding your subscription or to enter a new subscription, please write to us at Natural History, P.O. Box 5000, Harlan, IA 51593-0257. Postmaster: Send address changes to *Natural History*, P. O. Box 5000, Harlan, IA 51537-5000. Printed in the U.S.A.

For Richer or Poorer

In his review of Paul Farmer's *Pathologies of Power* ["Why Must the Poor Be Sick?" 2/04], Jeffrey D. Sachs doesn't seem to understand what structural violence is. It is an injury imposed on people by a social, political, and economic system, enforced by law or custom. Slavery is the classic example. The low prices paid for Haitian sugar, the low wages paid in Haitian sweatshops, and U.S interference in the affairs of Haiti—which has the effect of keeping the country poor for the benefit of U.S. corporations—constitute a more modern example.

Mr. Sachs argues that, in general, the rich are not getting richer, and the poor, poorer. But rich and poor are relative terms, and the gap between them is steadily increasing.

The battles of the poor countries to get affordable AIDS medications show how the interests of the poor countries conflict with those of the rich. Both Messrs. Farmer and Sachs seem to think that by instilling "a deep sense of mutual obligation between rich and poor," charitable efforts can succeed. But when you look at the big tax cuts for the rich, and the imposition of "structural adjustment programs" on the poorer countries, you see how silly that idea is. Capitalists will never contribute the necessary means to really fight poverty and disease in the world.

Richard Vineski
Wappingers Falls, New York

According to Jeffrey Sachs, one of the main themes persuasively argued in Paul Farmer's book is that "the poor are not the victims of their sins, but of their circumstances." Better to say they are victims of ignorance. Instead of demanding that U.S. taxpayers cure all the "poor" people of disease in distant lands, why don't we teach them sanitation and birth control?

Mr. Sachs further agrees that "the poor can be successfully treated and cured of disease" and that "the human rights community should be defending the rights of the poor to health." May I ask, at whose expense? One person's rights stop when they infringe on another's.

"Whatever happened to privacy?"

American taxpayers cannot take care of the whole world.

Treva Kelley Courter
Kevil, Kentucky

JEFFREY D. SACHS REPLIES: In response to Richard Vineski, I do understand what structural violence means. My point is that it is not a general explanation of extreme poverty. Nor is it true as a general principle that the rich are getting richer and the poor are getting poorer, either relatively or absolutely. In both China and India, for instance, the number of the extreme poor has been dramatically reduced in recent years. Poverty does not have a single cause or a single pattern.

There are indeed places characterized by structural violence. There are many other places where people are trapped by extreme poverty that is much better explained by various factors of human ecology—disease ecology, the loss of soil nutrients, geographical isolation, and so on—than it is by structural violence. Both Paul Farmer and I agree that the rich countries have not only an enlightened self-interest in helping the world's poor but also an international obligation to do so, an obligation that they have stated repeatedly but not fulfilled.

Those considerations are of course relevant in responding to Treva Kelley Courter. The U.S. and other rich countries have repeatedly acknowledged a responsibility to help the world's poor. To paraphrase Oliver Wendell Holmes Jr., who said that "taxes are what we pay for civilized society," donor-country support for the world's poorest countries is part of the price we pay for a civilized world. It is a small effort worth making if we want to avoid a descent into widespread anarchy, terrorism, pandemics of global disease, and other avoidable calamities.

Beetlemania

In his "Biomechanics" column ["Like Water Off a Beetle's Back," 2/04], Adam Summers cites investigators who suggest that a surface mimicking a long-legged Namib beetle's back would be a useful means to collect fog. But in our view, a solid surface will not prove the most effective design. Fog droplets are blown around any solid structure. Existing fog collectors are made with an inexpensive, porous polypropylene mesh that has proved highly efficient.

Robert S. Schemenauer
Executive Director, FogQuest
Thornhill, Ontario

As a resident of Berkeley, California, where summertime fog is a daily phenomenon, and as a plant biologist who has been investigating the role of fog water for coastal redwood trees, I've come to appreciate the ways both animals and plants "harvest" fog. We've recently learned that redwood leaves not only capture but also absorb fog. When the fog collected by redwood needles drips to the soil, it can provide between 30 and 50 percent of all a forest's annual water supply.

Todd E. Dawson
University of California, Berkeley

ADAM SUMMERS REPLIES: In spite of what Robert S. Schemenauer says, it seems premature to guess that the efficiency of collecting fog droplets is lower in flat panels than in netting. No doubt many droplets never get close enough to the surface of the panel to adhere, but then, many droplets pass through the holes in the netting. Orientation and surface shape should have a marked effect on droplet capture rates, and any comparison of the two technologies would have to consider maintenance and ease of installation.

I thank Todd E. Dawson for providing the example of the redwood trees. I suspect that a combination of hydrophobic and hydrophilic surfaces will prove to be a widespread device for capturing fog droplets in both plants and animals.

Snap Judgments

In "Underwater Urbanites" [12/03–1/04], J. Emmett Duffy describes Darwin's problem with social insect species in which most individuals are sterile. Mr. Duffy then goes on to discuss William D. Hamilton's "animal altruism" explanation, based on the fact that "the sterile workers, which are almost exclusively female, are more closely related to their sisters than they would be to their own offspring (if they had any)."

But that explanation has always left me vaguely dissatisfied. It seems to me that the only real players of the Darwinian game in, say, an ant colony, are the queen and any males she mates with. So why is it fitter for those individuals to produce so many sterile offspring than it is to concentrate on producing only fertile offspring?

Andrew Raybould
Irvington, New York

J. EMMETT DUFFY REPLIES: Hamilton's fundamental—and revolutionary—insight (foreshadowed by Darwin) was that producing offspring is not the only way to get ahead in the Darwinian game. Ample empirical research has confirmed his theory that, under certain circumstances, a gene promoting behavior that enhances reproduction of close relatives can increase in frequency in the population even if it reduces the direct reproduction of its bearer.

Yet the question of what promotes sterility—technically, the lack of reproduction—still defies a simple, general answer. In particular cases the sterility in workers can be attributed to incest avoidance, aggressive dominance by breeders, or even communal policing by other workers whose "interests" are ill served if their sisters reproduce.

AMENDMENT: The Web address for a report about the global trade in fishes was given incorrectly ("Finding Nemo," by Melanie L.J. Stiassny, 3/04). The correct address is www.unep-wcmc.org/resources/publications/WCMC_Aquarium.pdf

Natural History*'s e-mail address is* nhmag@naturalhistorymag.com

ICE AGE SIBERIANS

The verified human history of eastern Siberia just got 16,000 years longer. Several hundred miles north of the Arctic Circle, along one of northeast Asia's largest rivers, a team led by Vladimir V. Pitulko, an archaeologist at the Institute for the History of Material Culture in Saint Petersburg, Russia, recently discovered a 30,000-year-old encampment—almost twice as old as the next-oldest known Arctic settlement. The team has unearthed stone tools, animal bones showing signs of butchering and cooking, and spear shafts made from woolly rhinoceros horn and mammoth tusk.

Plant and pollen remains suggest the region was probably dominated by large expanses of floodplain meadow—an attractive landscape for plant eaters such as bison, hare, and reindeer. Whether the people at the site were permanent residents or seasonal hunters is unclear, but to some investigators their mere presence indicates that people had already habituated to a cold climate. More important, it raises the possibility that people were poised to cross the Bering land bridge to North America earlier than commonly believed—well before the height of the last ice age, 20,000 years ago. ("The Yana RHS site: Humans in the Arctic before the last glacial maximum," *Science* 303:52–56, January 2, 2004)

—*Kenneth D. Kostel*

Palliative or Poison?

Vultures, the quintessential garbage collectors, were a familiar sight in South Asia just a decade ago—particularly the Oriental white-backed vulture, *Gyps bengalensis*. But sometime in the 1990s they began dying off at an alarming rate. So J. Lindsay Oaks, a veterinarian at Washington State University in Pullman, and a team of colleagues decided to do a few hundred necropsies in Pakistan. What they found was widespread evidence of acute kidney failure, probably caused by the ingestion of something toxic.

Vultures are vanishing from the Indian subcontinent.

Arsenic, cadmium, copper, lead, mercury, pesticides, viruses, other infections—you name it, they tested for it and ruled it out. The actual culprit was a substance frequently present in the carcasses of dead livestock, the vultures' normal food source.

Nowadays, sick buffalo, cattle, and goats are often given diclofenac, a nonsteroidal anti-inflammatory drug that has become available in Pakistan in the past five years. Virtually every veterinarian and drug retailer sells it. Oaks and his team say the drug is the reason not merely for isolated cases of poisoning among scavengers, but for the near disappearance of the entire *G. bengalensis* species from the Indian subcontinent. ("Diclofenac residues as the cause of vulture population decline in Pakistan," *Nature* 427: 630–32, February 12, 2004)

—*Stéphan Reebs*

Evolutionary Circles

According to Dollo's law—an evolutionary maxim named after the nineteenth-century Belgian paleontologist Louis Dollo, and much favored by the late Stephen Jay Gould—complex physical features lost during evolution are seldom regained. Why? Well, presumably, once a gene no longer gives rise to a characteristic, natural selection no longer exercises quality control on the gene. Eventually the gene gets swamped by mutations. Transformed beyond recognition, it cannot fulfill its earlier function.

There are three possible exceptions to the pattern: First, after the old gene disappears, a brand-new gene with the same function might evolve elsewhere in the genome. Second, the gene might be co-opted for some other function, thereby remaining sufficiently unchanged to resume its old role later. Third, the gene might remain functional at the larval stage of life, though no longer useful in adulthood. In that case, a simple change in timing could shift the lost feature back from larva to adult.

Rachel Collin of the Smithsonian Tropical Research Institute in Panama City, Panama, and Roberto Cipriani of Simón Bolívar University in Caracas, Venezuela, have just provided the first good example of the third scenario by reconstructing the evolutionary tree of nearly a hundred species in the limpet family Calyptraeidae. The coiled shell that covered the ancestor of most of those species lost its coiling between 65 million and 99 million years ago, and so most limpet species now have a conical or somewhat hat-shaped shell. But 40 million to 80 million years later, the shell of one species regained the coil. Key to Collin and Cipriani's argument is the fact that many calyptraeid larvae still have a coiled shell, even though the adults do not. ("Dollo's law and the re-evolution of shell coiling," *Proceedings of the Royal Society of London B* 270:2551–55, December 22, 2003)

—*S.R.*

All in the Family

Rafflesia, a plant genus native to the jungles of Southeast Asia, is notorious for its flowers, the largest in the world. A *Rafflesia* flower can be as broad as three feet across and weigh close to twenty pounds. The plant is also completely parasitic. Lacking leaves, roots, and stems of its own, it depends on its host, a grapevine, for nutrients as well as for water. Except when flowering, it lives inside the vine. *Rafflesia's* most memorable feature, though, is that its enormous blossom stinks of rotting flesh, the better to lure the carrion flies that pollinate it. What on Earth are its evolutionary origins?

That mystery may finally have been solved by Todd J. Barkman, a botanist at Western Michigan University in Kalamazoo, and his colleagues, who have devised a family tree built from ninety-five likely relatives. Their approach was based on an analysis of mitochondrial, rather than nuclear, DNA—the latter changes so rapidly in *Rafflesia* that it proves of little use to genetic studies. *Rafflesia's* cousins turn out to be such modest blossoms as the passionflower, the poinsettia, and the tiny, fragrant violet; a few relatives are vines. Perhaps, say the investigators, there's something about the close contact between vines and the plants they entwine that fosters parasitism. ("Mitochondrial DNA sequences reveal the photosynthetic relatives of *Rafflesia,* the world's largest flower," *Proceedings of the National Academy of Sciences* 101:787–92, January 20, 2004) —*S.R.*

Get a whiff of this!

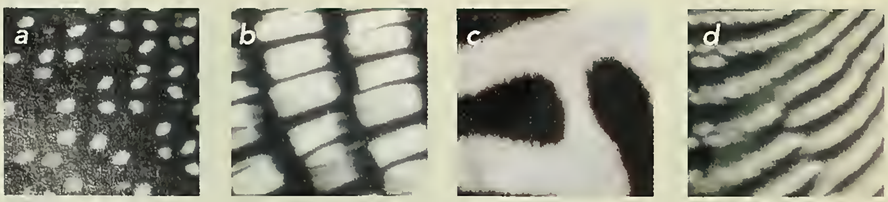
YOU TAKE THE MUSCLES, I'LL TAKE THE EARS

Geneticists are fond of pointing out that the DNA of people and chimpanzees is nearly 99 percent identical [see *"Searching for Your Inner Chimp," by Carl Zimmer, December 2002/January 2003*]. Explaining the manifest differences has become something of a cottage industry. What accounts for the elaborate verbal skills of humans, our technological proficiency, our ability to contemplate our own humanity?

Now Andrew G. Clark, a population geneticist at Cornell University in Ithaca, New York, and his colleagues have weighed in with a comparative study of more than 7,600 human and chimpanzee gene sequences that have a common origin but have been diverging as the two species have evolved. Any divergence could result from random mutation, but accelerated divergence suggests the operation of natural selection—the emergence and preservation of advantageous characteristics. Clark and his team aimed to identify the latter.

So what's been briskly diverging? To some extent, the genes that facilitate differing lifestyles. In chimpanzees, rapidly changing genes include the ones that encode embryonic muscle, bone, and connective tissue, as well as skeletal structure in adults. In people, notable modifications have taken place in the genes for smelling and hearing, for instance. Clark and his colleagues speculate that an increasingly fine-tuned sense of hearing has assisted humans in the comprehension of spoken language. ("Inferring nonneutral evolution from human-chimpanzee-mouse orthologous gene trios," *Science* 302:1960–63, December 12, 2003) —*Aimee Cunningham*

Cryptic Creatures



Only three of these pictures are close-ups of the same animal. Which one doesn't belong?

(Answer on page 71)

Feeling Pressured

Several hours before tropical storm Gabrielle struck Florida's Gulf Coast on September 14, 2001, all the juvenile blacktip sharks living in a shallow coastal nursery in Terra Ceia Bay moved to deeper—and safer—waters offshore. Michelle R. Heupel and her colleagues from the Mote Marine Laboratory in Sarasota painstakingly ruled out possible reasons for the sharks' collective departure—the noise of heavy rainfall, the decline in the bay's salinity, increased wind speed, abnormal tides. The only environmental cue that truly coincided with the departure time was a sudden drop in barometric pressure. That finding is the first behavioral evidence that some sharks (and perhaps other coastal species) come equipped with an internal barometer, enabling them to anticipate storms and hurricanes. ("Running before the storm: Blacktip sharks respond to falling barometric pressure associated with Tropical Storm Gabrielle," *Journal of Fish Biology* 63:1357–63, November 2003) —*S.R.*

Launching the Right Stuff

Who (or what) will make the better space explorer: robot or human being?

By Neil deGrasse Tyson

David Wojnarowicz, *Science Lesson*, 1981–82

More than a year has passed since the space shuttle *Columbia* broke into pieces over central Texas. This past January President Bush announced a long-term program of space exploration that would return human beings to the Moon, and thereafter send them to Mars and beyond. As this magazine goes to press, the twin Mars Exploration Rovers, Spirit and Opportunity, are wowing the scientists and engineers at the rovers' birthplace—NASA's Jet Propulsion Laboratory (JPL)—with their skills as robotic field geologists. JPL's official rover Web site (marsrovers.jpl.nasa.gov/) is being stampeded by visitors.

The confluence of these and other events resurrects a perennial debate: with two shuttle failures out of 112 missions, and the astronomical expense of the manned space program, can sending people into space be justified, or should robots do the job alone? Or, given society's sociopolitical ailments, is space exploration something we simply cannot afford to pursue? As an astrophysicist, as an educator, and as a citizen, I must speak my mind on these issues.

Modern societies have been sending robots into space since 1957, and people since 1961. Fact is, it's vastly cheaper to send robots: in most cases, a fiftieth the cost of sending people. Robots don't much care how hot or cold space gets; give them the right lubricants, and they'll operate in a vast range of temperatures. They don't need elaborate life-support systems, either. Robots can spend long periods of time moving around and among the planets, more or less unfazed by ionizing radiation. They do not lose bone mass from prolonged exposure to weightlessness, because, of course, they are boneless. Nor do they have hygiene needs. You don't even have to feed them. Best of all, once they've finished their jobs, they won't complain if you don't bring them home.

So if my only goal in space is to do science, and I'm thinking strictly in terms of the scientific return on my dollar, I can think of no justification for sending people into space. I'd rather send the fifty robots.

But there's a flip side to this argument. Unlike even the most talented modern robots, a person is endowed with the ability to make serendipitous discoveries that arise from a lifetime of experience. Until the day arrives when bioneurophysiological computer engineers can do a human-brain download on a robot, the most we can expect of the robot is to look for what it has already been programmed to find. A robot—which is, after all, a machine for embedding human expectations in hardware and software—cannot fully embrace revolutionary scientific discoveries. And those are the ones you don't want to miss.

In the old days, people generally pictured robots as a hunk of hardware with a head, neck, torso, arms, and legs—or maybe some wheels to roll around on. They could be talked to, and would talk back (sounding, of course, robotic). The standard robot looked more or less like a person. The fussbudget character C3PO, from the *Star Wars* movies, is a perfect example.

Even when a robot doesn't look humanoid, its handlers might present it to the public as a quasi-living thing. Each of NASA's Mars rovers, for instance, is described in JPL press packets as having "a body, brains, a 'neck and head,' eyes and other 'senses,' an arm, 'legs,' and antennas for 'speaking' and 'listening.'" On February 5, 2004, according to the status reports, "Spirit woke up earlier than normal today . . . in order to prepare for its memory 'surgery.'" On the 19th the rover remotely examined the rim and surrounding soil of a crater dubbed Bonneville, and "after all this work, Spirit took a break with a nap lasting slightly more than an hour."

In spite of all this anthropomorphism, it's pretty clear that a robot can have any shape: it's simply an automated piece of machinery that accomplishes a task—either by repeating an action faster or more reliably than the average person can, or by performing an action that a person, relying solely on the five senses, would be unable to accomplish. Robots that paint cars on assembly lines don't look much like people. The Mars rovers look a bit like toy flatbed trucks, but they can grind a pit in the surface of a rock, mobilize a combination microscope-camera to examine the freshly exposed surface, and determine the rock's chemical composition—just as a geologist might do in a laboratory on Earth.

It's worth noting, by the way, that even a human geologist doesn't go it alone. Unaided by some kind of equipment, a person cannot grind down the surface of a rock; that's why a field geologist carries a hammer. To analyze a rock further, the geologist deploys another kind of apparatus, one that can determine its chemical composition. Therein lies a conundrum. Almost all the science likely to be done in an alien environment would be done by some piece of equipment. Field geologists on Mars would schlep it on their daily strolls across a Martian crater or outcrop, where they might take measurements of the soil, the rocks, the terrain, and the atmosphere. But if you can get a robot to do the schlepping and deploy all the same instruments, why send a field geologist to Mars at all?

One good reason is the geologist's common sense. Each Mars rover is designed to move for about ten seconds, then stop and assess its immediate surroundings for twenty seconds, move for another ten seconds, and so on. If the rover moved any faster, or moved without stopping, it might stumble on a rock and tip over, becoming as helpless as a Galápagos tortoise on its back. In contrast, a human explorer would just stride ahead; people are quite good at watching out for rocks and cliffs.

Back in the late 1960s and early 1970s, in the days of NASA's manned Apollo flights to the Moon, no robot could decide which pebbles to pick up and bring home. But when the *Apollo 17* astronaut Harrison Schmitt, the only geologist (in fact, the only scientist) to have walked on the Moon, noticed some odd, orange and black soil on the lunar surface, he immediately collected a sample. It turned out to be minute beads of volcanic glass. Today a robot can perform staggering chemical analyses and transmit amazingly detailed images, but it still can't react, as Schmitt did, to a surprise. By contrast, packed inside the 150-pound mechanism of a field geologist are the capacities to walk, run, dig, hammer, see, communicate, interpret, and invent.

And of course when something goes wrong, an on-the-spot human being becomes a robot's best friend. Give a person a wrench, a hammer, and some duct tape, and you'd be surprised what can get fixed. After landing on Mars this past January 3, did the Spirit rover just roll right off its lander platform and start checking out the neighborhood? No, its airbags were blocking the path. Not until January 15 did Spirit's remote controllers manage to get all six of its wheels rolling on Martian soil. Anyone on the scene on January 3 could have just lifted the airbags out of the way and given Spirit a little shove.

The drive to explore may be hardwired, lying deep within the behavioral identity of the human species.

Let's assume, then, that we can agree on a few things: People notice the unexpected, react to unforeseen circumstances, and solve problems in ways that robots cannot. Robots are cheap to send into space, but can make only a preprogrammed analysis. Cost and scientific results, however, are not the only relevant issues. There's also the question of exploration.

The first troglodytes to cross the valley or climb the mountain ventured forth from the family cave not because they wanted to make a scientific discovery but because something unknown lay beyond the horizon. Perhaps they sought more food, better shelter, or a more promising way of life. In any case, they felt compelled to explore. The drive to explore may be hardwired, lying deep within the behavioral identity of the human species. To send a person to Mars who can look under the rocks or find out what's down in the valley is the natural extension of what ordinary people have always done on Earth.

Many of my colleagues assert that plenty of science can be done without putting people in space. But if they are between forty and sixty years old, and you ask what inspired them to become scientists, nearly every one (at least in my experience) will cite the high-profile Apollo program. It took place when they were young, and it's what got them excited. It's that simple. In contrast, even if they also mention the launch of *Sputnik I*, which gave birth to the space era, very few of those scientists credit their interest to the numerous other unmanned satellites and space probes launched by both the United States and the Soviet Union shortly thereafter.

So if you're a first-rate scientist drawn to the space program because you'd initially been inspired by astronauts rocketing into the great beyond,

(Continued on page 70)

Distinctive Destinations

FROM THE MOORS OF SCOTLAND
TO THE BEACHES OF BERMUDA:
FAR-FLUNG AND NEARBY DESTINATIONS
FOR NATURE LOVERS

Bermuda

Bermuda, a 21-square-mile subtropical paradise, is known for its pink-hued beaches and turquoise waters, pastel cottages and pristine gardens, and British propriety. The Island offers splendid golf courses (most with an ocean view) that attract top golfers from around the world and terrific tennis. It is a great place to learn to scuba dive or simply snorkel, with consistently warm water, delicate coral reefs, fascinating underwater caves, and the remains of over 300 shipwrecks waiting to be explored. It also has some of the best boating and sailing the world can offer. For naturalists, Bermuda is lush and alive with natural splendor. It has over 4,500 marine organisms and over 350 bird species, and you can swim with fishes of all colors, shapes, and sizes.

The Island's stunning caves, which many say inspired Shakespeare's "The Tempest," are full of amber-colored stalactites and clear, crystalline pools. Don't miss the Crystal Caves, where a pontoon bridge takes you over the underground Cahow Lake, whose crystal clear depth is 55 feet, and a path walks you through a labyrinth of stalagmites.

The *Fall into Spring* brochure, available at www.bermudatourism.com, lists daily activities on the island, most of them free, ranging from a high tea at the Royal Naval Dockyard–featuring scones with clotted cream, traditional rum cake, banana bread, and entertainment by steel pans–to a Botanical Beach Walk along the shoreline in Warwick. This interpretive walk will show you the unique adaptations of Bermuda's shore plants to their subtropical environment.

With accommodations ranging from luxury resorts to cottages and inns, it's no wonder so many travelers to Bermuda are repeat visitors.

Top: Bicycling through an isolated path; left: Golfing by the ocean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BERMUDA

West Virginia

photos: David Fattaleh/WV Tourism

Left: Seneca Rocks; above: A fishing expedition

Almost 80 percent of the Mountain State is forested, with over a million acres of state parks, forests, or wildlife management areas full of spectacular mountains, swirling rivers, and scenic countryside. In Wild and Wonderful West Virginia, nature is always nearby.

West Virginia has the best whitewater rafting outside of Colorado, whether you're looking for challenging, thunderous rapids or just beginning to get your feet wet. Sign up for a river adventure at www.wvwhitewater.com, which offers a range of trips, including tubing, canoeing, and a raft ride on the New River Gorge. followed by a climb up Seneca Rocks.

West Virginia is a rock climber's paradise, with many outfitters offering lessons and expeditions to the state's most popular climbs. From atop the 1,000-foot sandstone face of Seneca Rocks, enjoy a breathtaking view of the Potomac Highlands. For more information about climbing opportunities in West Virginia, contact the New River Gorge National River at 304-465-0508, the Seneca Rocks Visitors Center at 304-567-2827, or 1-800-CALL WVA. While in the area, stop by Seneca Caverns, West Virginia's largest caverns, which are 2,500 feet above sea level and, 165 feet below the surface.

The Mountain State is also an ideal destination for fishing. It has an extensive trout-stocking program, allowing year-round trout fishing, and some of the best fly-fishing in the east.

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Above: Whale-watching, Bay of Fundy; left: Irving Eco-Centre, La Dune de Bouctouche

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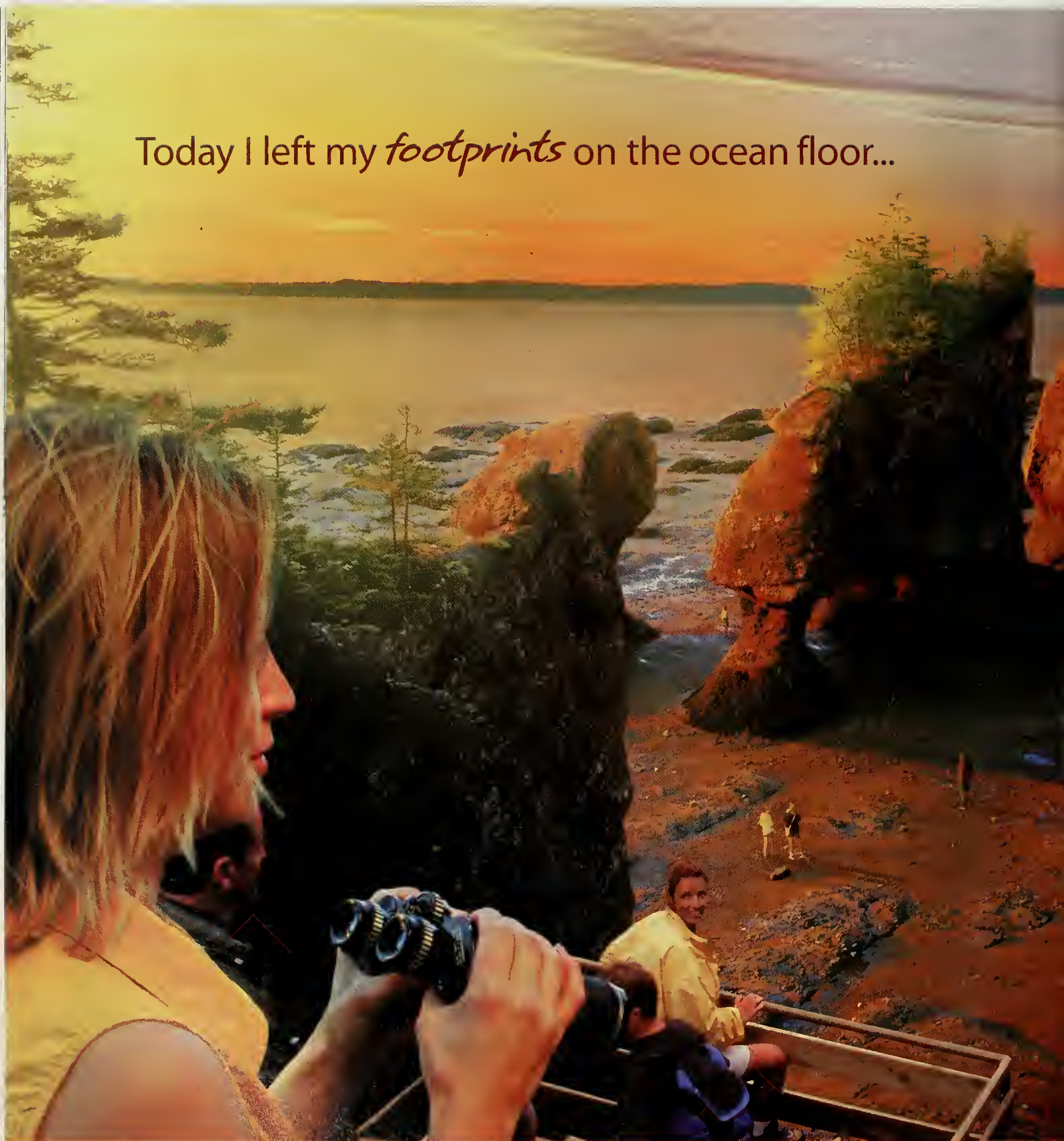

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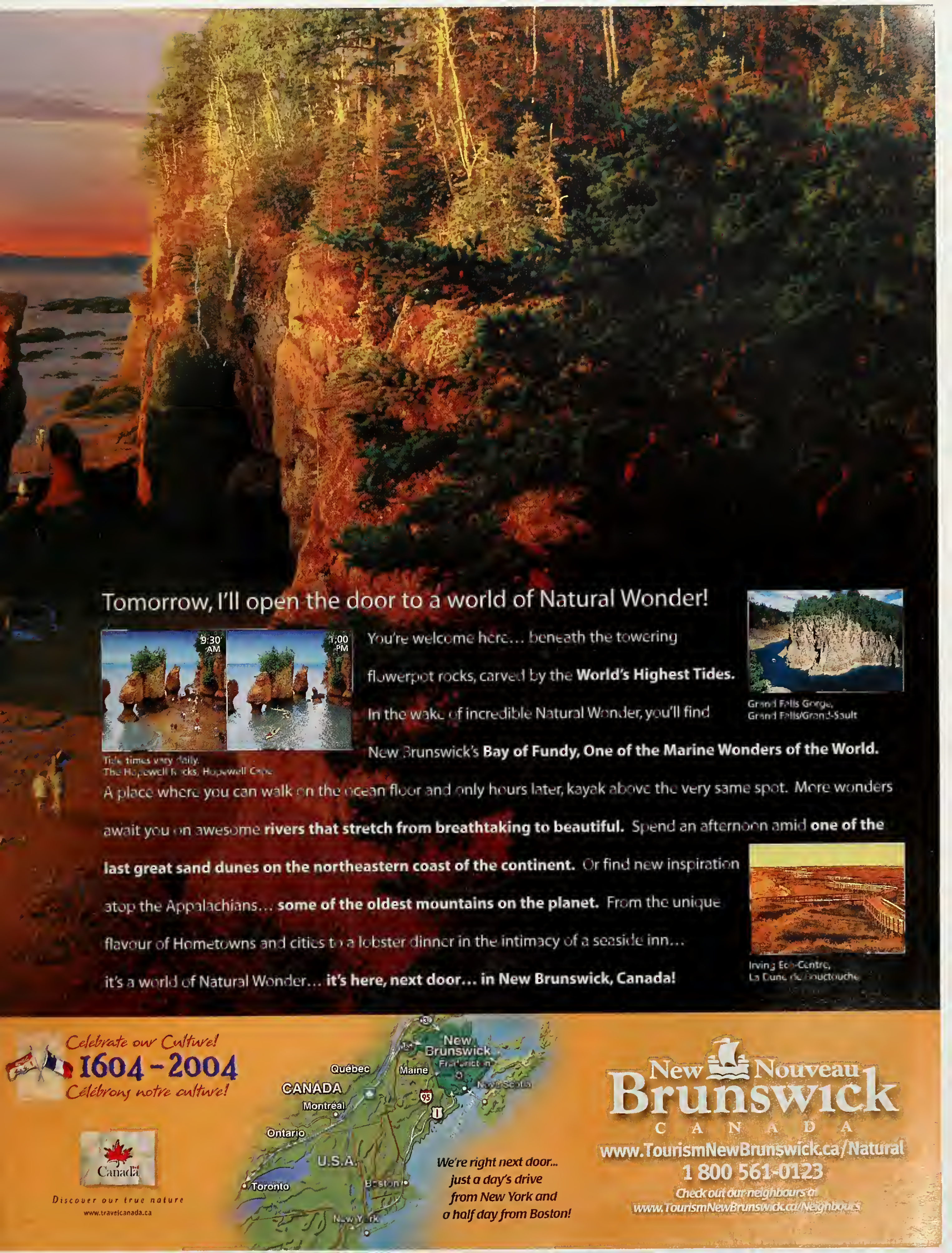
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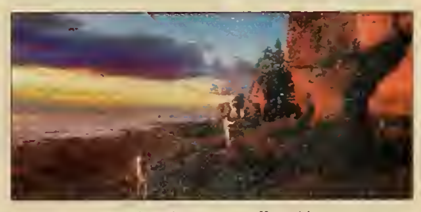

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Little St. Simons Island

Above: The pool, a tranquil oasis; below: The Hunting Lodge at twilight

Little St. Simons Island—a privately owned, 10,000-acre barrier island off the Georgia coast—is a rich and varied natural world. Since the early 1900s, the island's owners have welcomed guests to its unspoiled beaches, maritime forests, beautiful marshes, and meandering tidal creeks. Learn about the island's natural history by way of guided interpretive programs, boating, canoeing, hiking, biking, birding excursions, angling, saltwater flyfishing, and horseback riding.

Between activities, enjoy delicious meals, perhaps an oyster roast during the cocktail hour on the front lawn of the historic lodge. Hundred-year-old live oaks, draped with tendrils of Spanish moss, provide a natural canopy here. Dinners are often served fireside in the Hunting Lodge, where guests may muse over island photographs dating back to the early 1900s.

Scotland

P. Tomkins/Visit Scotland/Scottish Viewpoint

Castle Stalker, Argyll, built for James IV in the fifteenth century

This summer, why not visit the world's largest annual festival of the arts, the Edinburgh International Festival? Now in its fifty-fifth year, the festival showcases innovative performing arts for three weeks every summer, attracting thousands of visitors and international stars to Scotland's capital city. From Edinburgh, head north through rolling farmlands to the dramatic scenery of the Highlands. Here, amid mountains, lochs, and moors, visit ancient castles and explore the rugged seacoasts of beautiful towns such as Mallaig.

Just north of Edinburgh, visit the international home of golf, St. Andrews, an old university town with five 18-hole courses. Near Aberdeen, follow the "Malt Whisky Trail," featuring seven local distilleries, or the Castle Trail along the River Dee, a great spot for salmon fishing.

VisitBritain, the official national tourist office for the UK, hosts a website (www.visitbritain.com) geared to Americans traveling to Britain, with hundreds of special offers, deals, and discounts. You can even take a "virtual vacation" of Scotland before you go, to help plan your real one.

Deilmann Cruises

Cruises originating from Gdansk sail on Poland's Vistula River

From late March through early November, Peter Deilmann Cruises will offer more than 320 European river cruises on 10 deluxe ships operating on the Danube, Rhine, Moselle, Rhone, Saone, Po, Elbe, Vistula, and other rivers.

New for 2004 is the 108-passenger, five-star MV *Heidelberg*, which made its debut cruise on the Rhine in March. On the same day, the five-star *Frederic Chopin*, a 79-passenger vessel, inaugurated its cruises on Poland's Vistula River. Cruises originate in both Gdansk and Warsaw, and will also sail roundtrip from Gdansk in the summer months. Shore excursions include visits to the thirteenth-century Malbrok Castle, the largest fortification in Europe; the Gothic town of Torun, birthplace of Copernicus; and the historic Russian town of Kaliningrad. Seven-night cruises on the *Frederic Chopin* also visit Chopin's birthplace in Warsaw.

Deilmann is known for its luxury river ships—which resemble small floating hotels—and its low passenger-to-crew ratio of 2.5 to 1, ensuring the highest level of onboard service.

Summer Adventures

Top: Pacific Delight travels to Budapest; below: Norwegian landscape

Pacific Delight Tours has expanded its vacation offerings to the South Pacific, Europe, South America, and Africa. Its new itineraries include voyages of discovery to Scandinavia, the Baltic Sea, Iberia, the Mediterranean, and South America. Spend summer in the Baltics, traveling on a deluxe, floating "country house" ship with elegant style and modern amenities. The eighteen-day cruise, accompanied by distinguished guest speakers, includes stops in Stockholm, Helsinki, St. Petersburg, and Copenhagen. Pacific Delight also offers an eighteen-day "Viking Adventure," which travels from Copenhagen, along Norway's spectacular fjords, to the North Cape. The cruise features specialists in natural history, ornithology, archeology, and the rich history of the Northlands to enrich your experience of the people, plants, and animals of the region.

Summer—when the nights are as bright as day—is the perfect time to visit Norway. The Land of the Midnight Sun is wild and beautiful, with magnificent fjords, majestic mountains, and dramatic landscapes. The bustling capital city of Oslo has fascinating museums, waterfront restaurants and dockside pubs, and an abundance of outdoor recreational opportunities. Bergen, founded in 1070, still retains its historic charm, particularly around its colorful harbor. And of course, no trip to Norway would be complete without a visit to the fjords. Rent a small boat, or join an expedition to discover the Lysefjord, Hardangerfjord, Sognefjord, or Geirangerfjord, carved by glaciers during the ice ages. Some fjord trips can be done in less than an hour, but others last a day or more, and take you to places that you would otherwise never experience.

FIELD NOTES

Mud's Eye View

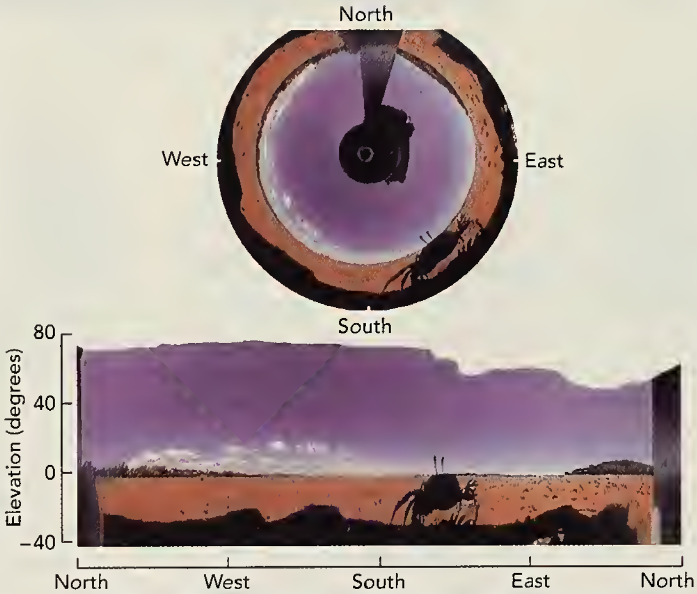
To understand the world of the fiddler crab, ecologists peer through a lens that renders a landscape as a doughnut-shaped panorama.

By Douglas Fox

As I stood on a coastal mudflat in northeastern Australia, the morning sun glistened off the wave-rippled surface of the muck. To the west, I was the only vertical feature for a quarter mile; to the east, the flatness reached clear to the horizon. All around me, hundreds of spidery fiddler crabs, of the genus *Uca,* milled about on the mud; as they ate their soggy porridge—quite literally, the mud—their faint, wet squelching noises registered just above the threshold of my hearing. The army of arthropods slurped bits of organic material out of the muck, then ejected balls of it like so many wads of chewing tobacco.

Welcome to Crabworld. To my eyes, the place looked mind-numbingly monotonous. But the crabs weren't seeing what I was. Crabworld, it turns out, isn't where you are; it's what you see. That little secret was my first lesson in a burgeoning discipline called visual ecology. Under the expert tutelage of Jochen Zeil and Jan Hemmi, two visual biologists at the Australian National University (ANU) in Canberra, I learned that the guiding principle of the discipline is to minimize—to eliminate, if possible—the biased guesses about animal behavior that human vision introduces. Instead, say the visual ecologists, begin with the ways the animals' own visual systems render the world.

That might sound like a straightforward call to study the anatomy and physiology of animals' eyes in the laboratory. But to understand how an animal behaves, Zeil says, you also need to study what the animal perceives in the environment to which it has adapted, and how in analyzes that information. Of course, some animals are easier to study than others. The fiddler crab, with its simple nervous system, its pancake-flat world, and its limited home range, makes a great place to start.



"Crabworld," the world as it appears to the fiddler crab, is simulated in the circular image at the top by a panoramic viewing device. The crab's compound eyes are roughly hemispherical in shape, and so the crab sees all around as well as overhead. Objects in the near foreground, including another crab nearby, appear at the outside of the circular image; the sky fills the entire center of the image, except for what is occupied by the viewing device itself. Just below the circular image is a digitally manipulated version of the same image, projected onto a more familiar-looking rectangular format. Notice, however, that to ordinary human vision the top of the rectangular image would appear nearly overhead, and that the left and right sides of the rectangle correspond to the same part of Crabworld. The reason for the apparent tear in the rectangular image is that the arm of the viewing device has been removed from the scene.

At least to a human being, Crabworld is bizarrely shaped. A fiddler crab's eyes are mounted on stalks that point straight up, and they command a panoramic, 360-degree view. The mudflat comprises the entire outer edge of the visual field, and the arching sky dominates the middle [*see image at left*].

Unlike human vision, the crab's vision is sharpest around the edges. That's a reasonable emphasis. After all, the outer edge is where other members of the species are scuttling about: both rival animals looking to steal one's precious burrow, and females in the market for a mate. But in the great round center of the crab's visual field there is nothing but sky—and the occasional bird swooping in for cold crabmeat cocktail. A crab in such precarious circumstances doesn't need to see its would-be predator in detail; all it has to do is sense the movement overhead, then scurry for safety in its burrow.

Ever since my first conversation with Zeil several years ago, I had wanted to experience first hand the convoluted, crab's-eye view of the world. And so one morning I wandered onto the mudflat, found a crab colony, and lay down in the mud. Viewed down low, Crabworld was trickier to deal with than it had seemed at first. For one thing, the mud is imprinted with wavy bumps, or corrugations, the marks left by the water at high tide. The bumps pose a navigation problem to the crab: as soon as the animal gets more than six inches from its burrow, they obscure its view of home. Yet the animals still venture as far as a yard away from the safety of their precious mud-holes.

Furthermore, down at crab height, the entire mudflat is compressed into a narrow horizontal band. In every direction the band bustles with a dozen scuttling crabs—some twelve inches away, others twelve feet. For me it was hard to tell the difference. But for a fiddler crab, the distance to each of the other crabs, relative to itself and to its burrow, is a fundamental piece of information.

Of course, my efforts at seeing crab-style were deeply flawed; I was relying on human vision to explore another creature's world. With few exceptions, no two species share the same visual system. Vision can vary in pigment sensitivity: The eyes of some species of mantis shrimps can respond to sixteen distinct wavelengths of light, giving them an unmatched ability to distinguish colors, whereas human vision is skewed toward red and green.

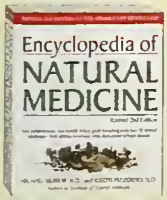
Vision can also vary in the maximum rate at which retinal cells can fire in response to light (the "flicker fusion point," at which a blinking light no longer seems to blink). Most people can't detect more than about sixty blinks a second. A fluorescent light, for instance, actually blinks on and off sixty times a second, but most people perceive the light as continuous. For dogs, though, the maximum detectable blink rate is closer to eighty blinks a second, and so fluorescent bulbs might prove a lot more irksome to dogs than they do to some people: a dog may actually see the flickering.

Fierce-looking, bright-colored claw of the male fiddler crab might make one think it is a terrible scourge of small animal life. It is not; the large claw is a product of sexual selection used in courtship displays. The claw in the photograph is roughly an inch long. The two protruding, vertical budlike organs above the claw are eyestalks; at the end of each eyestalk is a hemispherical compound eye.

Other features of human vision further complicate a visit to Crabworld. "Our vision doesn't sample the world like a video camera," Zeil points out. The highest resolving power for people is focused on a minute bit of retina, and so we have to move our eyes to scrutinize things.

In spite of being hopelessly human themselves, Hemmi and Zeil go to great lengths to put themselves in a crab's place. They have videotaped colonies with a special "crab camera" that captures the crab's sky-centered, "doughnut view" of the world. The camera was based on one originally built for self-navigating robots that are being developed by Mandyam Srinivasan and Javaan Chahl, both electrical engineers at ANU. Zeil has digitally massaged the images from the camera to reflect the crab's spatial resolution and color discrimination, and he's processed video clips through motion-detecting software to measure the movements a crab would see. Intriguingly, the motion-detecting software is biologically inspired; it's based on the way insects and other creatures with compound eyes are thought to sense motion. The software treats each pixel of the image as though it were a facet in a compound eye, and then looks for the signature of movement: a change in brightness registered at one pixel or facet, followed by a similar change in brightness at its neighbor, at its neighbor's neighbor, and so on.

Such pixel-processing software makes perfect sense for studying crab vision. Fiddler crabs, like their arthropod cousins the insects, have compound eyes. At the end of each eyestalk are some 10,000 ommatidia, or little eyes. Because the crab's compound eyes cap each eyestalk like a thimble on the end of a finger, most of the ommatidia are actually on the shaft of the eyestalk,



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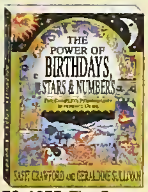

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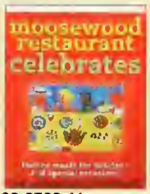

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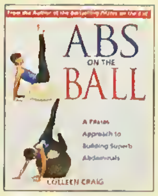

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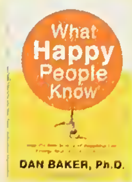

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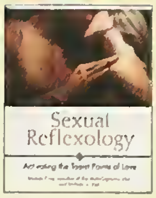

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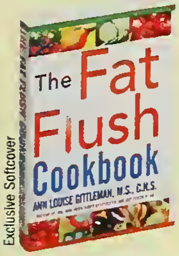

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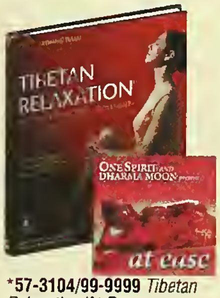

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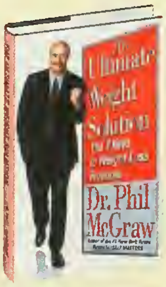

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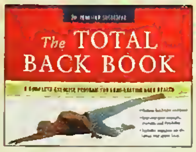

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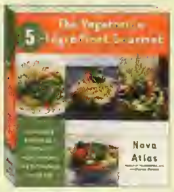

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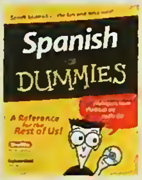

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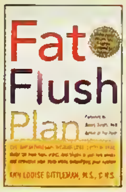

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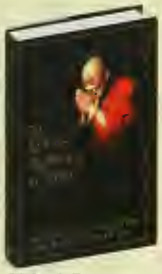

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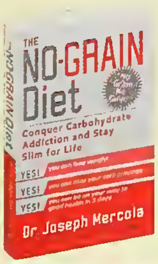

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and are aimed more or less horizontally. That simple geometry explains why the crab's vision is sharpest around the horizon. Even at its sharpest, though, a crab can resolve objects in its visual field only 2 percent as well as a person can. With such a low level of visual acuity, a crab must be seeing its fellows as indistinct lumps on the mud. Crab shells, however, also reflect ultraviolet light, which the animals can probably detect. Hence, even though to people the crabs look drab and blend into the mud, to other crabs they stand out like glowing lightbulbs.

Ultraviolet light notwithstanding, movement in the crab's visual field is probably the animal's main visual cue. In any event, that's about all the information the animal really needs, because natural selection has pared down the crab's world into two simple categories. "Everything in the sky is a predator," says Zeil, "and everything below the horizon is another crab." So if you drag a cylindrical dummy over the mud, the crabs treat the dummy as another crab—they either fight it, ignore it, or in some cases try to court it. But if you toss the cylinder over the colony, the animals make a beeline for their burrows.

In at least one Central American fiddler crab species, *U. musica,* the male exploits that visual shortcut to trap a mate. Females often wander several yards from their burrows. According to John Christy, a biologist at the Smithsonian Tropical Research Institute in Balboa, Panama, a male seeking to mate will, with his large claw held high, charge a female that has wandered near his burrow. "She sees an object above the horizon racing towards her," says Christy. A signal registers in the female crab's brain: it's a bird! So the frightened female bolts into the closest burrow available—the wily male's—and he follows in behind her.

A crab's most precious resource is its burrow. That's where the animal hunkers down at high tide, hides from birds, mates. And other crabs that leave the safety of their own burrows in search of a larger or better-positioned burrow are often the biggest threat. Any time one crab ventures even a few crabsteps from its burrow to slurp some mud, other crabs are constantly trying to steal its burrow, forcing it to dart back time and time again to defend its home.

In a strong sense, then, a fiddler crab's frame of reference—the equator and prime meridian of its entire world—is centered on its burrow. Because Crabworld's muddy surface is corrugated, however, the burrow is often out of view. Yet, despite the seeming difficulty of the task, the fiddlers manage to keep track of home.

According to John E. Layne, a visual ecologist at Cornell University in Ithaca, New York, fiddler crabs don't rely on landmarks or even use their eyes at all. Instead, they rely on an instinctive application of high school mathematics. "They measure how many steps they take, and the direction of those steps. So every time they take a step, they instantaneously recompute the position of the burrow." In fact, Layne concludes, they're actually whizzes at this kind of trigonometry problem. In spite of their meandering, they always know which direction to run, and how far, to reach their burrow in a straight line.

Zeil gave me a convincing demonstration of the method of triangulation that's apparently hardwired in the crab. He hid a square of sandpaper under the mud, and waited until a crab wandered onto it. Taking care not to frighten the crab, he gently dragged both sandpaper and crab about ten inches to the right of the crab's burrow. Then he intentionally startled the repositioned crab. It retreated instantly—not to its burrow, but to a position ten inches to the right of it.

Layne devised a demonstration just as clever. Working at a field site in Trinidad, he surreptitiously maneuvered a "crab treadmill" between crabs and their burrow; the treadmill is essentially a patch of plastic on which the crabs' feet slip, so that each crabstep is shorter than it normally is. When Layne frightened the crabs into making a retreat over the treadmill, they stopped short of home. The finding suggests that the animals really do count steps.

There is even more to the fiddler crabs' trigonometric prowess. A crab can accurately measure the distance between its burrow and other crabs on a mudflat—even when it can't see its burrow, and even when the other crabs, all potential burrow-snatchers, might approach from any direction. Back in Australia, Hemmi showed me how.

On the mudflat wasteland he set up a video camera mounted on a tripod. Below it was a neighborhood of five crab burrows. Strung through this little crab subdivision were two fishing lines, threaded through a system of pulleys. By tugging on the threads, Hemmi and

I, seated twenty feet away, could move a dummy "crab" back and forth across the ground near the burrows.

Analyzing data from hundreds of such maneuvers, Hemmi has shown how a fiddler seems to measure the distance between its burrow and a dummy. As Hemmi manipulated the dummy, a crab would consistently rush back to its burrow whenever the "invader" came within about ten to twelve inches of the burrow. The same result held no matter what the angles between the dummy, the burrow, and the resident crab—and no matter how far the resident crab was from its burrow. Apparently, the crab that owns the burrow treats a circular area around its burrow, with a radius of roughly ten to twelve inches, as inviolate; if an invading crab crosses into that circle, the home crab will retreat to its burrow, even if it is closer to the burrow than the invading crab is.

A crab measures its own distance from objects such as other crabs according to how high they appear in its visual field. (People use the same trick.) In a world that is almost perfectly flat, far-off objects look high, close to the horizon, whereas nearby objects appear relatively low in the visual field. The crab knows how far away its home is because it has been counting steps and keeping track of its direction, and is constantly refiguring the distance to its burrow. That information, plus the height and direction of any potential arthropod invader, would be enough to triangulate the distance between the potential invader and the burrow.

Of course no fiddler crab has the brainpower to understand triangulation and trigonometry. So how does a crab combine visual and odometric, or travel-distance, information in its brain to determine whether an intruder has entered the forbidden zone around its burrow? How, in other words, does it solve what is essentially a trigonometric problem without knowing how to do the trig?

Zeil and Hemmi think the crab has a shortcut hardwired into its brain. As a crab moves about the mudflat, it keeps the same side of its body pointed toward its burrow. That way, even when the burrow is invisible, it remains in the same region of the animal's visual field. The cluster of ommatidia that point toward the crab's burrow and the surrounding forbidden zone could then be wired up so that whenever those ommatidia detect movement, the crab races back to defend its burrow. There is one complicating factor: As the crab moves about, and as its distance from the borrow grows or diminishes, the forbidden zone becomes smaller or larger in the crab's visual field. Evolution could have solved that problem by wiring the crab's eye to its odometer: then, as the crab walked toward or away from its burrow, the cluster of intruder-detecting ommatidia in its eye would automatically grow or shrink.

To reinforce his point, Hemmi performed the initial run of an experiment on the crabs while I watched. Pulling a fishing line, he raised the dummy half an inch higher, and then passed it through the crab subdivision again. We watched a male that had consistently rushed to defend its burrow from the dummy on previous runs. But even when the raised dummy came within just three inches of the crab's burrow, the crab didn't respond.

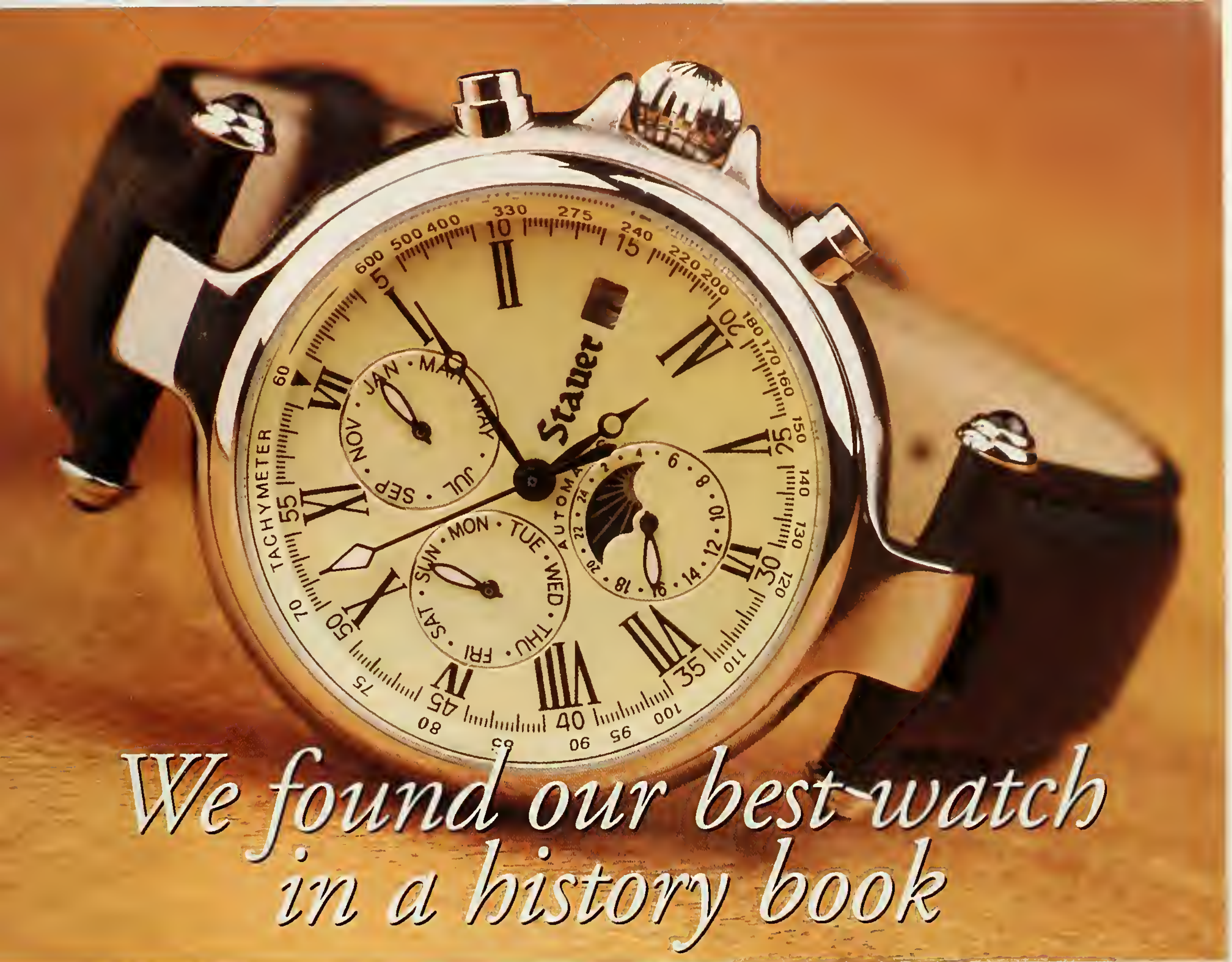
Hemmi was not at all surprised. A dummy raised above the ground, after all, appears closer to the crab's visual horizon; for the crab, that means it's farther away and less threatening. Of course, this run was still just the first test of the hypothesis. Other factors might have led to the same result: maybe the crab was distracted by a particularly delectable glob of mud. To justify his interpretation, Hemmi will need to analyze hundreds of runs with many different crabs. If he's correct, though, the crab's behavior is a potent indicator of how simple it can be to do trigonometry without the services of a mammalian brain.

Corrugations on fiddler crabs' native mudflats limit the animals' ability to see their burrows. Crabs depend on their burrows to protect them from high tides and predators, and the burrows are under constant threat of invasion by other crabs. Each crab (such as the female, background, and the male, foreground) keeps track of its own burrow during foraging excursions by counting steps and keeping track of direction.

As Hemmi and I fell silent beneath the vertical noon sun, the miniature dramas of Crabworld unfolded before us. There was chasing, eating, fighting, and mating, as well as vigilant watching and waiting. Each crab spied the world 360 degrees around for any threat, opportunity, or momentary advantage over its neighbor.

This flat cityscape in the mud, this crowded, competitive space, is their domain. For Hemmi and I, who stare down on it like gods from Mount Olympus, it's a difficult world to understand. But once we see it, at last, through the crabs' eyes, we have a much better chance of understanding what makes these little creatures tick.

Douglas Fox is a freelance science writer based in San Francisco. His work has also appeared in New Scientist, Discover, Scientific American, *and* U.S. News and World Report.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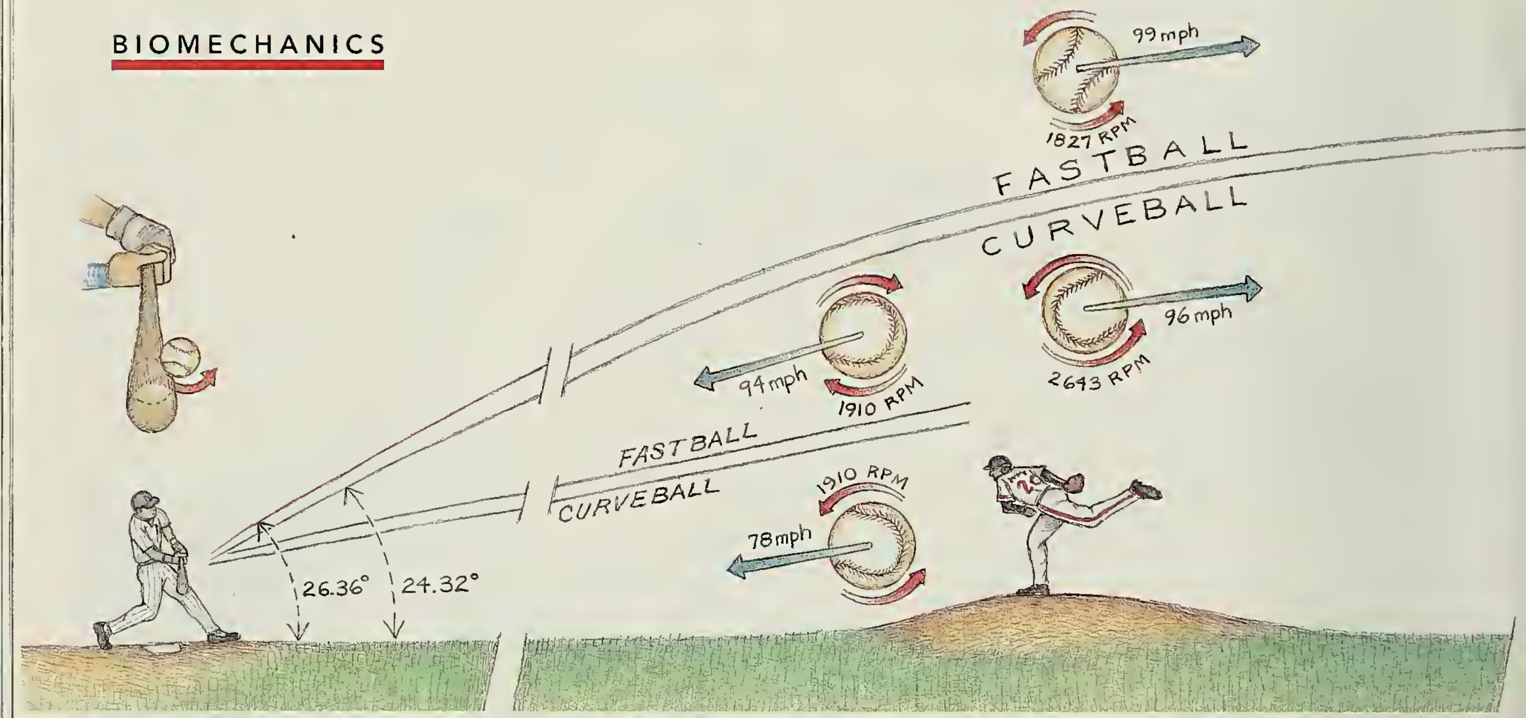


A Fly in the Curveball

As the 103rd Major League baseball season opens, physicists have now shown that a well-hit curveball trumps a well-hit fastball. Pitchers must be so scared.

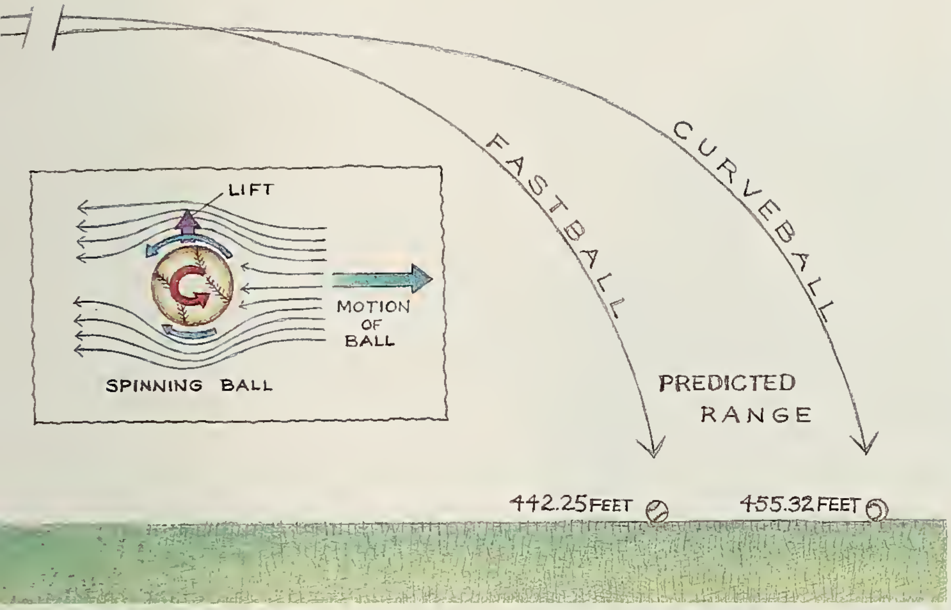
By Adam Summers ~ Illustration by Patricia J. Wynne

There is a morbid fascination in watching a Little League pitcher who develops a good curveball at a tender age; more than one talented young fastball hitter has switched to basketball after facing that aerodynamic phenomenon, which can turn the most powerful swing into physical comedy. Some youngsters find the rhythm of this evasive pitch and learn to hit it with the same authority as they do a fastball. But for most batters (even at the highest levels of competition) the curve is a devil to hit—not quite as bad as trying to swat a flying mosquito with a toothpick, but almost.

Conventional baseball wisdom has long held that even if the bat does meet the curveball, the batter is still at a disadvantage; many observers maintain that even if a batter manages to crush both curveball and fastball with equal force on the sweet spot of the bat, the curveball won't sail as far as the fastball. But that clubhouse conviction has now fallen victim to a careful analysis of the physics of pitched baseballs. It turns out that good wood on a slow curve will carry the ball deeper into the cheap seats than it will Roger Clemens's best fastball.

As a boy I never got beyond the "keep your eye on the ball" stage of hitting, which led to a pretty abbreviated career in organized baseball. But now that engineers Gregory S. Sawicki of the University of Michigan in Ann Arbor, Mont Hubbard of the University of California, Davis, and William J. Stronge of the University of Cambridge have shown what it takes to accomplish the task, I don't feel so bad about my early retirement. To get the job done in the batter's box, they show, "all" the batter has to do is integrate at least fifteen variables and constants that define several physical characteristics of the bat, the ball, the atmosphere, and the world at large.

Hubbard and his colleagues have built a computerized model that gives a fascinating account of the dynamic between pitcher and batter. Standing just sixty-six feet, six inches away from home plate, the pitcher delivers a ball that may move at more than ninety miles an hour and spin at more



Physics of an optimally batted ball shows that the longest home runs should come off curveball pitches. When a ball with backspin moves through air (see inset), the air just above the ball moves faster than the air just below it. The pressure of the faster-moving air is necessarily lower, and the differential creates an upward lift. A seventy-eight-mile-an-hour curveball and a ninety-four-mile-an-hour fastball are each thrown to spin at 1,910 revolutions per minute, the curveball with topspin, the fastball with backspin. When a batter hits each ball for maximum distance, just under its center of mass, the ball gains backspin as it leaves the bat. But the collision augments the spin of the curveball, whereas it reverses the spin of the fastball. Thus the curveball, with more backspin, has the greater lift once it leaves the bat, and despite its lower speed, it flies several yards farther than the fastball.

than 1,900 revolutions per minute.

Of course, different pitches arrive at wildly different speeds and spins. A fastball can cross the plate in excess of a hundred miles an hour; expert pitchers can throw one with a backspin that exceeds 1,800 revolutions per minute. (In backspin, the top of the ball spins away from the direction the ball is traveling.) The curveball, by contrast, travels toward the batter at a far more sedate seventy miles an hour, but it can have topspin (the reverse of backspin) that exceeds 1,900 revolutions per minute.

The reason a curveball curves is that its spin drags a layer of air across one surface of the ball faster than it does across the opposite surface [*see illustration above*]. Where air moves faster, its density is lower, and the difference in the density of the air surrounding the spinning ball pushes, or "lifts," the ball toward the lower-density air. Thus the backspin on a fastball causes the air on top of the ball to move faster and the air on the bottom to move slower; the net effect is to push the ball up. The topspin on a curveball pushes the ball down.

Of course, the faster a ball moves, the greater its kinetic energy: a fast fastball brings more energy to the collision between bat and ball than a slower fastball does, and so the well-hit fast fastball travels farther. A swing that sends a fifty-five-mile-an-hour fastball 410 feet would smack an eighty-five-mile-an-hour burner an extra thirty feet. Similarly, higher bat speed yields better distance. An extra mile an hour in bat speed translates to an extra seven and a half feet on the ground.

But the usual difference in speed between fastball and curveball pitches still doesn't mean that batters should hit fastballs farther than curveballs. The real keys to distance are two related variables: the spin of the hit ball and the undercut of the bat. When the bat hits the ball, the spin of the ball changes dramatically. Its final spin velocity depends on its initial speed and spin, the speed of the bat, and the undercut, which is the vertical distance between the centers of mass of the bat and the ball.

Undercut has a big effect on the ball's spin, and thus on the distance the batted ball travels. With a level swing, a ninety-four-mile-an-hour fastball hit with a half-inch undercut scarcely spins at all, and travels only about 160 feet. Increasing the undercut to roughly an inch, though, increases the spin to 1,800 revolutions per minute and sends the ball 390 feet. Curiously, swing angle has a much smaller effect on flight distance than undercut distance has. If the undercut is correct, even swinging slightly down on the ball will send it 390 feet. That's often long enough for a home run.

Perhaps the most counterintuitive result of the engineers' model is that an optimally hit seventy-eight-mile-an-hour curveball travels about 455 feet. In contrast, the same hit off a ninety-four-mile-an-hour fastball carries 442 feet, thirteen feet less. Spin makes all the difference. The initial backspin of the fastball is abruptly reversed by the undercut of the bat, whereas the initial topspin of the curveball is augmented by the bat. The net result is that the batted curveball spins some 800 revolutions per minute faster than the batted fastball, and that extra spin provides a bit more lift as the curveball sails out of the park.

So even if some precocious master of the curveball manages to make most of his opponents look bad, he'd better be careful. A pitcher never knows when the next player with the great eyes of Ted Williams will show up to demonstrate what a curveball hitter can really do.

Adam Summers (asummers@uci.edu) *is an assistant professor of ecology and evolutionary biology at the University of California, Irvine.*

NATURAL HISTORY
APRIL 2004

Supercrop

The yam bean, a tuber undaunted by drought, poor soil, or insects, produces astonishing yields. The crop is the focus of a worldwide effort to unlock its potential.

By Marten Sørensen

If you have ever sampled the menu at restaurants that offer such showstoppers as salmon encrusted with black sesame seeds, or breast of chicken in mango-ginger sauce, or mesclun salad with pear slices and Gorgonzola, there's a good chance you have come face to flesh with the ingloriously named yam bean. If you're a fan of Malaysian or Thai cuisine, there's an even better chance you've eaten it. How ironic, then, that although you've probably (albeit unknowingly) enjoyed at least one species of yam bean—the jicama—and although your local supermarket may well have these large, pale beige, flaky skinned, vaguely turnip-shaped tubers in stock, you've probably walked right past the small mound of them without giving them a second thought.

But if there is anything at all rational about the future consumption of food crops (a big "if"), the yam bean could become the hottest food item of the year. Few people realize what a treat they'd have in store if they merely took one home from the grocery, peeled it, cut it into slivers, and just crunched into it raw.

The yam bean (a name subsuming various members of the genus *Pachyrhizus*) is one of the most adaptable, low-maintenance, nutritious foods ever to grow in soil. Its agricultural properties, moreover, are well established: yam beans, indigenous to the tropical regions of the Western Hemisphere, have been grown there since well before the arrival of Columbus. The plant yields abundantly, produces well even in dry spells, does not need nitrogen fertilizers or good-quality soil, and resists pests and diseases. The harvest keeps well for months. Like the potato, the yam bean is a tuber—a fleshy subterranean stem. Like the bean and the pea, however, it is also a legume—generously endowed with proteins. And as a legume, its root nodules harbor symbiotic colonies of nitrogen-fixing bacteria: under good growing conditions, a season's crop of yam beans can release as much as fifty-three tons of usable nitrogen per acre into the soil.

Although the tuber is delicious eaten raw, there's also a truly dazzling variety of ways to prepare and consume the various species and cultivars of *Pachyrhizus:* as flour, juice, soup, tortillas, baby food, or moonshine; as a component of salad, a fruit, a stewed vegetable, or a preserved sweet; grated, sliced, squeezed, cooked, toasted, soaked, fried, dried, pickled, fermented, candied, mixed with milk in a porridge, or sprinkled with lime juice and chili powder as a street snack. With a bit of processing, every part of the plant becomes edible: the tubers, both young and mature; the seed pods, both young and mature, but always cooked; the oil from the pressed seeds; the leaves, as animal fodder. *Pachyrhizus* seeds also produce their own insecticide—which of course must be extracted before their oil can be used for cooking.

Yet despite the economic, environmental, and nutritional virtues of the yam bean, it is practically unknown in much of the West. In 1985, with support from the European Community's Science and Technology for Developing Countries program and the Danish Research Council for Development Research, I set up the Yam Bean Project. The aim of the project is to explore the plant's breeding and cultivation, as well as the potential for introducing it into new regions of the world. After all, out of some 6,000 cultivated species of plants, only a small fraction—perhaps nine or ten, such as the most commonly grown species of the cereals rice, wheat, maize, and millet; beans, especially soybeans; and several tuber and root crops, including potatoes, sweet potatoes, manioc, and taro—constitute the backbone of our planet's agriculture. Yet many less frequently cultivated species are well adapted to inhospitable growing conditions, and many crops that are nearly unknown globally may be—or may in earlier centuries have been—national or regional staples. The yam bean, tuber extraordinaire, is one such crop.

Of the three cultivated species of yam bean, the first to be scientifically recorded was the Mexican species *P. erosus.* That is the species commonly known as jicama (*jícama* in Spanish), and the one you've most likely tasted. It's also the species most widely grown today. The late-seventeenth-century English botanist Leonard Plukenet, gardener to the queen of England, depicted and described the jicama in his four-volume botanical catalog *Phytographia;* the eighteenth-century father of taxonomy, the Swedish botanist Carolus Linnaeus, relied on *Phytographia* for his pioneering *Species Plantarum* of 1753, a compilation of descriptions of roughly 6,000 plants from around the world, including *P. erosus.*

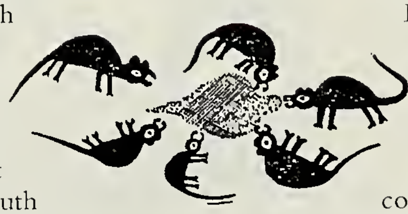
Archaeological evidence indicates that the jicama was grown by all the major early Mesoamerican civilizations, including the Olmec, Maya, Toltec, and Aztec. The Spanish introduced it to the Philippines in the sixteenth century; cultivation then spread to Southeast Asia, the Far East (including China), and the islands of the

Amazonian yam bean is pictured in this hand-colored illustration from an early nineteenth-century flora. The plant produces a nutritious and versatile tuber (lower right), which was cultivated in South America and the Caribbean for millennia before the arrival of Columbus. The image is from The Picturesque and Medicinal Flora of the Antilles, *by the French naturalist Michel Etienne Descourtilz, with illustrations by his son Jean-Théodore Descourtilz.*

Pacific. Because yam beans stay fresh without being refrigerated, they may have been eaten on extended sea voyages in subsequent centuries, and those voyages may help account for the plant's almost pantropical cultivation. In 1821, believing the jicama to be an East Asian crop, the French botanist and explorer Gustave Samuel Perrottet played a central role in spreading the species westward from Indonesia. He introduced jicama seeds to the islands of Mauritius and Réunion in the Indian Ocean, proceeded on to what is now Senegal, in West Africa, and finally planted jicama in French Guiana, on the north coast of South America. In so doing, he came close to reintroducing the yam bean to its homeland.

Mexican yam bean, or jicama, often eaten raw, was grown by the early civilizations of Mesoamerica and introduced into Southeast Asia in the sixteenth century by Spanish colonialists.

The Amazonian yam bean species, *P. tuberosus,* occurs as far north as Venezuela and as far south as Paraguay, but its history is more obscure than that of the Mexican species. Part of the reason for the obscurity is doubtless that the humid tropical lowlands of South America can be quite inhospitable to archaeological remains. But a combination of factors suggests that *P. tuberosus,* too, has a long history of domestication: The plant is widely distributed. It has a multitude of vernacular names (in various language groups), including *ashipa, chuín, iwa, jacatupé, jíquima, mbacucú, nupe, poi,* and *yushpe.* And in many rural areas it is still grown by indigenous peoples according to traditional cultivation practices, such as slash and burn.



Some ethnobotanists and anthropologists are convinced that root and tuber crops were among the first plants to be domesticated. After all, it is easy to imagine a transition from gathering roots in the local environment to cultivating them close to the family dwelling. In fact, the edible tubers of the Amazonian species of *Pachyrhizus* are thought to have been gathered in Peru before the advent of agriculture—that is, before 8500 B.C. And, as with other traditional root and tuber crops from South America that were later cultivated in the Caribbean, the presence of *P. tuberosus* in Cuba, Hispaniola, Jamaica, Puerto Rico, and Trinidad today suggests that the crop was introduced by Amerindians from northern South America, and thus points to a history of cultivation that predates Columbus.

The earliest European report on the cultivation of the Amazonian yam bean dates to the work of a mid-sixteenth century missionary, who describes how tribes living along the coastline of Brazil used the plant. Some four centuries later, two German-Brazilian investigators—the émigré botanist and chemist Theodor Peckolt and his son, Gustavo Peckolt—reported that it was cultivated as food for slaves on large estates. The long, thick tuberous roots, they noted, were dried and smoked, turning them into what the Peckolts called "vegetable sausage."

The third cultivated species, the Andean yam bean (*P. ahipa,* locally known as *ahipa* or *ajipa*), rarely occurs today outside Bolivia. But it, too, has a long history of pre-Columbian—indeed, pre-Inca—cultivation in the Andes. Dried ahipas were among the provisions buried with the dead two millennia ago on the south coast of Peru, accompanying the hundreds of lavishly wrapped mummies discovered beneath the arid sands of the Paracas Peninsula. The ahipa was also depicted on the embroidered cloaks, knitted textiles, and imaginatively sculpted and painted ceramics produced by such thriving pre-Columbian societies as the Nazca, the Moche, and the Chimú.

The various species and cultivars have found their way into a dizzying array of utilizations. In seventeenth-century China, diced yam beans were preserved in syrup and eaten as candy; during the same period in Mexico, the diced tuber was wrapped in sweet dough, then placed in syrup-filled jars and exported to Spain. Today Mexicans often put jicamas inside piñatas—the decorative papier-mâché containers that are filled with goodies and then smashed to pieces at festive occasions. Taiwanese fishermen often take jicamas with them on long expeditions, as nutritious and imperishable provisions. In the towns and villages of southern Bolivia—notably in Tarija—during the Corpus Christi celebrations in June, people sip fermented or unfermented fruit juices from vessels formed of hollowed-out ahipas ornamented with flowers. And thirsty Peruvian field laborers in the high, dry Andean forests, often finding themselves far from sources of freshwater, simply harvest, peel, and squeeze a yam bean to get a refreshing drink.

Of the three domesticated species of *Pachyrhizus,* the Amazonian species—*P. tuberosus*—boasts the most variations and the greatest array of culinary possibilities. Both the *cocotichuín* cultivar, which takes only four months to grow to full size, and the *ashipa* cultivar, which takes twelve months, are eaten raw as fruit or processed for their juice. A third cultivar, the *chuín,* has a much higher proportion of dry matter (starch, fiber, and protein) than do the other two. Chuíns are always eaten cooked, and people process them in numerous ways. In the valleys of the Marañón and Ucayali rivers of north-central Peru, for instance, chuíns are often turned into *farinha,* a toasted, homemade flour, and *almidón,* a sweet, sun-dried paste. Those preparations become the basis of toasted cakes, alcoholic drinks, and puddings (one kind of pudding is made from farinha mixed with raw tortoise eggs and sugar). Often those same products are made from manioc roots *(Manihot esculenta),* a common, though far less nourishing, staple food.

Besides being consumed as food, the yam bean has been used in numerous other ways in traditional societies: It serves as an aid to lactation in nursing mothers, as a digestive, and as an antipyretic. It is a key ingredient in remedies for respiratory and urinary-tract ailments. Fresh seeds—first ground or chewed, then mixed with lard—are applied as an ointment against itch and mange. Supervised experiments have borne out the validity of some of the plant's alleged digestive benefits and other medicinal uses.

Practically no part of the plant is wasted. Its seeds and, to a lesser extent, its foliage—both of which have been found to contain the insecticidal compound rotenone—have long been used for the control of insect pests. Once the rotenone is extracted from the mature seeds, the remaining oil is a fine alternative to cottonseed, peanut, or soybean oil. And once both the rotenone and the oil have been extracted, the remaining "seed cake"—which contains roughly as much protein as the similar residue from soybeans—is commonly fed to cattle and pigs.

Dried yam beans accompany the mummies buried two millennia ago on the south coast of Peru.

In most areas of Amazonia there is little or no trade in yam beans; they are consumed by the people who grow them. In the Andes, however, yam beans are sold both locally and in the larger cities. In Bolivia, for instance, ahipas fetch a price

Farmers in central Thailand harvest their abundant crop of jicama.

Chuín cultivar of the Amazonian yam bean is more potato-like than the other species and cultivars. It is only consumed cooked or otherwise processed—as flour, as an alcoholic drink, and as a basic ingredient in puddings and cakes.

(by weight) comparable to or even higher than that of manioc, peanuts, and potatoes, but their economic promise there seems limited. Unlike those comparably priced crops, ahipa plants must be pruned several times a season. Another downside is the plant's relatively short growing season; manioc, peanuts, and potatoes, in contrast, provide cash flow throughout the year. Finally, the demand for fresh ahipa juice has waned as the demand for commercially produced soft drinks has increased. Thus the ahipa's market share in both urban and rural areas is not only small but also steadily declining—and will remain that way unless the crop is promoted.

One yam bean cultivar yielded more than seventy tons an acre—about thirty pounds of food per square yard.

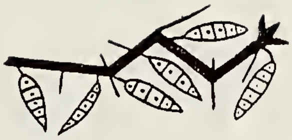
The jicama, by contrast, has become an economic success in central Mexico, with local differences in elevation making it possible to have two complementary cultivation cycles. It is now a major crop both for local use and for export: more than half a million tons are shipped abroad each year, and the wholesale price in 2001 (the most recent year for which aggregate data are available) was $1.13 per pound. That is an amazingly high price for a root crop in bulk. Most of the Mexican jicama crop goes to the United States.

To be marketable, however, the jicama tuber must have a regular, rounded shape and weigh between one and two pounds. To achieve those characteristics, the grower must make sure each plant is building just one tuber, and must remove all the flowering shoots three or four times during the growing season. That amount of pruning is no small task.

Traditionally, farmers cultivate between 24,000 and 32,000 jicama plants an acre, growing them together with maize and beans in the same fields (a technique known as intercropping). The average yield in central Mexico, where yam beans have been cultivated under irrigation for close to two millennia, is roughly thirty-five tons of tubers an acre, an impressive figure for a tuber or root crop. And in field experiments in the central Mexican state of Guanajuato, a locally bred commercial jicama cultivar yielded more than seventy tons of tubers an acre—the equivalent of about thirty pounds a square yard—perhaps a world record for a tuber or root crop (or at least a tie with the sugar beet).

The only other tropical subterranean crop whose yields even come close to those of the cultivated yam bean species is manioc, though in other respects yam beans have the edge: a typical *Pachyrhizus* crop, except for that of the ashipa, is ready to harvest in less time (four to seven months, depending on the species), and its protein content by weight is four to five times greater than manioc's. Moreover, once harvested, all yam bean tubers can be kept in a natural state for several months without significant deterioration, whereas manioc roots must be covered with paraffin to discourage desiccation and the growth of fungi.

When I started the Yam Bean Project in 1985, the gene banks of the project held few seed samples and little information. Eventually investigators carried out a number of field surveys, and by now they have gathered several hundred collections of samples from farmers, villages, and wild plant populations. In addition, details about the origin, distribution, and cultivation of the collected material have been catalogued.



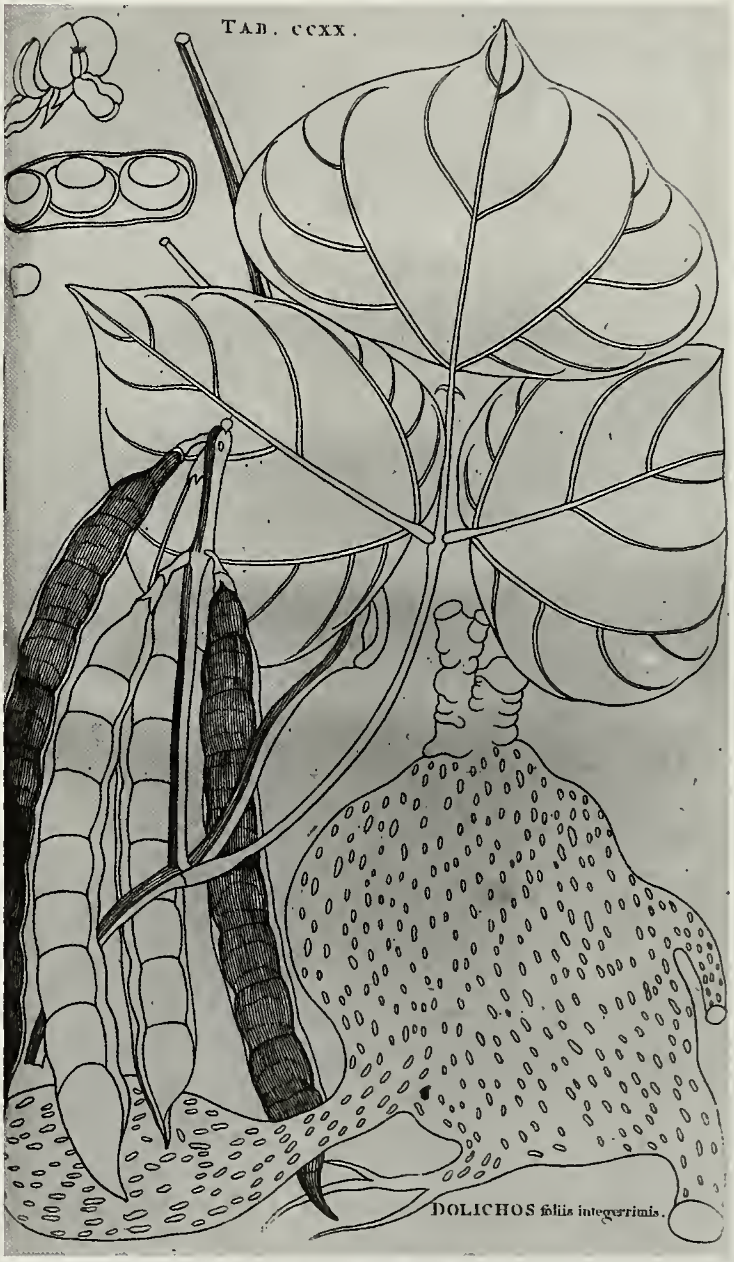
The project also conducts hybridization experiments, aimed at developing high-yield and drought-tolerant cultivars that appeal to local consumers. Ideally the hybrids will combine the Amazonian species' vigor, the Andean species' habit of self-pollination and its indifference to variations in temperature, and the Mexican species' high yields. Endowed with that combination of attributes, the crop would grow well under many climatic conditions. Laboratories and greenhouses participating in the project are testing some 600 hybrids, and field trials are being carried out at various altitudes as well as in both rainy and semiarid regions.

In trials carried out in Benin, Costa Rica, Mexico, and the Pacific island kingdom of Tonga, for instance, two cultivars of the Mexican jicama have each yielded between thirty-five and seventy tons an acre. A Haitian variety of one Amazonian cultivar has yielded more than thirty tons an acre in Benin. Trials in Spain and Portugal have demonstrated the astonishing potential of the Andean ahipa, even when grown under conditions quite unlike those in South America. The Mediterranean yields were almost twenty-five tons an acre—compared with yields of less than four and a half tons per acre when the Andean potato was originally introduced into Europe.

Getting people to eat something new, however, can be quite a challenge. When the yam bean was first introduced into Tonga, local people were reluctant to accept it, even though the traditional Tongan diet is based largely on tubers and other subterranean crops. The yam bean's crisp, juicy quality—and the idea of eating the tuber raw—struck the Tongans as exotic and peculiar.

Nevertheless, the combination of the demand by local Asian and European residents, the ease of cultivation, and the introduction of the chuín cultivar, which must be cooked, has persuaded Tongans to grow, sell, and swallow yam beans in increasing quantities. The news from Benin is similarly encouraging: thanks to media coverage, several field trials have had to cope with the "problem" of unauthorized nighttime sampling by local farmers. The biggest practical problem, though, is the availability of seeds for local cultivation.

Today crops are grown on only about 12 percent of the Earth's land surface. But if we *Pachyrhizus* aficionados have our way, your local health food store will soon be selling freshly pressed jicama juice as an alternative to carrot juice; your local bakery will be creating pastries made with chuín paste; your local supermarket will be stocking yam bean oil in the salad-dressing aisle; and you'll be spraying rotenone on the tomato plants in your backyard. Just give us a few more years. □



Seventeenth-century drawing of an Amazonian yam bean—known as Dolichos *until the early nineteenth century, when the genus was renamed* Pachyrhizus*—was made by the French priest and botanist Charles Plumier. The illustration on page 39 is a later copy of Plumier's drawing.*

Johannes Covens and Cornelis Mortier, celestial planisphere, eighteenth century

Virtual Universe

Centuries of astronomy, plus video-game technology, combine to offer a stunning new perspective on our place in space.

By Brian Abbott, Carter Emmart, and Ryan Wyatt

Gazing up at the sky on a clear, dark night, you can readily convince yourself that the stars are tantalizingly close—close enough, if not to touch, then at least to visit with a spacecraft. A small dose of astronomy, however, quickly dispels the hope of interstellar travel: the stars are impossibly distant, separated by trillions of miles, and the distances we humans have traveled vanishingly small. With that in mind, you could be forgiven for revising your first reaction to the night sky and becoming convinced that any journeys our species makes to the stars will take place only in our imaginations.

But imagination thrives on ideas. Stirring people's imaginations with an accurate and dynamic representation of our place in the universe is well worth engaging the best minds and methods. After all, the first maps of the New World, and the first reasonably accurate globes of Earth, created a powerful sense of wonder, widening our perspective of humanity's place in the world.

Similar flat maps and globes, as elaborately decorated as fantasy could inspire, have for centuries portrayed the stars and constellations of the night sky [*see illustration above*]. But unlike a globe of the Earth, a celestial globe has little practical use today. No one believes anymore, as scholars did in the Middle Ages, that the stars are lights on a uniformly distant sphere. Tracing a path from star to star on such a surface, as if it were the outline of a constellation, reveals next to nothing about the shifting perspective that a true stellar voyager might experience, or what our Sun might look like from another star. No flat map, no globe painted with stars, can accurately render the true three-dimensional spatial relations among the objects scattered across the sky.

Imagine that you could travel to the Big Dipper in a faster-than-light spaceship that could take you there in less than a minute. At the beginning of your journey, the small group of seven bright stars takes its familiar shape: three stars for the handle, four stars for the bowl of the dipper. Some of those stars, of course, are actually closer than others. So as you leave our solar system and approach the Dipper, its outlines become distorted. You pass the nearest star, then the second-nearest, the third, and now, with the seven stars all around you, it hardly makes sense to think of them as a dipper at all. They have become just a collection of stars.

Until recently, a trip to the Big Dipper could take place only in one's imagination. But now, powerful new tools have been created that enable you to experience such an interstellar journey in a planetarium or even on a laptop computer, with an accuracy as pinpoint as modern astrophysics can provide.

The possibility of taking such a virtual tour of the universe in three dimensions has been realized by the NASA-supported Digital Universe atlas, developed by the Hayden Planetarium of the American Museum of Natural History. Depending on your taste and the time you devote to your tour, the Digital Universe can carry you anywhere—from the orbits of the innermost planets, to the stars that form the constellations, to the galactic neighborhood of our own Milky Way, to the most distant known objects in the universe.

The best way to begin is to let an astronomer take you for your first spin, while you enjoy the ride. The dome in the Hayden Planetarium, or in any other large planetarium, is an ideal theater for traveling along the simulated starways. But if you want to drive, to pilot your own spaceflight and change course whenever you like, you can download the free software and catalog of celestial objects over the Internet (www.haydenplanetarium.org/hp/vo/du/download.html). Ride or drive, either way the look and feel of our stellar and galactic neighborhoods have become accessible not only to the professional astronomer, but to virtually everyone.

The Digital Universe atlas has grown out of a convergence of two great streams of technical achievement: celestial mapmaking, the product of centuries of observation and scientific breakthrough, combined with hardware and software engineering, which enables sophisticated data visualization. In principle, the merging of those two streams is simple; in practice it is laborious but brilliantly synergistic. Together they have drawn back the curtain on the universe in all its three-dimensional glory.

Knowing the positions of celestial objects makes it straightforward to calculate their apparent relative positions from any fixed perspective. Recalculating positions from a series of perspectives along a smooth trajectory, and displaying them rapidly in sequence, creates the illusion of smooth, animated motion through space. Thus, an abstract collection of data becomes a visceral experience.

Cosmic cartography begins with astronomical measurements. Astronomers share those measurements through a network of catalogs and publications, and computers have combined and seamlessly integrated the network into the atlas. In that way, hundreds of thousands of celestial objects from numerous catalogs have found their way into the Digital Universe.

At its base, the Digital Universe atlas is built on highly precise astrometry—the "latitude" and "longitude" of objects in the sky—combined with the best available estimates of the distances of those objects from Earth. The work of mapping the former two coordinates, at ever-increasing precision, constitutes thousands of years of effort. But surprisingly, it was only 166 years ago that astronomers made the first relatively accurate distance measurement to an object outside our solar system. Until that time, nothing definite was known except that the stars were very far away.

In 1838 Friedrich Bessel, then director of the Königsberg Observatory in Berlin, calculated the distance to the star 61 Cygni. Bessel measured how the star appeared to shift relative to the surrounding stars, a result of viewing it from one side of the Earth's orbit around the Sun, then observing it again from the other side of the orbit six months later. This shift in perspective is called parallax, and from its magnitude Bessel calculated the approximate distance to 61 Cygni with simple geometry.

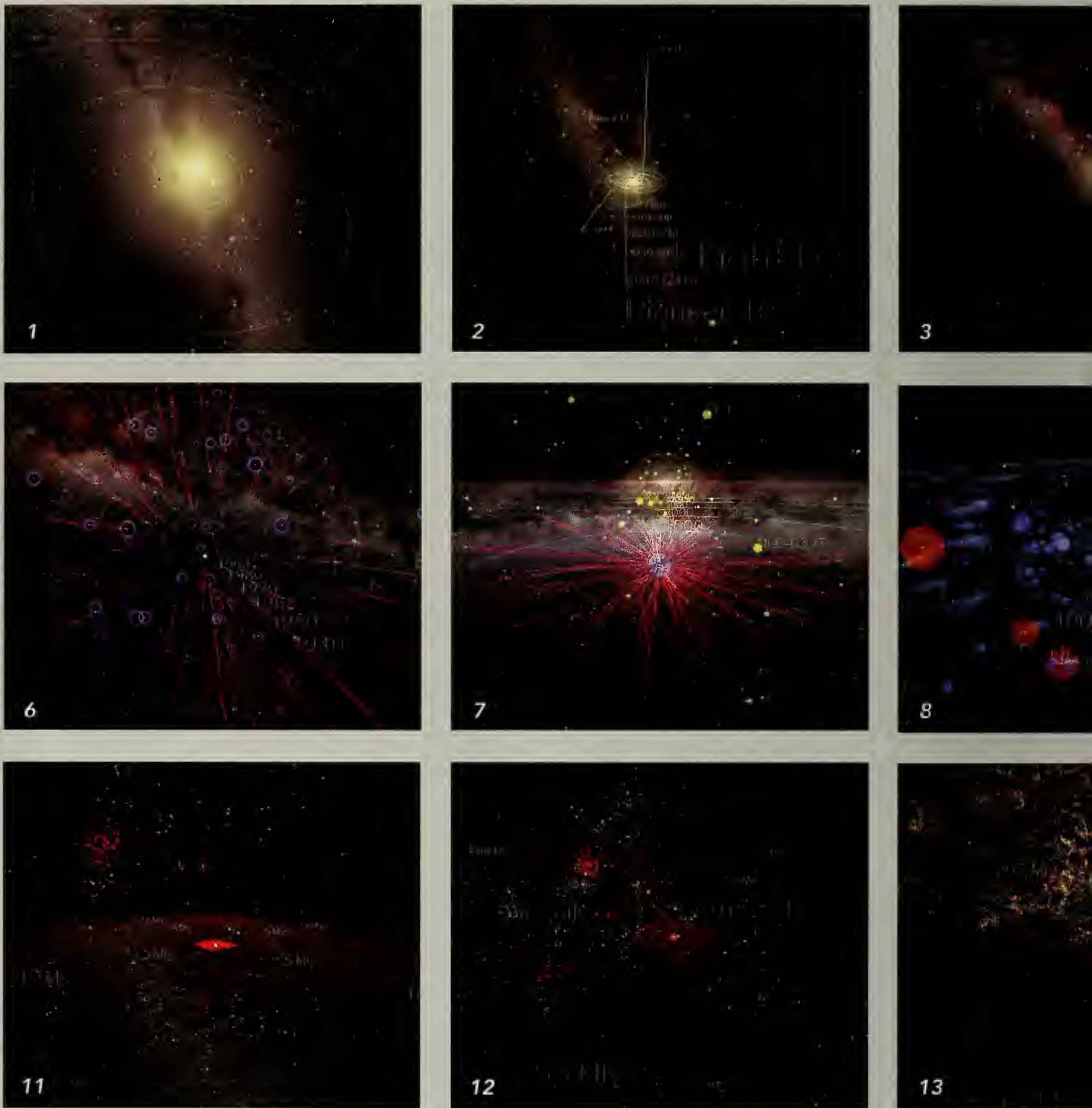
The parallax method remains the most accurate technique for measuring distances to objects outside our solar system. But the diameter of the Earth's orbit, 186 million miles, limits the use of the method to the nearest stars, within about 500 light-years of Earth. A light-year is about 6 trillion miles, and so 500 light-years seems quite a substantial distance. Yet it constitutes only a small "bubble" of observable space, centered on Earth.

The look and feel of our stellar neighborhood has become accessible to virtually everyone.

How can distances to objects be surveyed beyond our neighborhood bubble? Within our Milky Way, a star's spectrum reveals its luminosity class—hence, its intrinsic brightness. By comparing a star's intrinsic brightness with its apparent brightness (as seen from Earth), its distance can be estimated. Unfortunately, the method is not as accurate as parallax, but it is the best method available for most stars that are too far away for parallax measurements.

Another method relies on the knowledge of variable stars, whose brightness varies periodically. The rate at which the apparent brightness of certain variable stars changes is directly related to their intrinsic brightness. If you measure the period over which a star varies, as well as its brightness as seen from Earth, you can estimate its distance. In 1918 the astronomer Harlow Shapley applied that method to find the distance to many globular star clusters in the Milky Way. In fact, he was ultimately able to locate the center of our galaxy—a giant leap forward in the spatial understanding of the universe. With the variable-star method, the bubble of known distances extends outward into extragalactic space, about 50 million light-years from Earth.

Beyond that distance, other objects can serve as "standard candles"—objects whose brightness at



Perspective views from the Digital Universe atlas, a virtual-reality computer program developed at the American Museum of Natural History, demonstrate some of the power of the program to take viewers on virtual space voyages from Earth to the far reaches of the universe. Starting with our Sun and its family of planets (1), seen against the band of the Milky Way, the trajectories of our most distant space probes (2) are plotted to their positions in 2050, the equivalent of the distance light travels in a day. At a distance of one light-week (3), our solar system is lost in the Sun's glare; even farther out (4) is a collection of cometary objects called the Oort Cloud, depicted as a sphere one light-year across. From a distance of some twenty light-years (5), constellation outlines converge toward the Earth's location; the positions of the known planets outside the solar system are highlighted with blue circles. The Earth's most powerful radio signals have by now expanded to fill a sphere 65 light-years in radius (6), barely discernible from 1,000 light-years away (7)—a

vantage point that also shows distorted constellation lines, globular star clusters, and, in the background, the center of our Milky Way. The star clusters nearest our own indicate the flatness of our home galaxy (8), represented as a typical four-arm, barred spiral (9): the galaxy is home to several hundred billion stars. Our nearest galactic neighbors, members of a collection called the Local Group (10), lie within 2 million light-years or so. The Local Group disappears rapidly as the vantage point becomes even more distant: in the regions between clusters of galaxies (11), a square grid marks out distances out to 10 million light-years from Earth. The Virgo Cluster includes some 1,000 galaxies (red cluster of points, upper left of center in 12), with a reference grid out to 100 million light-years. New astronomical surveys, revealing galaxies and clusters (13) several hundred million light-years from home, unveil the large-scale structure of the universe (14). Quasars, billions of light-years away, are highlighted against the most distant radiation detectable, the cosmic microwave background (15).

their source is always the same, much like lightbulbs of equal wattage. For example, if one lightbulb is ten feet from an observer, and a second lightbulb is a hundred feet away, the farther lightbulb would appear to be the dimmer (a hundred times dimmer, to be precise). Similarly, astronomers infer distance by assuming, on sound independent grounds, that certain astronomical objects all have the same "wattage," and so they can all serve as mutually corroborating standard candles. One standard candle, detectable from as far away as about 5 billion light-years, is the explosion of a certain kind of massive dying star known as a type-Ia supernova. All type-Ia explosions are assumed to be of similar luminosity.

Beyond the 5-billion-light-year boundary, yet another method is available for determining three-dimensional structure: redshift. In the 1920s the astronomer Edwin Hubble noted that the farther a galaxy is from Earth, the greater its redshift, or the amount by which its light is shifted toward longer, or redder, wavelengths of the electromagnetic spectrum. The same effect governs the pitch of a train whistle: to a listener standing on a platform, the wavelength of the sound becomes longer, and the pitch becomes lower, as the train speeds away. By measuring the redshift and applying Hubble's relation between redshift and distance, one can estimate distances to the farthest reaches of the observable universe, many billions of light-years away.

As you move among the stars in the vicinity of our Sun, you may find that it is all too

While astronomers were radically expanding their view of the universe in the early part of the twentieth century, a new invention was also fueling a rising public enthusiasm: the planetarium. The first optical-projection planetarium made its debut in 1923, when engineers at the Carl Zeiss Company in Jena, Germany, projected stars on the interior of a hemisphere. A marvel of engineering, the "Wonder of Jena" attracted tremendous attention, and similar technology soon spread across Europe and the United States. A faithful reproduction of the night sky—pinpoint, luminous stars that rose and set, along with planets that followed their proper trajectories—formed the core of planetarium technology, enabling instructors to give dramatic demonstrations of the science of celestial motions and Newtonian physics.

As astronomical knowledge about the universe has grown, new tools have been invented or acquired to keep the planetariums up to date. In the decades from the 1920s until the early 1990s, slide, film, and video projectors were added to the mix of planetarium technology to tell the story of astronomical progress. But portraying the wonders of a universe that seemed to be expanding as knowledge grew proved to be challenging. How could planetariums convey the immensity of the universe? How could they simulate the experience of a flight to the farthest reaches of time and space?

Even astronomers had to grapple with the difficulty of representing their discoveries in a two-dimensional format. A classic example is the discovery of the large-scale structure of galaxies in the 1980s: astronomers were forced to analyze the size and shape of the local universe by viewing two-dimensional "slices" through the three-dimensional data.

When smaller, more powerful computers became available, astronomers were finally able to examine data more comprehensively—and with greater insight. All the objects in a virtual space could at last be plotted in proper perspective. Around that same time, the Evans & Sutherland (E&S) Computer Corporation in Salt Lake City, a pioneering company in computer graphics, introduced a digital projector for planetariums that could, with a single lens on a video projection tube, display a black-and-white star field—as well as other monochromatic images made up of dots and lines. Unlike earlier planetarium projectors, E&S's device presented a three-dimensional universe: the stars had depth, the orbits of the planets in the solar system could be observed from any angle, and users could input data from many sources.

For the Hayden Planetarium, the new technology offered the potential to convey contemporary astrophysics as never before. In 1995 the American Museum of Natural History was embarking on a complete redesign of the planetarium, then sixty years old. The public viewing space was to be housed within a sphere suspended in a glass cube, in what would become the Rose Center for Earth and Space. Several years earlier, in 1991, J. Richard Gott III, an astrophysicist at Princeton University, had chaired the museum's study on the future of planetariums. The museum, which had just completed a renovation of its dinosaur displays to reflect new understanding, was receptive to Gott's suggestions about how to revamp the Hayden Planetarium so as to represent the current state of knowledge about the universe.

Optical-mechanical projection systems, such as the Zeiss star projectors, worked extremely well at depicting stars as they appear from Earth, because stars appear "fixed" in the night sky. The Sun, Moon, and planets seem to move relative to the stars, and their motions could readily be reproduced by small, special-purpose lens systems. But to create seamless, full-color images of the varying scales of the universe, a more flexible system was needed: a computer in which the graphics cover the entire planetarium dome. A mosaic of video projections could act as an enormous computer monitor, presenting a full hemisphere of imagery.

When the Hayden Planetarium reopened in 2000, after its extensive renovation, a virtual trip through the universe required a supercomputer. Navigating databases of thousands of celestial objects and displaying them in a series of still images at the standard video rate of thirty times a second posed a tremendous computational challenge. Fortunately, the phenomenal growth and popularity of flight simulators and electronic video games spurred the field of 3-D data visualization to grow up almost overnight. Thanks in part to the video-game industry, personal computers today incorporate graphics processors that surpass the capabilities of the supercomputer the planetarium purchased only five years ago. The new technology arrived practically ready-made for transfer into industry and academia.

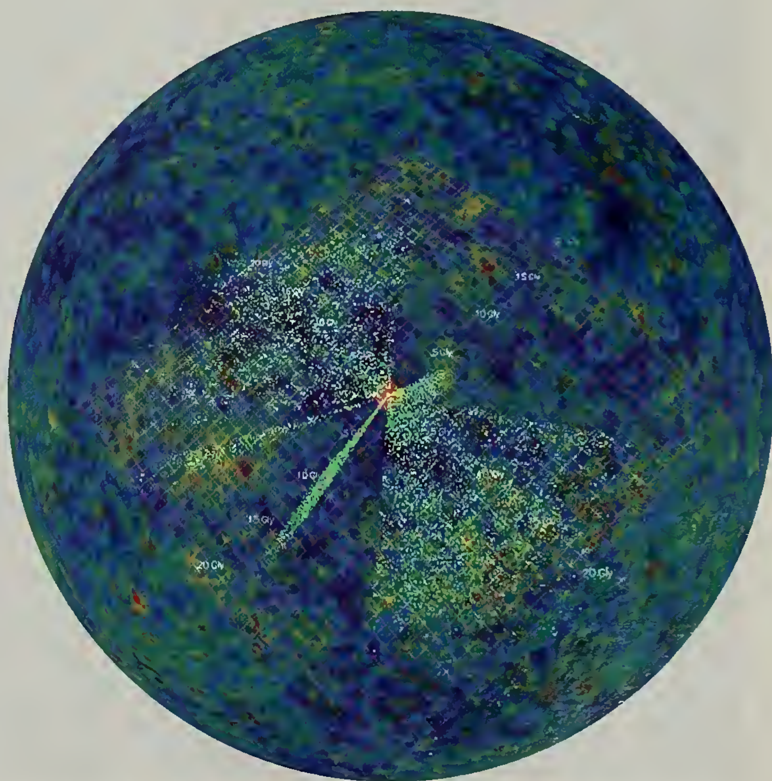
sy to get lost.

To view the Digital Universe atlas created at the Hayden Planetarium, you can use a program called Partiview (for "particle view"), developed by Stuart Levy, a research programmer at the National Center for Supercomputing Applications in Champaign-Urbana, Illinois. A Partiview user can explore any part of the observable universe. The technology renders a series of perspective views fast enough for you to explore the database of stars and galaxies as if you were "traveling" in real time, rather than flipping through two-dimensional snapshots, one after another.

The illusion of motion is critical to gaining an understanding of the spatial relations among celestial objects, because it gives the viewer a physical experience of the scales and positions of the objects. As you move among the stars and galaxies in the vicinity of our Sun and our Milky Way, you learn how to find your way around. But you may also find that it's all too easy—and a humbling and disorienting experience—to get lost!

Cruising the stars and galaxies is no longer confined to facilities with supercomputers and multiple video projectors. The technological innovations that fueled advances at the Hayden Planetarium and other large institutions around the world are making their way into smaller domes as well, and even onto laptop computers. Single fish-eye projectors that cover an entire dome now display digital skies in planetariums in many schools, science centers, and public libraries.

The observable universe is immense beyond any ordinary experience, but not beyond the human ability to chart, visualize, and share. We begin to grasp its immensity by translating it into something we can see. As visual creatures, we use "immersive" technology to gain a sense of familiarity with the region around us, beginning with the Earth and moving constantly outward to expand our horizon of the familiar. By experiencing our place in ever-widening regions, we come to identify a much larger "home" than we ever imagined before. In much the way our species has, for millennia, viewed the night sky with awe, perhaps the Digital Universe can help stimulate a cosmic perspective toward our own species. □



"Edge" of the observable universe, the most distant source of data from astronomical surveys in any direction, is depicted by the Digital Universe atlas. The projection of the image lends it a remarkable, if superficial, resemblance to the planispheres of former centuries. Because light travels at a finite speed, the image portrays the distant past, not long after the big bang. Representing the cosmic horizon is the cosmic microwave background radiation, whose minute temperature variations are rendered here in false-color blues and greens.

No Place to Call Home

Japanese Brazilians discover they are foreigners in the country of their ancestors.

By Takeyuki Tsuda

Elderly Japanese teacher instructs her pupils in a Japanese commune near São Paulo. Japanese immigrants and their descendants began establishing communities in Brazil as early as 1908; they now number more than 1.2 million. Some, including the teacher in the photograph, go out of their way to maintain their ethnic heritage; others would gladly blend into the majority population if it were not for their recognizable physical features.

From my window on the train rolling into the station in Tokyo, the people waiting on the station platform were a blur. As we slowed down to our precise stopping point, Japanese faces came into focus. The doors opened, and people shuffled in or out of the car. Just before the doors closed, three men strolled in. Compared with the other passengers, these Japanese appeared quite different, their demeanor casual and leisurely. Two were dressed in shirts of bright mixed colors and jeans with a stripe down the side. The third wore a T-shirt with the word "Brasil." They were in the middle of a loud, boisterous conversation, in Portuguese.

"It's really funny," one of them remarked, leaning against a handrail with his hands in his pockets. "He goes on talking and talking, but the Japanese don't understand him."

"The poor guy," another said. "It's because his Japanese is old-fashioned. Not only that, it's a dialect from Okinawa." They laughed.

Instantly the three men—Brazilians of Japanese descent—drew the attention of the surrounding native-born Japanese. Some looked up from their newspapers to stare. Other gave furtive glances, pretending not to notice the strangers. Two women sitting beside me turned their eyes away from the men and looked at each other. They exchanged one word: *gaijin* ("foreigners").

I felt like an eavesdropper two times over. Born in the United States of Japanese immigrants, I, too, was a *gaijin*, at least technically. But my parents had seen to it that I absorbed their native language and culture, and I had visited "the homeland" many times. In Japan, by observing all the social graces, I could often pass for a native. My anthropological fieldwork, however, focused on Japanese-

Brazilian immigrants, like the three men on the train. To learn about their prior lives in Brazil, I had spent more than eight months in Porto Alegre and Ribeirão Preto, conducting interviews and participating in community activities. Now, to understand the experiences of the Japanese Brazilians who had come to live in Japan, I was spending much of my time working alongside them in a Japanese factory. I was probably the only other passenger who could follow the conversation in Portuguese. Yet for the moment I kept mum and observed passively. Juggling my various private and public identities in the field was a strain, and I was off duty.

Brazilians of Japanese descent began arriving in Japan during the late 1980s, in search of high-paying factory jobs. Their anomalous ethnic status attracted considerable attention from the start. "The first time the Japanese Brazilians came to town, I was really surprised," one young Japanese man told me. "I thought, wow, look at these weirdos! What in the world are they anyway? They looked Japanese, but they weren't real Japanese. They acted completely differently, spoke a foreign tongue, and dressed in strange ways. They were like fake Japanese, like a fake superhero you see on TV."

With a population of about 280,000, Japanese-Brazilian immigrants have become the third-largest group of foreigners living in Japan, after the Koreans and Chinese. To social scientists they are "return migrants," because they are going back to their ethnic homeland. Yet most of them were born and raised in Brazil, do not speak Japanese very well, and have become culturally Brazilian to various degrees.

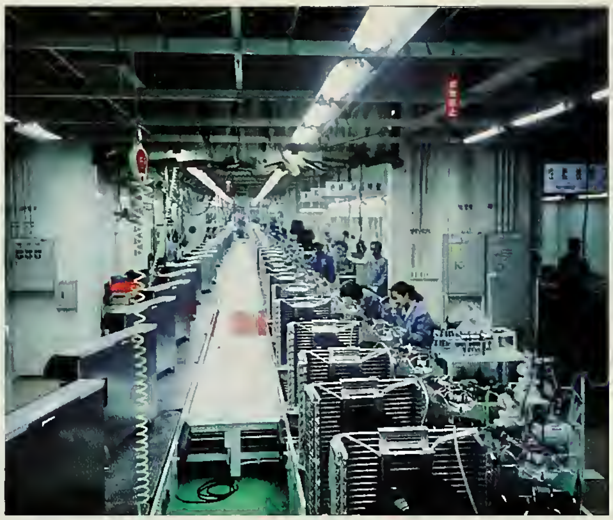
Japanese Brazilians in São Paulo chant during a Buddhist ceremony that honors deceased members of their community. Such occasions serve to preserve some of the Japanese ethnic heritage in a foreign land.

Such ethnic return migration is a worldwide phenomenon. In recent decades more than half a million people of Korean and Japanese descent, who were scattered across China, Eastern Europe, and Latin America, have return-migrated to Korea and Japan. In Europe, there has been a massive return of several million ethnic German, Hungarian, Italian, and Spanish descendants from Eastern Europe and Latin America to their homelands. Motivated by long-held traditions, millions of Jews, notably from Eastern Europe, have settled in Israel.

Because they and their forebears have become assimilated into the culture of a foreign land while living abroad for generations, the return migrants often find themselves treated as ethnic minorities in their "home" countries. Many of them work as unskilled manual laborers, which confines them to low social and economic status. Hence, whatever nostalgic longing and attachment they might have felt toward their ancestral homelands, return migrants often find the reality of their new circumstances alienating. In response, many adopt a strong sense of national allegiance and identification with the country they left behind, stronger than any they ever felt before. Others assume the identity of a diasporic people, whose sense of belonging cannot be defined in nationalist terms.

Ironically, the parents or grandparents of the Japanese Brazilians had left Japan in search of a better life in Brazil. Many of those emigrants were farmers, recruited as contract workers for Brazil's booming coffee plantations. The labor flow began in 1908 and continued into the early 1960s. Although most of the emigrants intended to return to Japan after several years, the vast majority settled permanently in Brazil with their families. There, they went on to become independent farmers and landowners. Many have since urbanized and their descendants have entered Brazil's middle class as professionals and business owners with educational levels and incomes substantially higher than the Brazilian average. Numbering more than 1.2 million, they constitute Brazil's oldest and by far its largest Asian minority.

Japanese Brazilians are now relatively well integrated into Brazilian society, but because of the attention that is given to racial appearance in Brazil, other Brazilians always refer to them as *japonês.* I noticed this kind of treatment a few days after I arrived in Porto Alegre. *"Oi, japonês!"* a Brazilian street vendor called out to me, trying to interest me in his goods. A little while later a bus-station attendant gestured, not at all impolitely, toward a bench where I could sit while waiting: *"Espera aqui, japonês."* There it was again; I was beginning to realize it was common practice. "Even if we become completely Brazilian and act as Brazilian as possible," a young Japanese-Brazilian student told me, a hint of resignation in his voice, "we will always be seen as Japanese because of our faces. We can go to a soccer game and cheer on our favorite São Paulo team, or even dance samba in the streets, and in the midst of it, someone will say, 'Hey, *japonês!*'"



Brazilians of Japanese descent, who have migrated to Japan to work on an assembly line in Oizumi, are branded by their blue, factory-issue uniforms.

But in contrast to most minority groups, who suffer from low socioeconomic status, prejudice, and discrimination, the Japanese Brazilians generally enjoy higher-than-average status and may even be admired for their "Japanese" cultural attributes. Indeed, the Japanese Brazilians in Brazil have capitalized on the prevailing favorable image by embracing their Japanese identities while generally distancing themselves from what they perceive to be the negative aspects of Brazilian culture.

Drawn by factory jobs, one-fifth of all Japanese Brazilians now live in Japan.

In the early 1980s, eight decades after the first Japanese emigrants set foot in Brazil, the Brazilian economy entered a prolonged period of crisis. Meanwhile, the Japanese economy, which had grown beyond all expectations to become the second largest in the world, was suffering from an acute shortage of unskilled labor. Immigration-policy makers in Japan decided to admit *nikkeijin* (people of Japanese descent born and raised abroad) from South America as foreign workers. Government officials rather cavalierly assumed the *nikkeijin* would assimilate smoothly into Japanese society, providing much-needed immigrant labor without disrupting Japan's cherished ethnic homogeneity.

Seeking to maintain their standard of living, the Japanese Brazilians started arriving in Japan, and their numbers continue to grow steadily, despite that nation's current economic recession. Close to one-fifth of the entire Brazilian *nikkeijin* population now lives in Japan. Well-educated and middle-class in Brazil, most of them work as unskilled laborers in small and medium-size firms in the manufacturing and construction sectors. Still, based on the exchange rate, they earn five to ten times their Brazilian incomes. Like their own forebears, most of them arrive in the new country intending to work for just a couple of years and then quickly return to Brazil with their savings. Consequently, they have also become known as *dekasegi,* short for *dekasegi rōdōsha,* Japanese for "temporary migrant worker." But many have already brought their families to Japan, and the process of long-term immigrant settlement has begun.

Given my experience in Brazil and my familiarity with Japanese customs, I felt well positioned to explore both sides of the ethnic encounter between the return migrants and their native hosts. I started my research in Ota city and adjacent Oizumi town, three hours by train to the north of Tokyo. They are part of an industrialized area that has the highest concentration of Brazilian *nikkeijin* in Japan. The local government has welcomed the immigrants and provided them with an array of services, including both standard schooling and special language classes for the children.

In the anthropological tradition of "participant observation," I arranged to work in a factory, essentially as a return migrant myself, alongside Japanese and Japanese Brazilians. I tried to get to know my co-workers while I installed utility cables and pressure gauges on the inspection section of an air-conditioner assembly line. I also conducted interviews with Japanese Brazilians who were not factory workers—owners of ethnic businesses, graduate students, liaisons and assistants for local governments and labor-broker firms, and members of *nikkeijin* assistance organizations. After four and a half months I moved to Kawasaki city, near Tokyo, to do more interviews for another eight months.

Approaching the native Japanese workers proved to be far more difficult than I could have imagined. I wore the same blue uniform as the Japanese-Brazilian factory workers, ate lunch with them in a separate room, clustered with them during breaks, and was heard speaking Portuguese. I was dismayed to realize that as far as the Japanese were concerned, I was as Brazilian as samba and carnival. None of the Japanese workers interacted with me socially: there were no greetings, no smiles of recognition in the morning, no small talk. They didn't even bother to ask or remember my name; instead they simply called me *gaijin-san* ("Mr. Foreigner"). For me it was quite disorienting.

It seemed as if it ought to be simple enough for me to introduce myself and clarify my ethnic and professional identity. In practice, though, it took a lot of persistence. The initial reaction was apt to be one of subdued surprise, because my fluency in Japanese was unexpected. When I then explained that I was from the United States, the reaction would be another expression of surprise: not being white, I hardly fit their stereotypical image of an American, and if I was American, why was I working in a Japanese factory and why did I speak Portuguese? My final revelation—that although I was working on an assembly line I was "actually" a graduate student doing research—generally elicited a skeptical "Really?" or a noncommittal "I see."

On one occasion I introduced myself to a foreman on a section where I worked for a few days. Later, one of my co-workers told me that the foreman thought I had lost my mind. "He can't deal with the fact that he is a *dekasegi* in Japan," the foreman supposedly said. "So he's creating some kind of fantasy that he's an American and doing research."

The Japanese workers were particularly reluctant to reveal their attitudes toward the Japanese Brazilians. The topic was controversial, and management put a lot of pressure on them to treat the *nikkeijin* well and avoid creating conflict. Outside the factory I had better success: there I was better able to present myself with Japanese manners and demeanor, and gain more candid interviews.

"The Japanese do not perceive the *nikkeijin* well," one middle-class Tokyo resident told me. "They are seen as people who were from rural villages and were poor. They were the type of low-level people who couldn't survive in Japan. So they had to discard Japan and go abroad." Native Japanese go on to assume that the Japanese Brazilians have now migrated to Japan because they could not succeed in Brazil either. Thus the migration legacy of the *nikkeijin* subjects them to a double social stigma.

The racial appearance that marks the *japonês* as a minority in Brazil doesn't differentiate them once they arrive in Japan, but that doesn't spare the return migrants from being seen as an ethnic minority. Both the Japanese government officials, as well as most of the Japanese workers and residents I interviewed, were quite disappointed to discover how culturally Brazilian the *nikkeijin* had become. As a result, the return migrants became targets of common negative stereotypes of Brazilian or Latino character.

"Even if they don't have money to live tomorrow," an older Japanese woman told me, "they de-

Samba parade in Oizumi, Japan, offers Japanese-Brazilian immigrants a chance to embrace their South American heritage. Back in Brazil, some would have shunned such a performance.

cide to enjoy life today and worry about tomorrow when it comes. They are open and jovial people, but careless, irresponsible, and lazy. Warm countries are like this." Some Japanese residents complained that Japanese Brazilians living in the neighborhoods make excessive noise in their apartments and party until late at night on weekends.

One Japanese worker expressed a common sentiment: "The *nikkeijin* don't work hard, and can't work properly. Lots of people resent them because they can't work well and cause problems for the Japanese workers, who have to work extra to make up for them." Most Japanese workers I interviewed did not seem fully aware that the *nikkeijin*, as a migrant labor force with high turnover, tend to be new workers with relatively little experience in the factory. In contrast, the Japanese employers generally had a favorable impression of the *nikkeijin*, compared with Japanese seasonal or part-time workers. But employers also had criticisms. "They are too individualistic, selfish, and think only about their own personal needs and not those of others," one employer told me. "They have no group consideration and don't help each other, but instead harass those among them who try to do more to raise group efficiency." Whatever their private prejudices, though, most native Japanese residents and factory workers I observed did not express those prejudices to the *nikkeijin*.

"To be considered Japanese, it is not sufficient to have a Japanese face."

In contrast to my experience interviewing native Japanese workers, I found it easy to relate to the Japanese Brazilians on the assembly line. They were quite conscious of their counterparts in the United States, like me (the so-called *nipo-americanos*); most of them also knew what an *antropólogo* was.

For their part, many Japanese Brazilians "return" to their ethnic homeland expecting to be socially accepted, if not eagerly welcomed, and are disappointed to find they are socially isolated and treated as foreigners. "To be considered Japanese, it is not sufficient to have a Japanese face and eat with chopsticks," one man said. "You must think, act, and speak just like the Japanese." In Brazil the Japanese Brazilians had considered their own demeanor to be relatively quiet and restrained. In Japan they discover that the ways in which they walk, dress, and gesture is strikingly different from those of the Japanese. At the same time, the return migrants contend that, compared with themselves, the Japanese are people lacking *calor humano* ("human warmth").

Some return migrants, having been raised on antiquated images of Japanese culture, are keenly disappointed to find Japan is so Westernized. But most of them also arrive with idealistic images of Japan as a highly developed First World nation with ultramodern cities, high-tech industries, and luxurious living standards. As a result, they are also disappointed to discover that the country has its share of narrow streets, small houses, poor neighborhoods, homes without flush toilets, and small, dingy factories.

Almost mirroring the Japanese on the assembly line, the *nikkeijin* were often critical of the native workers. "The Japanese think they are superior to us because they have been in the factory for much longer and have more experience," one woman maintained. "But the Brazilians work better. In my workplace, I do the work of three Japanese and do it more efficiently and seriously. The Japanese workers don't want to contribute to quality. If the Brazilians do better work, the Japanese get jealous."

Because so much of my fieldwork involved soliciting the views of the return migrants and the native Japanese toward each other, I often found myself enacting mutually incompatible *nikkeijin* and Japanese identities, often in rapid succession or even simultaneously. Fieldworkers have come to realize that their own cultural and personal biases and characteristics may directly affect the outcome of their work, and that a sanitized, depersonalized account actually undermines the very scientific objectivity it is supposed to express. The observer is also being observed by the natives, and what the natives perceive as the anthropologist's professional, ethnic, gender, class, and other characteristics will influence their responses. My own experiences were a constant reminder of the need to remain aware of such interpersonal dynamics in the field.

When denied their previously cherished Japanese identity, some Japanese-Brazilian return migrants look to religion to fill the void. Others, particularly those who are isolated from their ethnic peers, suffer from mental disorders, creating imaginary friends or even turning to suicide or to criminal behavior. But the most common reaction is a reaffirmation of their Brazilian identity. Although back home many were critical of aspects of Brazilian society, in Japan they tend to speak highly of Brazil's living conditions, natural resources and agriculture, sports heroes, food, and friendly people. Instead of striving to blend in as native Japanese, they begin acting in overtly Brazilian ways, speaking Portuguese loudly in public, wearing Brazilian clothes, and introducing themselves as Brazilians. They also take part—more actively than they ever did in Brazil—in events that feature Brazilian music, dance, clothes, and food.

Among the most visible of the "Brazilian" events are the samba parades, organized in communities with high *nikkeijin* concentrations. Although most Japanese Brazilians never bothered to participate in samba in Brazil (and even scorned it as a lowly activity), they suddenly find themselves dancing the samba in Japan and enjoying it a great deal.

Since most of them never became thoroughly knowledgeable about samba, however, their parades tend to be somewhat improvised and haphazard. In one parade I attended in Oizumi town, the samba costumes ranged from simple bathing suits, clown outfits, and festival clothes with Brazilian national colors to simple T-shirts and shorts. The contrast to the elaborate outfits expressly designed for samba festivals in Brazil could not be more striking. Furthermore, most of the *nikkeijin* did not even seem to know how to synchronize their body movements properly. Nevertheless, the performance affirmed their Brazilian identity, and the crowds of curious Japanese spectators, who clogged up the street with their cameras and camcorders, validated the dancers' sense of "otherness."

Even if they try to blend into the rest of Japanese society, the return migrants have little chance of doing so. The sizable number of them who give up their original plans to return to Brazil will live out their lives as outsiders. Many of their children, though, will be able to bridge the ethnic gap. They are not only learning to speak the language in Japanese schools, they are also adopting Japanese attitudes and even prejudices about the country their parents left behind. They will not long remain strangers in their ethnic homeland. □

Japanese Brazilians in Oizumi, Japan, cheer the Brazilian soccer team at the start of the 2002 World Cup final, which was played in Yokohama. (Brazil defeated Germany, 2–0.)

Singapore's Vest-Pocket Park

A rainforest survives within sight of skyscrapers.

By Jamie James

In 1819 the English administrator and naturalist Thomas Stamford Raffles landed on what is now Singapore's main island, with a mandate to establish a colonial port. He found a population of about 150 Malay inhabitants and a tropical rainforest edged by pestilential swamps. Commerce and rubber planting soon transformed Singapore into one of the most profitable jewels in the crown of the British Empire. Today it is an independent nation of 4.1 million people and skyscrapers that soar from its city center.

Only a few slivers of rainforest survive within the 246 square miles of the main island. One such area is Bukit Timah Nature Reserve, which ranges across the highest hill (533 feet) in the interior. Although the reserve covers little more than 400 acres, its value to naturalists can only grow, as developing nations in Southeast Asia rapidly clear-cut their virgin forests.

View east from the summit of Bukit Timah hill, looking toward the Upper Peirce Reservoir in the Central Catchment Nature Reserve. High-rise housing in the distance is in Singapore's northeastern satellite towns.

In the Malay language *bukit timah* means "tin hill." The hill *(bukit)* is made of granite, however, so it's a good guess that the original name was Bukit Temak: *temak* is Malay for a species of gigantic *Shorea* tree, and someone may have applied that name loosely to the related species that grow on the hill. Part of the hill's claim to fame is that the English naturalist Alfred Russel Wallace began his historic study of Malay flora and fauna in and around it in 1854. He stayed at a Jesuit mission surrounded by logging camps, where, in just two months, he collected 700 species of beetle. He attributed his phenomenal success to the loggers, who left behind heaps of sawdust and rotting wood detritus that provided the insects with a veritable banquet.

The principal danger Wallace faced during his sojourn there was from tigers. As he wrote in his classic account *The Malay Archipelago,* "It was rather nervous work hunting for insects among the fallen trunks and old sawpits, when one of these savage animals might be lurking close by, waiting an opportunity to spring upon us." Almost as treacherous were the tiger traps, pits dug fifteen to twenty feet deep, which dotted the island.

According to Richard T. Corlett, an ecologist at Hong Kong University who has investigated the history of the reserve, Bukit Timah was probably subject to a degree of logging, as Wallace's writings imply, but it has been under some form of protection since at least 1848. That is not to say the forest has enjoyed uninterrupted tranquility. In 1942 the hill was on the front line of the battle for Singapore, one of the worst British defeats of the Second World War. The Japanese occupiers respected the reserve, however, bringing in Kwan Koriba, a botanist from Kyoto University, to oversee the island's parks. Some caves near the peak of Bukit Timah, which served as military depots during the war, are now grated over and offer safe roosts for bats.

The skirmishes at Bukit Timah since the war have been disputes about encroaching development. In 1986 a major highway was completed along the reserve's eastern perimeter, separating the area from the Central Catchment Nature Reserve, where the major remaining rainforest of Singapore lies. And granite quarrying nearby—another bone of contention—did not cease until the late 1980s.

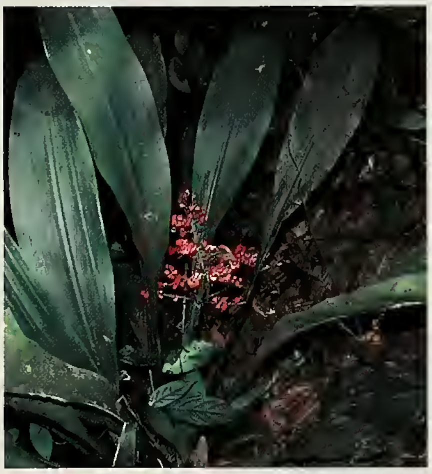
In 1967, in their book *The Theory of Island Biogeography,* the ecologist Robert H. MacArthur and the biologist Edward O. Wilson of Harvard University proposed that the degree of biodiversity surviving in an island ecology is a function of the area of the island and its distance from the source of immigrating species. Those principles have been tested and confirmed for artificially created islands of primary habitat, as well as for landmasses actually surrounded by water. The rule of thumb is that an island reduced to one-tenth its original size will lose half its species.

By that standard, Bukit Timah is beating the odds. Although more than 99 percent of the original rainforest on the island of Singapore has been cleared, the reserve still retains nearly half the original native bird species and many small mammals.

But the large vertebrates have not been so fortunate. The island's last tiger was reportedly shot in the Choa Chu Kang district in 1930 (not, as local folklore would have it, in 1902 in the billiards room of the Raffles Hotel in downtown Singapore). The last one at Bukit Timah was killed in 1924 (the reticulated python has replaced the tiger at the top of the reserve's food chain). Other large mammals that have vanished are the leopard, the largest species of deer (the sambar and the barking deer), the pig-tailed macaque, and the wild pig. Some ecologists think that once the big vertebrates are gone, it is just a matter of time before the entire fabric of biodiversity unravels.

The loss of many native bird and mammal species from Bukit Timah can be traced to hunting and trapping, rather than to isolation and habitat degradation. That may sound like a dismal conclusion, but it speaks well, at least, for the potential of a small reserve to maintain the diversity of its fauna.

The flora seem even more resilient. Singapore's National Parks Board, which manages both the Bukit Timah and Central Catchment nature reserves, undertakes only moderate reforestation, allowing parts of both reserves to regenerate naturally. As Chew Ping Ting, a research officer, explains, the park service concentrates on rare tree species that produce adequate numbers of seedlings for



Hanguana malayana grows on the forest floor.

transplantation, such as *Aquilaria malaccensis.* Whenever possible, the reserve managers try to replant where there are gaps in the forest canopy, to give the saplings an edge.

WILDLIFE SAMPLING

Birds Asian fairy bluebird, greater racket-tailed drongo, olive-winged bulbul, orange-bellied flowerpecker, and striped tit-babbler.

For visitor information, contact:
National Parks Board Headquarters
1 Cluny Road
Singapore 259569
(65) 6471-7808
www.nparks.gov.sg/

Mammals Common tree shrew, long-tailed macaque, mouse deer, pangolin, plantain squirrel, slender squirrel, and flying lemur (not a lemur at all, this last species, which glides like a flying squirrel, is one of just two extant species in the order Dermoptera).

Reptiles and amphibians Black-bearded flying lizard, elegant bronzeback snake, green-crested lizard, paradise tree snake, reticulated python, spiny turtle, and Wagler's pit viper.

Insects Atlas moth, forest grasshopper, giant forest ant, giant honeybee, green-bodied cicada, jungle cockroach, *Nephila maculata* spider, rhinoceros beetle, sky blue butterfly, and wood scorpion.

Trees *Aquilaria malaccensis,* jelutong, keruing, nemusu, and seraya.

Shrubs and herbs Ant plant, black lily, *Hanguana malayana* [*see photograph on this page*], pendant ixora.

Ferns Bird's nest fern, resam, staghorn fern, and various grass ferns and tree ferns.

Jamie James is a critic, novelist, and travel writer based in Jakarta.

Heat Exchange

The global warming debate mixes daunting complexity with high political stakes, a toxic brew that continues to test dispassionate science.

By Robert Ehrlich

Robert & Shana ParkeHarrison, *Cloud Cleaner*, 1999

The complex mix of science and politics bundled together under the label "global warming" usually prompts one of two generic responses in books for the general public. One is a call to action, as in Al Gore's *Earth in the Balance*. The second is a call to inaction, as in the wittily titled *The Satanic Gases,* by Patrick J. Michaels and Robert C. Balling Jr. In *The Discovery of Global Warming,* Spencer R. Weart brings a welcome third perspective to the subject: the historical point of view.

Weart, as it happens, is both a physicist and a historian of science, and his diverse activities make him well qualified for the task he sets out to do (and accomplishes!) in his book. His aim is to describe the many converging strands of science that led to the "discovery" of global warming—by which he means the emerging scientific consensus that people are discernibly (and probably quite significantly) affecting Earth's climate through the greenhouse effect.

As Weart makes clear, the "discovery" announced in his title is quite different from the usual discoveries in physics. The latter can often be traced to a particular moment in time and to the work of a particular person or group. But the consensus among scientists about the effects of global warming developed gradually, Weart tells us. And by "connecting the dots among roughly a thousand of the most important papers in the science of climate change," he shows how that happened. (The Web site that supplements Weart's published volume, hosted by the American Institute of Physics at www.aip.org/history/climate/, includes roughly three times more material than the book does, but it is both clearly organized and surprisingly easy to navigate.) In some places the book does indeed read almost like an elaborate mystery story, with all the attendant false clues and twists of plot.

Some of the plot thickeners are quite instructive. Take for instance the view that emerged during the 1960s and early 1970s, according to which the planet was probably facing a new ice age. That view was embraced by some of the same investigators who today are quite certain the Earth is headed for some serious warming. To be fair, however, that shift is by no means just a reversal of opinion. Rather, it represents a refinement of a still-evolving climate theory—an outcome that should come as no surprise to anyone familiar with the way science really works. In fact, the current understanding among most climate scientists is that both views (warming and cooling) are right. We are facing both near-term global warming, because of a buildup of greenhouse gases, and an eventual serious cooling (another ice age), probably as a consequence of small shifts in the Earth's axis of rotation. Weart's approach, then, gives just the kind of treatment that places the history of ideas in the context they demand.

The Discovery of Global Warming
by Spencer R. Weart
Harvard University Press, 2003; $24.95

Weart is probably correct in asserting that the consensus today is more reliable and more robust than the ice-age predictions of thirty years ago. The belief in a human-induced warming trend is more widely held within the scientific community than the belief in a coming ice age ever was. The evidence for an anthropogenic cause of recent warming also rests on firmer foundations, given that climate-modeling tools are far more sophisticated now than they were in the 1970s. Still, science is not an enterprise in which "majority rules." And Weart reports that though nearly all the computer models now agree in "predicting" the present climate—that is, taking into account conditions and trends in the past, their computational results are in accord with today's climate—the critics of global warming point out that the models have been "laboriously 'tuned' to match [current climate] by adjusting a variety of arbitrary parameters."

None of these caveats imply that the climate modelers are wrong; science generally makes gradual progress toward the truth. But the caveats ought to remind people that when climate models are projected into the future, their predictions should be viewed with some degree of caution, particularly when it comes to the assumptions built into the models. In most places Weart is appropriately cautious in his assertions, reminding his readers that

> scientists rarely label a proposed answer to a scientific question "true" or "false," but rather consider how likely it is to be true. Normally a new body of data will shift opinion only in part, making the idea seem a bit more likely or less likely.

Weart also is forthcoming about the many uncertainties about global warming that remain, despite the present consensus.

Weart's decision to write from the historical perspective—understandable as that is for a historian of science—does present some structural problems for the reader. For one thing, information on specific topics is spread throughout the book. Readers who want to know about the role of aerosols in the global climate, for instance, have to read about the subject in dribs and drabs. They won't find out whether, on balance, aerosols tend to warm or to cool the planet until they are three-quarters of the way through the book. That's a more serious shortcoming than it may at first appear, because aerosols are one example of what global-warming skeptics call a "fudge factor": one whose effects can be arbitrarily adjusted in the computer models.

Another quibble I have is that, though *The Discovery of Global Warming* is intriguing and well written, its readability suffers from the author's attempt to weave together so many different threads of the story.

But the book's biggest problems are

some conspicuous omissions, and a certain lack of balance. Take the discussion of feedback. Seven scattered passages in the book address feedback, yet one never gets a hint that feedbacks can be negative as well as positive. Positive feedbacks tend to amplify initial disturbances that warm or cool the planet; negative feedbacks tend to damp them down. Negative feedbacks, whether they operate in the presence of heating or cooling factors, drive a perturbed global climate back to the state it was in before the perturbation in question; they are a force for equilibrium rather than instability.

There are many examples of negative feedback. Atmospheric carbon dioxide (CO_2), for instance, stimulates the growth of plants, and the plants absorb more CO_2 from the atmosphere. Another example is the cloud-evaporation cycle: low-altitude clouds formed by temperature-driven evaporation block the sunlight. The blockage cools the planet, which leads to reduced evaporation. But not only does the book shortchange its discussion of negative feedbacks; it also usually describes the action of positive feedbacks in unnecessarily ominous terms. Feedbacks that simply amplify planetary temperature changes—perhaps only modestly—become changes that "[switch] the climate system to a drastically different state."

Some of Weart's other omissions are equally disturbing. Why, for example, does he leave out any discussion of satellite data on global temperatures, and the degree to which they deviate from readings at weather stations on Earth's surface? The disagreement deserves attention on its merits, but to ignore it entirely arouses suspicion about Weart's objectivity. Satellite data show a much smaller increase in global warming than do measurements at ground stations or projections based on computer climate models. The satellite data have been repeatedly cited by some skeptics of global warming as a major objection to the mainstream consensus. Because they are averaged over larger areas, satellite data are less subject to bias than data from ground stations, so skeptics argue that satellites yield the more reliable data set.

Although the book is certainly no polemic—there is no call for action to avert catastrophic global warming—the reader can find many instances in which Weart's biases color his presentation. (Bias, of course, like beauty, is in the eye of the beholder; it is entirely possible that some of the imbalance discussed here may belong to the reviewer rather than to the book's author.)

Weart's discussion about global-warming skeptics and their arguments is probably where he strays furthest from his otherwise reasonable tone. In several brief passages he treats two of the more vocal among them: the atmospheric physicist S. Fred Singer and the physicist Frederick Seitz. Weart's discussion, though not disrespectful, focuses more on their sources of funding, methods of publication, and backing by politically conservative groups than it does on their actual arguments.

Weart notes that "the most outspoken scientific critiques of global warming predictions rarely appeared in the standard scientific publications"—but instead, with few exceptions, in venues backed by industrial, business, or conservative policy interests. The point is true, but one wonders why Weart regards it as relevant. Attacking the "most outspoken" skeptics is really attacking a straw man. Would Weart offer up a similar assertion—equally true—about the "most outspoken" believers in an imminent global-warming catastrophe? They, too, rarely publish such dire appraisals in scientific journals, but instead, with few exceptions, in venues backed by liberal, anti-industry groups.

Further on in his narrative, Weart belatedly acknowledges that some skeptics, such as the meteorologist Richard S. Lindzen of the Massachusetts Institute of Technology, are highly respected climate scientists who have published their findings in the peer-reviewed literature. But for the reader, the impression has already been created that most of the skepticism about global warming is based on ideology, not on science.

Another part of Weart's narrative that might have benefitted from a more evenhanded approach is his detailed discussion of the Intergovernmental Panel on Climate Change (IPCC). The body of hundreds of scientists and government representatives arrived at its own conclusions about global warming in its first report, issued in 1990, and, through its subsequent reports, played a major role in forging the present consensus. "Because they were under a mandate to make only statements that virtually every knowledgeable scientist could endorse," Weart writes, "IPCC's consensus statements were highly qualified and cautious."

What he fails to mention is that, unlike the IPCC reports themselves, the executive summaries for policy makers have been anything but cautious about the way they highlight certain points in their presentation of the global-warming problem. He also fails to note that some major contributors to the IPCC reports have been highly critical of their contents. Lindzen, for instance, has said that "the possibility of large warming, while not disproven, is also without a scientific basis."

So just what does the IPCC project for the next hundred years? The third and latest report, issued in 2001, notes that during the twenty-first century, average global temperatures could rise by between 2.5 and 10.4 degrees Fahrenheit (between 1.4 and 5.8 degrees Celsius). What is notable about the latest IPCC projection is its high upper limit and its significant uncertainty: a factor of four between the upper and lower limits. How does the IPCC arrive at those numbers?

The answer comes not so much from the global-climate models themselves, but from inputs to those models. The inputs depend in turn on projections of future worldwide economic growth, and the extent of its dependence on fossil fuels. To arrive at temperature increases by the year 2100 anywhere near the IPCC's upper limit, you have to assume that developing nations will soon catch up with the West, and that when they do, they will be just as wasteful about energy as Americans are today. All that seems fairly improbable, though a governmental organization such as the IPCC is unlikely to admit as much. As for the lower limit to the IPCC's projection, which assumes much less future reliance on fossil fuels, an increase of that magnitude in the next century is probably something to which the world can adjust.

At the end of the book, Weart implicitly acknowledges that the magnitude of any future climate warming is largely unpredictable. "The biggest source of uncertainty now," he writes, "is not in the science." True, the predicted climate changes caused by greenhouse gases, emissions of aerosols and smoke, and the management of crops and forests, among other things, can be calculated, he writes. But "these changes depend less on geochemistry and biology than on human actions." The skeptic Lindzen might put the matter much the same way.

So what is the global warming debate really all about? It's not about whether global warming is real or not—nearly everyone agrees that it is, at least to some degree. What is ultimately at stake is how best to react to a threat whose severity and impact are so uncertain. And one of the most pressing questions is whether the cost of remediation outweighs the cost of inaction.


Robert & Shana ParkeHarrison, *Reclamation*, 2003

It's also worth pointing out that global warming may not be entirely negative. Weart is far too dismissive of that possibility; he gives it only one short paragraph in the entire book. Yet if the temperature increase in the coming century remains in the lower half of the range projected by the IPCC (that is, less than 5.4 degrees Fahrenheit, or 3 degrees Celsius), there could be numerous benefits both locally and globally, particularly in regions of severe cold.

In part, the benefits would stem from the expected patterns of warming: the warming should be much greater in winter than in summer, and greater in very cold regions than in the more temperate or tropical regions. Hence in most places warming would benefit agriculture—or, at worst, shift it poleward. Higher CO_2 levels and fewer killing frosts should also benefit crops, and higher temperatures would make it feasible to grow valuable crops such as citrus in regions that were once too cold. As for the direct effects of warmer temperatures on human mortality, they should, on balance, be positive in most regions, because the reduction in extremely cold days should more than offset the increase in the number of extremely hot days. Storms and droughts might become more frequent in some places, but not necessarily worldwide, as Weart suggests.

Some consequences of global warming, of course, will be far more negative than positive. A rising sea level would inundate many coastal cities and communities, and both inundation and rapid temperature increases would almost certainly damage natural ecosystems. The latter consequence is particularly worrisome; one recent study has suggested that between 15 percent and 37 percent of all living species could be driven toward extinction by 2050 by global warming. No one can put a dollar value on such terrible loses, should they occur.

But among the impacts that can be calculated, the overall picture is far from clear. Some economists estimate that, on the whole, the effect of a warming up to 5 degrees Celsius could be economically positive for the United States and other developed nations. The effect on developing nations is less likely to be benign. Yet if the scenarios that yield the largest temperature increases are correct in assuming that those nations will soon catch up economically, maybe they, too, will have enough resources to be able to cope with the situation.

On the other side of the ledger, suppose you concede that the overall effect of global warming would probably be negative. Then you might ask, What would it cost to prevent it? Here Weart does not have a great deal to say. He does note that "more and more experts were confident that they could find practical ways to keep climate change within tolerable limits without harming industrial efficiency." Most of the remedies he cites, however, would lead to only modest reductions in greenhouse gases. That isn't to argue against some of Weart's pay-for-themselves ideas for conserving energy and reducing the consumption of fossil fuels. No one who wants to reduce U.S. dependence on foreign oil can dismiss them, just because they do not go very far toward solving the problem of global warming.

Some other ideas of Weart's, however, seem well outside the bounds of what is politically possible—or desirable. For example, he suggests that the United States emulate Europe and add several dollars in tax to gasoline prices. That is simply not going to happen—nor should it. A sizable gasoline tax is regressive, and it would have a drastic economic impact on the nation if imposed suddenly.

Whenever one thinks about the likelihood of a catastrophic impact from global warming, the so-called precautionary principle comes into play. As Weart puts it, "If there is even a small risk that your house will burn down, you will take care to install smoke alarms and buy insurance." So, given all the uncertainties, why shouldn't humanity do whatever it can to eliminate even the smallest risk of a catastrophic warming? My response to that question is: "Smoke alarms, sure, but insurance, maybe not."

The decision to buy insurance can depend on many factors: its cost, how

fireproof your house is, the amount to be paid in the event of a claim, the limitations of the policy, the likelihood that a better policy might be available in the short term. As an insurance policy, for instance, the Kyoto Treaty (which Weart discusses mainly to demonstrate how isolated the U.S. is from world opinion) appears to have little to recommend it. It offers only insignificant reimbursement—in terms of the warming effects it would prevent—in return for what could be a very high cost. A fully implemented Kyoto Treaty would make almost no difference to either the rise in sea level or the probable loss of species. Yet it might divert huge amounts of capital for replacing fossil fuels rapidly with alternative energy sources.

If the dimensions of the global warming problem should turn out to be as severe as many people claim, action far more painful than what is required by the Kyoto Treaty could become necessary. For now, however, the picture is not at all clear—as Weart notes, it may never become completely clear. Nations should certainly adopt prudent, "no-regrets" actions that make sense no matter what the future levels of global warming. Energy conservation and the promotion of nonfossil-fuel energy sources, including nuclear energy, fall in that category. Market forces, including the end of cheap oil and the exploitation of less expensive renewable sources of energy, as well as possible technical fixes for the global-warming problem, such as extracting CO_2 during fossil-fuel combustion, may make any remedial action that much easier in the future. In the meantime, then, why not just stick with "no-regrets" actions?

Robert Ehrlich is a professor of physics at George Mason University in Fairfax, Virginia, and the author most recently of Eight Preposterous Propositions: From the Genetics of Homosexuality to the Benefits of Global Warming *(Princeton University Press, 2003), a series of case studies in how to evaluate evidence for and against controversial questions.*

By Laurence A. Marschall

Ishi's Brain: In Search of America's Last "Wild" Indian
by Orin Starn
W. W. Norton & Company, 2004; $25.95

When Orin Starn visited the Olivet Memorial Park cemetery, just south of San Francisco, several years ago, he could not help noting how strange it was that America's last "wild" Indian now rested in a stark white columbarium flanked by a row of faux Greek columns. Ishi had spent most of his fifty-odd years hunting and gathering along the creeks of northern California. Now his ashes lay behind the glass window of Niche 601, in a black pot of Pueblo Indian origin. Ishi's history, it seems, had ended as incongruously as it had begun.

Ishi, recovering from starvation, September 1911

In August 1911 newspapers nationwide reported the discovery of a starving man crouching in the backyard of a slaughterhouse near the northern California town of Oroville. He wore only a tattered denim shirt, carried a rough sack with some manzanita berries and dried meat inside, and spoke a language no one understood. The anthropologist Alfred Lewis Kroeber, suspecting that Ishi was a cultural fossil, had him brought to San Francisco. Kroeber settled Ishi at the newly opened Museum of Anthropology and saw to it that he was hired as a part-time janitor.

Ishi ultimately adapted well, even to his duties as a "living exhibit," putting on Sunday demonstrations of arrowhead making and other native arts for eager crowds of visitors. He learned to converse in broken English and developed a taste for doughnuts and ice-cream sodas. Professors came west to interview him, take down his utterances, and make wax cylinders of his chants. When he died of tuberculosis in March 1916, the *San Francisco Examiner* reported that he had been cremated "according to the customs of the California tribes," along with his bow and arrows, some acorn meal, and a pouch of tobacco.

But Ishi's story had only begun. Over the years, Californians transformed him into an icon of an unspoiled past they'd never known, the one that existed before the missions, the forty-niners, the farmers, and the freeways turned the state's promised land into a nightmare. In 1961 Kroeber's widow Theodora wrote a best seller portraying Ishi as a noble savage; the book became a favorite of the 1960s flower children.

In the 1980s and 1990s, newly empowered Native Americans began to retell Ishi's story as a case study in cultural imperialism. In 1997 Art Angle, a political activist and a descendent of the Maidu, neighbors of Ishi's Yahi kinfolk, organized an effort to rebury Ishi in the old Yahi territory near Mount Lassen. Rumors circulated among some of the Maidu that Ishi's brain had been removed for scientific study just after his death, though it was not clear what had happened to it after that.

Starn, a cultural anthropologist at Duke University in Durham, North Carolina, played a role in finding the brain, which had been preserved in a jar and sent to the Smithsonian Institution in Washington, D.C., and he writes with undisguised empathy for the California tribespeople who brought Ishi home. But he's too much of a scholar not to note the cultural ironies of the case. Little is known of Ishi's Yahi ancestors, and practically nothing of Ishi himself. But even before he set foot in San Francisco, Ishi

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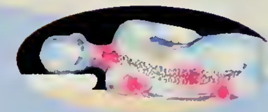

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was no unspoiled innocent. He wore garments of factory-made cloth, foraged for food near homesteads and general stores, and even spoke a few words in the language of his neighbors (Maidu and perhaps Spanish).

The various tribes of native Americans who contributed to bringing about his reinterment have more culture in common with each other—and with the residents of Brooklyn—than they do with Ishi's ancestors. They drive gasoline-powered vehicles, watch the NFL on the tube, and pay more heed to Arnold Schwarzenegger than to the spirits of the hills and woodlands. In the end, the lessons of Ishi's story have more to do with managing cultural identity in the modern era than with returning to Ishi's way of life.

The Book Nobody Read: Chasing the Revolutions of Nicolaus Copernicus
by Owen Gingerich
Walker & Company, 2004; $25.00

Everybody knows that a book by Nicolaus Copernicus set in motion the scientific revolution of the Renaissance, but it's a safe bet that practically no one alive today has read it. *De revolutionibus orbium coelestium* ("On the Revolutions of the Heavenly Spheres"), written in a language no longer spoken, went to press while the Polish astronomer lay on his deathbed in 1543. Even sixteenth-century scholars, who traded Latin one-liners at the dinner table, must have been daunted by the technical prose. Accordingly, and despite its provocative content, Copernicus's book initially raised few hackles among Catholic clergy, who did not place it on their "Index of Prohibited Books" until 1616. In his 1959 best seller *The Sleepwalkers,* Arthur Koestler summed it up as "the book that nobody read."

Was it? In 1970, when Owen Gingerich, then an astrophysicist at Harvard, had a chance to examine a copy of the first edition of *De revolutionibus,* he was impressed by its extensive annotations. Someone had taken the time to examine all of Copernicus's arguments, even the most turgid mathe-

Anon., Nicolaus Copernicus, *German School, 1575*

matical sections. Someone clearly felt the book was worthy of a reading as close as any reading of the Bible or the Talmud. The commentator was unidentified, but the possibility that others might have made such an intensive study of Copernicus was too strong to ignore.

Fascinated by the marginal notes as well as the antiquarian texts themselves, Gingerich became a full-time historian of science. His thirty-year quest to locate, identify, and study all the early editions of Copernicus's magnum opus, with a particular emphasis on annotated copies, became "The Great Copernicus Chase." The chase turned up a rich collection of marginalia, which has led to a deepening understanding of Copernicus's influence and of the intellectual climate of the era. And it culminated, two years ago, in Gingerich's weighty *An Annotated Census of Copernicus' De Revolutionibus.*

Few people are likely to read Gingerich's census, but anyone who appreciates the printed word will gallop through his new account of how it came to be. *The Book Nobody Read* moves around the world like an espionage thriller—from federal courtrooms in Washington (where Gingerich was an expert witness in the prosecution of a book thief), to Beijing, Australia, Soviet-era Leningrad, and the Vatican. Using investigative techniques worthy of Sherlock Holmes, Gingerich has identified the personal copies owned by such figures as Johannes Kepler and Adam Smith. Many, *pace* Koestler, bought the book to read it; others became buyers just because it was rare and important.

Gingerich describes their lives so vividly that it seems he's met them in the flesh. Yet whenever the reader begins to tire of historical minutiae, Gingerich throws in charming tidbits of bibliophilic lore. Attentive readers will learn how many books a sixteenth-century printing press could produce in a day, which insects bore round holes through the pages of old books, and how a German library once sold off a copy of Newton's *Principia* because it was too heavily annotated, only to discover that the notations were made by Newton's contemporary and archrival Gottfried Wilhelm Leibniz.

Now that its first editions bring as much as $800,000 at rare-book auctions, *De revolutionibus* has truly become a book that few can read, at least in its original editions. Spend a few hours, then, with *The Book Nobody Read,* which, title notwithstanding, is a book to be read by everybody.

A Bat Man in the Tropics: Chasing El Duende
by Theodore H. Fleming
University of California Press, 2003; $50.00

A disclaimer: my experiences with bats amount to a few memorable jousts at two A.M., when, roused from my slumber by a thrumming of wings followed by a nudge from the other side of the bed, I have grabbed a tennis racket and ushered a night flyer out through an open bedroom window. Beyond these close encounters, I knew little about bats before reading this book, though, unlike many, I regard them as more annoying than fearsome.

Bats, I now recognize, are victims of bad PR. In the countryside of Mexico and in rural Central America, reports Theodore Fleming, it is common to assume all bats are vampires. But few bats are actually bloodsuckers. Most bats, if they eat meat at all, eat insects, small rodents, and lizards; several insect-eating species consume half their own body weight (and sometimes more) in insects on each night's foraging raid. Bats are therefore not to be feared but conserved, not only for their control of insect populations, but also for their pollination and seed dispersal of many highly valued plants, including such delicacies as mangoes and figs.

A good deal of credit for dispelling misinformation about bats goes to Fleming, one of the rare humans for whom bats are a passion. Among bat mammalogists, he's something of a gray eminence. Fleming can identify species by their smell, their sound, or their droppings. He's perfectly at home sitting in a pitch-dark cavern while tens of thousands of web-winged creatures flap around him. He even knows which bats urinate while hanging upside down, and which turn themselves upright beforehand (the smaller species do it upside down).

Black flying foxes (Pteropus alecto), *western Australia*

Fleming's account of his studies is notable not just for war stories and bat lore, but also for his instructive account of the variety of investigative techniques required to practice good biology. In the 1970s he began to attach small radio transmitters to the backs of bats (they didn't seem to mind). By day, the radio signals would guide him to hidden sleeping places in hollow trees and in hillside caves in the Costa Rican rainforest. By night, as the bats emerged from their roosts, he and a small group of volunteers and graduate students would track the beeps, patiently mapping out the bats' activity patterns and favorite foraging places.

Later, in studies of the lesser long-nosed bat *(Leptonycteris curasoae)*, which pollinates cactus flowers in the Sonoran Desert of Mexico, Fleming attached small vials of luminous chemicals to the backs of the bats. Then, taking advantage of the open terrain, he simply watched the moving "fireflies" through binoculars from a high vantage point to see which cactuses best attracted the bats. When he discovered that some species migrate hundreds of miles a year, he began snipping minute samples of wing tissue from bats he caught in mist nets. He could then track a migrating population by analyzing the samples for their mitochondrial DNA.

For the future, Fleming has both good news and bad news. Bat species may be more resilient to habitat loss than other wild mammals because their diets are more adaptable and because they can fly. And public appreciation of bats is beginning to work in their favor too, thanks to some enlightened efforts at environmental education. But during his three decades in the field, Fleming has seen so many dirt roads become paved highways, and so many forests turned to cropland, that he cannot be certain how much longer his beloved creatures will continue to rule the night.

Laurence A. Marschall, author of The Supernova Story, *is the W. K. T. Sahm professor of physics at Gettysburg College in Pennsylvania, and director of Project CLEA, which produces widely used simulation software for education in astronomy.*

The Good Earth

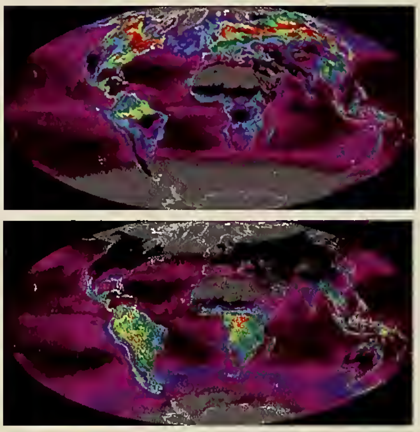
By Robert Anderson

With the coming of spring and the return of green to the Northern Hemisphere, what better way than the Web to explore the extraordinary process of photosynthesis? If you're lucky enough to cultivate your own garden, you know you must seed on a tight schedule, often dictated by the arrival of the final frost of winter. To find maps showing average annual minimum temperatures in the United States, visit the monthly garden zine (www.thegardenhelper.com). Under the title, click on "Garden Encyclopedia," then scroll down until you find the list of links for "USDA Hardiness Zones." On the same page, check out the schedule of gardening tasks for April.

Not surprisingly, perhaps, the process that greens the planet also protects it. Photosynthesis helps cool the atmosphere by absorbing carbon dioxide, a greenhouse gas, and it is a critical factor to consider in forecasting climate change and global warming [*see "Heat Exchange," by Robert Ehrlich, page 58*]. I found a remarkable, fresh perspective on photosynthesis at NASA's "Earth Observatory" site, in an animation that accompanies an article on Earth's carbon "metabolism" (earthobservatory.nasa.gov/Newsroom/NPP/npp.html).

Every eight days for the years 2001 and 2002, NASA combined land-based data with data from Terra and Aqua, two Earth-orbiting satellites, to generate composite maps of the world's "net primary production" of carbon dioxide—the amount absorbed during photosynthesis, minus the amount given off during respiration. Scroll down the "Earth Observatory" site to "animations," on the right, where you'll find the composite maps compressed into a short film (download the larger, twenty-megabyte version if you have a fast Internet connection). In the film, tides of photosynthesis ebb and flow with the seasons across the oceans and continents of our planet [*two images made from the maps are shown below*].

NASA also keeps track of the abundance of aquatic life by measuring the chlorophyll in the microscopic marine plants known as phytoplankton. At nasa.gov/Observatory/Datasets/chlor.czcs.html you can use data sets obtained by satellites to "build" your own animated illustrations of the shifting concentrations of chlorophyll.



False-color maps from NASA's "Earth Observatory" Web site (see text) graphically portray satellite data showing photosynthesis rates in June (top) and December (bottom). The colors depict the rate of the Earth's "metabolism"—the rate of carbon absorption by plants: the rates are highest in red and yellow areas, and progressively lower in areas colored green, blue, and purple.

If you want to start your acquaintance with photosynthesis with some history and a simple explanation, go to www.chm.bris.ac.uk/motm/chlorophyll/chlorophyll_h.htm, a site run by Paul May, a chemist at the University of Bristol in England. Another approach—one my children prefer—is through well-illustrated pages, such as the ones at David Watson's "Flying Turtle" site (www.ftexploring.com/photosyn/photosynth.html).

Devens Gust, a biochemist at Arizona State University in Tempe, offers a good introduction to the importance of photosynthesis for life on Earth (go to photoscience.la.asu.edu/photosyn, scroll down to "Educational Resources," and click on "Why Study Photosynthesis?"). Gust works at the university's Center for the Study of Early Events in Photosynthesis, which has become a Web clearing house for information on the subject. In the same resources list, you'll also find a long, well-organized directory of related sites (click on "Photosynthesis and the Web").

As the name implies, photosynthesis is powered by electromagnetic radiation. Even a cursory glance at a diagram of the chain of events needed to convert photons into food hints at what a complex process it is. (See, for instance, the diagram at www.uqtr.ca/labcarpentier/eng/home_frames.htm of "Electron transport in the photosynthetic membrane," by Robert Carpentier, a biochemist at the University of Quebec at Trois-Rivières.) For more information about how the photosynthetic process got under way on Earth, you can try www.ucmp.berkeley.edu/bacteria/cyanointro.html, a site run by UCLA's Museum of Paleontology.

Perhaps the most intriguing aspect of the study of photosynthesis, however, is the promise it holds for a sustainable future. The world's hunger for fossil fuels is rapidly depleting the photosynthetic bonanza that took hundreds of millions of years to store as coal and oil. But biochemists may soon figure out how to duplicate nature's most important chemical reaction, and harness it more directly to make our fuel from scratch.

Robert Anderson is a freelance science writer living in Los Angeles.

EXPLORER GUIDE

it's somewhat disingenuous of you to contend that people should no longer go into space. To take that position is, in effect, to deny the next generation of students the thrill of following the same path you did: enabling one of our own kind, not just a robotic emissary, to walk on the frontier of exploration.

Whenever we hold an event at the Hayden Planetarium that includes an astronaut, I've found there's a small but noticeable uptick in attendance. People invariably seek the astronaut's autograph. This celebrity status holds even for astronauts most people have never heard of. Any astronaut will do. The one-on-one encounter makes a difference in the hearts and minds of Earth's armchair space travelers—whether retired science teachers, hardworking bus drivers, thirteen-year-old kids, or ambitious parents.

Of course, people have been excited about robots lately, too. From January 3 through January 5, 2004, the NASA Web site that tracks the doings of the Mars rovers got more than half a billion hits—506,621,916 to be exact. That's a record for NASA.

The solution to the quandary seems obvious to me: send both robots and people into space. Space exploration needn't be an either/or transaction, because there's no avoiding the fact that robots are better suited for certain tasks, and people for others.

One thing is certain: in the coming decades, the U.S. will need to call upon multitudes of scientists and engineers from scores of disciplines, and astronauts will have to be extraordinarily well trained. The search for evidence of past life on Mars, for instance, will require top-notch biologists. But what does a biologist know about planetary terrains? Geologists and geophysicists will have to go, too. Chemists will be needed to check out the atmosphere and sample the soils. If life once thrived on Mars, the remains might now be fossilized, and so perhaps we'll need a few paleontologists to join the fray. People who know how to drill through kilometers of soil and rock will also be must-haves, because that's where Martian water reserves might be hiding.

How to recruit the scientists of the future? Introduce a kid to an astronaut.

Where will all those talented scientists and technologists come from? Who's going to recruit them? Personally, when I give talks to students old enough to decide what they want to be when they grow up, but young enough not to get derailed by raging hormones, I need to offer them a tasty carrot to get them excited enough to become scientists. That task is made easy if I can introduce them to astronauts looking for the next generation to share their grand vision of exploration and join them in space. Without such inspiring forces behind me, I'm just that day's entertainment. My reading of history tells me that people need heroes. Nobody ever gave a ticker-tape parade for a robot.

Twentieth-century America owed much of its security and economic strength to its support for science and technology. Some of the most revolutionary (and marketable) technology of the past several decades has been spun off the research done under the banner of U.S. space exploration: kidney dialysis machines, implantable pacemakers, corrosion-resistant coatings for bridges and monuments (including the Statue of Liberty), hydroponic systems for growing plants, collision-avoidance systems on aircraft, digital imaging, infrared handheld cameras, cordless appliances, athletic shoes, scratch-resistant sunglasses, virtual reality. And that list doesn't even include Tang.

Although solutions to a problem are often the fruit of direct investments in targeted research, the most revolutionary solutions tend to emerge from cross-pollination with other disciplines. Medical investigators might never have known of X rays, since they do not naturally occur in biological systems. It took a physicist, Wilhelm Conrad Röntgen, to discover them—light rays that could probe the body's interior with nary a cut from a surgeon.

Here's a more recent example of cross-pollination. Soon after the Hubble Space Telescope was launched in April 1990, NASA engineers realized that the telescope's primary mirror—which gathers and reflects the light from celestial objects into its cameras and spectrographs—had been ground to an incorrect shape. In other words, the billion-and-a-half-dollar telescope was producing fuzzy images.

That was bad.

As if to make lemonade out of

lemons, though, computer algorithms came to the rescue. Investigators at the Space Telescope Science Institute in Baltimore, Maryland, developed a range of clever and innovative image-processing techniques to compensate for some of Hubble's shortcomings. Turns out, maximizing the amount of information that could be extracted from a blurry astronomical image is technically identical to maximizing the amount of information that can be extracted from a mammogram. Soon the new techniques came into common use for detecting early signs of breast cancer.

But that's only part of the story.

In 1997, for Hubble's second servicing mission (the first, in 1993, corrected the faulty optics), shuttle astronauts swapped in a brand-new, high-resolution digital detector—designed to the demanding specs of astronomers whose careers are based on being able to see small, dim things in the cosmos. That technology is now incorporated in a minimally invasive, low-cost system for doing breast biopsies, the next stage after mammograms in the early diagnosis of cancer.

So why not ask investigators to take direct aim at the challenge of detecting breast cancer? Why should innovations in medicine have to wait for a Hubble-size blunder in space? My answer may not be politically correct, but it's the truth: when you organize extraordinary missions, you attract people of extraordinary talent who might not have been inspired by or attracted to the goal of saving the world from cancer or hunger or pestilence.

Today, cross-pollination between science and society comes about when you have ample funding for ambitious, long-term projects. America has profited immensely from a generation of scientists and engineers who, instead of becoming lawyers or investment bankers, responded to a challenging vision posed in 1961 by President John F. Kennedy. "We intend to land a man on the Moon," proclaimed Kennedy, welcoming the citizenry to aid in the effort. That generation, and the one that followed, was the same generation of technologists who invented the personal computer. Bill Gates, co-founder of Microsoft, was thirteen years old when the U.S. landed an astronaut on the Moon; Steve Jobs, co-founder of Apple Computer, was fourteen. The PC did not arise from the mind of a banker or artist or professional athlete. It was invented and developed by a technically trained workforce, who had responded to the dream unfurled before them, and were thrilled to become scientists and engineers.

Yes, the world needs bankers and artists and even professional athletes. They, among countless others, create the breadth of society and culture. But if you want tomorrow to come—if you want to spawn entire economic sectors that didn't exist yesterday—those are not the people you turn to. It's technologists who create that kind of future. And it's visionary steps into space that create that kind of technologist. I look forward to the day when human beings travel the solar system as if it's our own backyard—not only with robots, but with real live people, guided by our timeless and boundless need to explore.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of the Hayden Planetarium in New York City. He was recently appointed by President Bush to serve on the nine-member President's Commission on Implementation of United States Space Exploration Policy.

Answer to "Cryptic Creatures" puzzle (page 14): c

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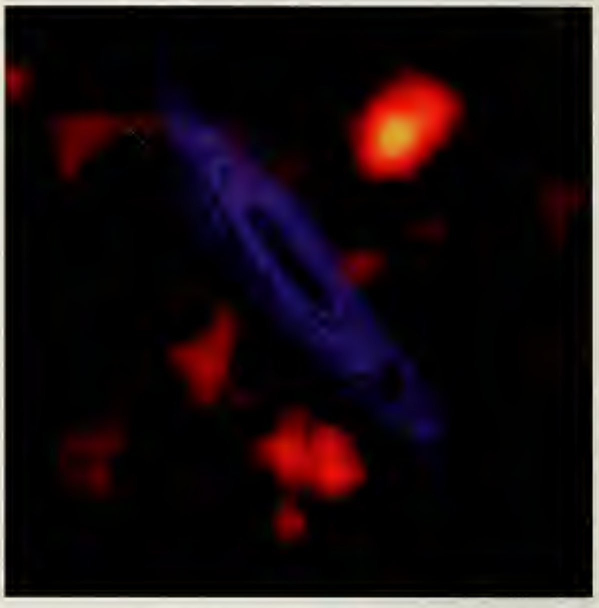
Gas Guzzlers

When great galaxies gobble gobs of matter, new stars are born.

By Charles Liu



False-color radio image shows the Andromeda Galaxy (tilted blue disk, center) and its surrounding hydrogen clouds. The blue disk, approximately 100,000 light-years across, is all that is seen of Andromeda in visible light; the red patches are swiftly moving clouds of cold gas whose radio emissions were recently detected. These clouds appear to orbit Andromeda and may eventually fall into the galaxy, providing fuel for new generations of stars.

Young galaxies grow by making lots of new stars. Those stars begin to form when diffuse gas collects into clouds; eventually the clouds collapse under their own weight, and their cores become hot and dense enough to ignite nuclear fusion. So if you spot a galaxy whose mass is mostly interstellar gas, it's probably still young and still growing rapidly; in billions of years, as the galaxy passes through adolescence and into maturity, it will consume nearby gas clouds while its star population proliferates.

By that benchmark, our own galaxy is an old-timer. The Milky Way is known, on independent grounds, to be more than 10 billion years old, and the mass of its interstellar gas is only about a hundredth that of its stars. It could still grow by eating up its neighbors—the Sagittarius dwarf galaxy, for instance [*see "Warp Factor," by Charles Liu, April 2003*]—thus adding ready-made bunches of stars to its own stellar population. Or, if the galaxy being eaten also contains a large amount of gas, a new burst of star formation could take place.

Such episodes have happened in the past and may happen again soon: a vast river of gas is streaming toward the Milky Way from two smaller, gas-rich galaxies called the Magellanic Clouds, perhaps foreshadowing their eventual consumption by the Milky Way.

Astronomers have long wondered, however, whether our galaxy is also still forming stars the old-fashioned way, by gathering clouds from diffuse gas. In the past several decades we've detected hundreds of big, cold gas clouds moving rapidly all over the sky. Some astronomers have theorized that many of those clouds are made of interstellar gas left over from the Milky Way's youth—gas now in orbit about our galactic environs and slowly being sucked in. But it's been impossible to tell whether the clouds are orbiting the Milky Way, or simply occupying interstellar space at large, random distances from the galaxy—and thus not likely ever to fall in and form stars.

Now a team of astronomers led by David A. Thilker of the Johns Hopkins University in Baltimore has reported an important new result that addresses that question, albeit indirectly. The team has found a system of large, starless interstellar gas clouds orbiting a nearby galaxy: Andromeda.

Andromeda is the Milky Way's sister in space. Both galaxies are spirals of roughly the same age, with stars strewn across flattened disks of roughly the same size, more than 100,000 light-years across. And they are only about 2.5 million light-years apart, barely a stone's throw in intergalactic terms. Together, they anchor the so-called Local Group of galaxies, a loose aggregate of several dozen collections of stars, dust, and gas.

Andromeda's proximity and similarity make it an important astronomical laboratory. Stuck as we are in a corner of our galaxy's stellar disk, we astronomers need to look at the neighbors for clues about what our own galaxy's outer structure might be. The nearby Magellanic Clouds and other dwarf galaxies such as Sagittarius are too small to serve as proxies for the Milky Way; Andromeda, though, fits the bill just fine.

Such a cosmic comparison is exactly what's needed to test the large-scale spacing of the big, cold gas clouds that seem to be associated with the Milky Way. The logic of the test goes like this: First, assume that if Andromeda has old gas clouds orbiting around it, then the Milky Way does too. Then look for a set of orbiting clouds in Andromeda and its vicinity. From our distant vantage point it should be possible, at least in principle, to see clouds orbiting Andromeda even farther out than the 100,000-light-year diameter of its disk. If the clouds do seem to be orbiting Andromeda, then at least some of the clouds near the Milky Way are probably orbiting our galaxy as well.

Old, cold gas clouds don't show up in optical telescopes. But they do emit radio waves twenty-one centimeters long—about a tenth the wavelength of an FM radio signal. So Thilker and his colleagues trained the 8,000-ton Green Bank Telescope (GBT) at the National Radio Astronomy Observatory in West Virginia in the direction of Andromeda. With that instrument, Thilker's group discovered more than twenty distinct gas clouds within 150,000 light-years of Andromeda, as well as an extensive system of gaseous filaments interlaced among them. The motions of the clouds appear to be those of an orbiting system, gravitationally bound to the galaxy; a number of the clouds appear to be part of a broad stream of gas more than 60,000 light-years long.

No one knows whether all the clouds orbiting Andromeda are left over from the galaxy's early history. Some of them may be the gaseous remnants of satellite galaxies swallowed by the main galaxy long ago. Either way, whenever one of the gas clouds wanders too close to Andromeda, its gas becomes fresh fuel for the creation of stars. It's like pouring lighter fluid onto a campfire of cosmic scale: the staid old galaxy flares up in a new burst of star birth, recalling the heady days of its youth.

The existence of a gas cloud system around Andromeda strongly suggests that at least some of the isolated gas clouds detected around the Milky Way are also part of an orbiting ensemble. That, in turn, would mean that every so often, just as with Andromeda, our galaxy gets another infusion of gas, which, soon thereafter, begets a brand-new gaggle of stars. With such regular refreshment, there will be plenty of young stars in the Milky Way for a long time to come—and, even as it cruises through middle age, our galaxy will continue to grow.

Charles Liu is professor of astrophysics at the City University of New York and an associate at the American Museum of Natural History.

THE SKY IN APRIL

By Joe Rao

Mercury can be spotted for the first few evenings of April far to the west of Venus. On the evening of the 1st, Mercury shines at magnitude 0.6 and sets at about the end of twilight. Look to the west-northwestern horizon about forty-five minutes after sunset. For the next several days Mercury fades rapidly, to magnitude 1.6, and sets progressively earlier; by the 5th the planet almost vanishes. Inferior conjunction, the midpoint of its passage between the Earth and the Sun, takes place on the 17th.

Venus grows ever brighter in the warming spring evenings. As April begins, it's as high in the sky as it ever gets at sunset, and sets about four hours after the Sun. The early nights of April have an extra treat in store: the planet nearly crosses paths with the Pleiades. On the 3rd, in fact, Venus approaches so close—about half a degree from the center of the star cluster—that its dazzling light will probably overwhelm even the brightest star in the cluster. You may need binoculars to see the cluster properly then—though on other nights both planet and cluster should be visible to the unaided eye. Throughout April a telescope shows Venus slimming from nearly half-lit to a distinct crescent.

Mars opens the month shining at magnitude 1.4, about 180 million miles from Earth, situated between the V-shaped Hyades and the Pleiades star clusters. It is hard to believe such an unassuming point of light is the same object that made headlines last August when it passed so near the Earth. Throughout April Mars appears to "chase" Venus, recalling the romantic affair of their mythical namesakes. By month's end Mars dims even further, to second magnitude, and recedes to a distance of more than 201 million miles from Earth.

Jupiter, though still a splendid sight in the constellation Leo, the lion, is now well past its glorious opposition of March 4. Hence as twilight ends, the planet is already high in the southeast. After Venus, Jupiter may well be one of the first "stars" you'll see as darkness falls. As dusk deepens, look for the star Regulus, shining only about one-twenty-eighth as brightly as Jupiter, nine or ten degrees to the planet's west. The Moon visits Jupiter twice in April. On the evening of the 2nd, the planet shines with a bright and silvery light to the right of the Moon; by the 29th, just after sunset, the Moon appears to hover almost directly above Jupiter, high up in the south.

Saturn, in the constellation Gemini, the twins, is readily visible all month long as a yellowish-white zero-magnitude "star" in the western sky during the first half of the night. Even in a small telescope, Saturn continues to tip its ring system toward us with eerie elegance. On the evening of the 24th the planet dances with a fat crescent Moon.

The Moon waxes full on the 5th at 7:03 A.M. It wanes to last quarter on the 11th at 11:46 P.M. and becomes new on the 19th at 9:21 A.M. It waxes to first quarter on the 27th at 1:32 P.M.

Spring ahead in much of Canada and the United States, as daylight saving time returns at 2:00 A.M. local time on Sunday, the 4th. Remember to set clocks forward one hour.

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


AMNH

EarthBulletin in the Gottesman Hall of Planet Earth

Science Bulletins

Bringing science news into the halls—and beyond

by Ashton Applewhite

New planets! New species! Eruptions! Quakes from space! How can a museum present science in a way that reflects its dynamic nature? When the Museum opened a series of permanent exhibition halls—the Hall of Biodiversity in 1997, the Gottesman Hall of Planet Earth in 1999, and the Cullman Hall of the Universe in the Rose Center for Earth and Space in 2000—it wanted to be certain that there were ways to present current science. Enter the EarthBulletin, BioBulletin, and AstroBulletin: cutting-edge science delivered electronically on plasma screens, touch-screen kiosks, and the Museum Web site (**http://sciencebulletins.amnh.org/**).

Each Bulletin is housed in its respective hall and presents current science in three formats: documentary feature stories, data visualizations, and weekly news about events like the rover *Spirit*'s landing on Mars, the devastating earthquake in the Iranian city of Bam, or the dire consequences of illegal logging in Indonesia. Created in high-definition digital video and projected on large plasma screens at four times the resolution of standard television, the Bulletins look spectacular. "It can be a challenge to convey the dynamic nature of science in a museum setting, and that's why we're excited about the Bulletins," says Mike Novacek, Senior Vice President and Provost of Science. "The combination of compelling images and 'breaking news' really engages visitors in what's happening across the sciences and around the world."

Staff scientists collaborate intensively on the content of each program. "The combination of high production values with demanding editorial standards really makes the Science Bulletins unique," comments Rosamond Kinzler, Director of the National Center for Science Literacy, Education and Technology, a group within the Department of Education that works to extend the scientific and cultural resources of the Museum beyond its walls. The overall editorial content is overseen by Michael Shara, Curator-in-Charge, Department of Astrophysics, Edmond Mathez, Curator, Department of Earth and Planetary Science, and Eleanor Sterling, Director, Center for Biodiversity and Conservation.

The documentary features are five- to seven-minute high-definition videos that follow men and women into the field as they conduct their research. Describing the $80,000 camera as "a computer on your shoulder," Director of Photography Jason Lelchuk gets to hoist it while chest-deep in Thailand's Andaman Sea shooting mangroves, or leaning out the belly of a fixed-wing Cessna to pan across the Arctic National Wildlife Refuge. Keeping all the gear working is only part of the job. The other part is figuring out how to tell the story, which, according to Lelchuk, is largely a matter of being in the right place at the right time. "There are going to be a series of sincere, real moments that you cannot re-create. A good documentary is usually based on getting a bunch of them"—like the moment that the first herd of wild horses to roam free in Mongolia in 50 years thundered out of their crates and into the Gobi Desert.

Scientists now study extremely complex phenomena using massive amounts of computer-generated data, and these data have to be rendered visually in order to be comprehensible. Staff scientist Ned Gardiner is the team's expert in the remote sensing technology on which this component of the Bulletins is based. "We're the first generation of humans to be able to step back and see Earth," he observes. "The first astronauts were changed forever by seeing the thin blue line separating life as we know it from the vast emptiness of deep space." That fragile envelope and its contents are the focus of the Bulletins' Earth and Bio data visualizations, which use NASA satellite data to bring complex, large-scale, and long-term natural phenomena to life, such as changes over time in the ozone hole, sea ice extent, sea surface temperature, land cover, fires, and urban sprawl. Annotations explain the information contained in the data, and how conservation biologists, planners, and ecologists like Gardiner himself put it to use. Staff scientist and geophysicist Al Duba observes that the EarthBulletin helps visitors understand how the planet works, "which helps them make informed decisions in important areas like conservation, mitigating hazards, and maintaining a healthy environment."

Compelling images and breaking news engage visitors in what's happening in the sciences.

Animator and production designer Bill Bourbeau creates animations for the features and the data visualizations. "I have to learn the science in layman's terms and then translate it graphically," he explains. His toughest recent task was to make an animation of the first 10,000 years after the Big Bang for a story on cosmic microwave background radiation. "I had to create a dynamic system that matched the physics the scientists were telling me about, and at the same time make something that was interesting to watch," he explained.

The Bulletins also use compelling 3-D graphics to report on a weekly basis on changes in the biosphere, Earth events, and news from space—explosions from an Ecuadorian volcano, for example, or a black hole devouring a companion star. Reporting these high-concept research programs is tough, especially when it comes to astrophysics. "You're typically using specialized scientific terminology, the time and space scales are huge, and you're describing phenomena that are invisible," points out Research Scientist Orsola De Marco. "And you have to convey why they're important."

The technical challenge comes from working in so many different media types. A staff of only 14, not counting the scientific advisors and Rose Center staff who provide technical assistance, does all the production, "which is rare in this field," comments Senior Producer Vivian Trakinski.

The Bulletins were designed with the idea of disseminating them to other museums, but this involved a technical first: encoding high-definition video efficiently enough to enable distribution and weekly updating over the Internet. "Now I'd call it cutting-edge technology, but when I first came, it was bleeding edge," acknowledges Distribution Manager Len Siegfried with a grin. It took many hours of figuring out the encoding process, a high-bandwidth Internet connection for the Museum, and the evolution of MPEG2 technology. But now, for the cost of the basic hardware plus a modest subscription fee, science centers, museums, and other sites can receive the Bulletins online every week like clockwork. Twenty institutions in 14 states and Canada are already on board, including five NASA facilities.

Trakinski loves working with her "phenomenally talented" Bulletins crew, as well as the opportunity to document science in action. She's observed cosmic microwave radiation with scientists in Antarctica and traveled to Sioux City, Iowa, to cover the birth an ox-like animal called a gaur, the first endangered species to be cloned. This "inside scoop" on how science is done enables the Bulletins to engage museum visitors across the country in the nature and scope of ongoing scientific discovery of the highest caliber.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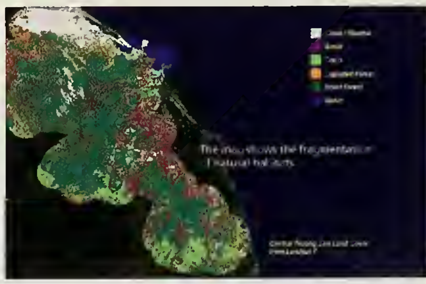
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Left to right: Science Bulletins crew working on the BioBulletin *Wild at Heart*, about elephants in Thailand; Breaking News in Astronomy: Extrasolar Planets (illustration created by NASA); Data visualization: Vietnam land cover (data source: NASA's Landsat 7)

The AstroBulletin is generously supported by Toyota Motor North America, Inc. Significant educational and programming support is provided by the National Aeronautics and Space Administration (NASA). The EarthBulletin is generously supported by Morgan Stanley. Funding for the BioBulletin provided by The New York Times Company Foundation.

Museum Events

AMERICAN MUSEUM of NATURAL HISTORY

EXHIBITIONS

Exploratorium/AMNH
Through August 15
This exhibition invites visitors to explore fundamental concepts and phenomena in the natural sciences. Fun, hands-on displays clustered around four themes—Earth processes, rotation, mirrors and illusion, and pendulums—encourage audiences of all ages and all levels to investigate and play.

Exploratorium/AMNH is funded in part by a grant from the Small Business Administration. For information on accessibility, call 212-769-5100.

Seasons of Life and Land: Arctic National Wildlife Refuge
Through September 6
Over 40 large-format color photographs by conservationist Subhankar Banerjee focus on the interdependence of land, water, wildlife, and humanity in Alaska's Arctic Refuge.

Petra: Lost City of Stone
Through July 6
This exhibition tells the story of a thriving metropolis at the crossroads of the ancient world's major trade routes.

In New York, *Petra: Lost City of Stone* is made possible by **Banc of America Securities** and **Con Edison.** The American Museum of Natural History also gratefully acknowledges the generous support of Lionel I. Pincus and HRH Princess Firyal and of The Andrew W. Mellon Foundation. This exhibition is organized by the American Museum of Natural History, New York, and the Cincinnati Art Museum, under the patronage of Her Majesty Queen Rania Al-Abdullah of the Hashemite Kingdom of Jordan. Air transportation generously provided by Royal Jordanian.

The Bedouin of Petra
Through July 6
Photojournalist Vivian Ronay's evocative color photographs document the Bedoul group of Bedouin tribes living near the archaeological site of Petra in Jordan.

This exhibition is made possible by the generosity of the Arthur Ross Foundation.

The Butterfly Conservatory: Tropical Butterflies Alive in Winter
Through May 31
The butterflies are back! This popular exhibition includes more than 500 live, free-flying tropical butterflies in an enclosed tropical habitat where visitors can mingle with them.

The Butterfly Conservatory is made possible through the generous support of Bernard and Anne Spitzer.

LECTURES

WNET Innovation Series
Thursday, 4/8
7:00 p.m.

A preview screening of "Healing Cell," an exploration of cutting-edge biomedical breakthroughs, part of Thirteen/WNET New York's *Innovation* series for PBS.

Lords and Lemurs
Thursday, 4/15, 7:00 p.m.
Alison Jolly discusses conservation in Madagascar, a country where tribal kings, ex-colonialists, and powerful multinationals all have a stake. Book signing follows.

FIELD TRIPS

Spring Bird Walks in Central Park
Eight Tuesdays, 4/6–5/25
7:00–9:00 a.m.
Eight Wednesdays, 4/7–5/26
7:00–9:00 a.m.
Eight Thursdays, 4/8–5/27
7:00–9:00 a.m. or
9:00–11:00 a.m.
Observe the spring migration of birds in Central Park with Museum naturalists.

FAMILY AND CHILDREN'S PROGRAMS

Dr. Nebula Explores: Light and Optics
Sunday, 4/18, 3:00–4:00 p.m.
(Ages 4 and up, accompanied by an adult)
Dr. Nebula and his apprentice Scooter expose the mysteries of light and optics.

Astro Favorites for 4- to 6-Year-Olds
Three Thursdays, 4/15–29
4:00–5:30 p.m.
(Ages 4–6, each child with one adult)
Our most popular children's workshops, Einstein: Adventures in Light; I Want to Be an Astronaut; and Moons, Meteorites, and Mars, are now available as a discounted series.

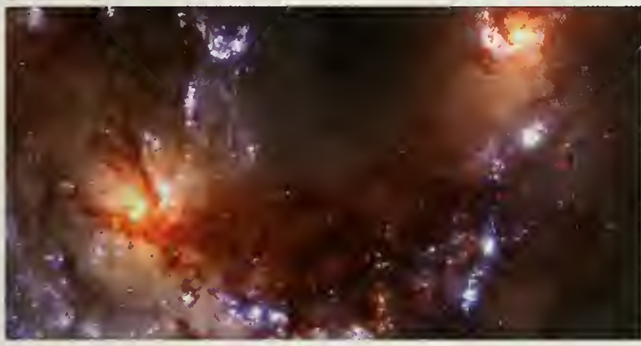
VIVIAN RONAY

Tourists entering Petra through the Siq

Life on Mars?
Saturday, 4/24
12:30–2:00 p.m. (Ages 8–10)
3:00–4:30 p.m. (Ages 11–13)
Learn how humans might survive on Mars: from recycling water, to growing your own food, to what to do in your spare time.

HAYDEN PLANETARIUM PROGRAMS

2004 ISAAC ASIMOV MEMORIAL PANEL DEBATE
The Dark Side
Wednesday, 4/21, 7:30 p.m.
A lively debate on all that is dark and unknown in the universe.
Made possible through the generosity of the Asimov family and friends.



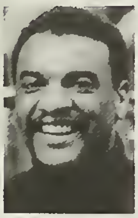
B. WHITMORE (STSCI) AND NASA

The Antennae Galaxies, NGC4038 and NGC4039, are colliding.

Space Explorers: The Moon and Its Phases
Tuesday, 4/13, 4:30–5:45 p.m. (Ages 10 and up)
On the second Tuesday of each month, kids can learn under the stars of the Hayden Planetarium Space Theater.

STARRY NIGHTS
Live Jazz

Friday, April 2
5:30 and 7:00 p.m.
Rose Center for Earth and Space



Joe Chambers and the Urban Grooves Band

Tune in to the 5:30 set live on WBGO Jazz 88, hosted by *Morning Jazz*'s Gary Walker.

Starry Nights is made possible by Lead Sponsor Verizon and Associate Sponsors CenterCare Health Plan, Constellation NewEnergy, and WNBC-TV.

TUESDAYS IN THE DOME

Virtual Universe: The Distance Stepladder
Tuesday, April 6, 6:30–7:30 p.m.

This Just In. . . April's Hot Topics
Tuesday, April 20
6:30–7:30 p.m.

Celestial Highlights: The Comet Is Coming (Maybe)
Tuesday, April 27
6:30–7:30 p.m.

COURSES

All about Telescopes
Four Mondays, 4/26–5/17
6:30–8:30 p.m.

Introduction to Astronomy
Six Mondays, 4/19–5/24
6:30–8:30 p.m.

Stellar Death
Five Thursdays, 4/1–29
6:30–8:30 p.m.

Scientific Explosion: The Expanding Universe
Five Thursdays, 4/1–29
6:30–8:30 p.m.

Photons to Photos
Four Tuesdays, 4/6–27
6:30–8:30 p.m.

LECTURES

Galaxies and the Cosmic Frontier
Monday, 4/19, 7:30 p.m.
With William Waller, NASA's New England Space Science Initiative in Education.

The Acceleration of the Universe
Monday, 4/26, 7:30 p.m.
With Ruth Daly, Penn State University.

PLANETARIUM SHOWS

SonicVision
Fridays and Saturdays
7:30, 8:30, 9:30, and 10:30 p.m.
A mind-warping musical and visual roller-coaster ride.
SonicVision is made possible by generous sponsorship and technology support from Sun Microsystems, Inc.

The Search for Life: Are We Alone?
Narrated by Harrison Ford
Made possible through the generous support of Swiss Re.

Passport to the Universe
Narrated by Tom Hanks

LARGE-FORMAT FILMS

LeFrak Theater

Volcanoes of the Deep Sea
Explore Earth's most hostile environments and its strangest creatures, and consider the implications for our search for life in the universe.

India: Kingdom of the Tiger
A glorious tribute to this magnificent land and its greatest ambassador—the mighty Bengal tiger.

INFORMATION

Call 212-769-5100 or visit www.amnh.org.

TICKETS AND REGISTRATION

Call 212-769-5200, Monday–Friday, 9:00 a.m.–5:00 p.m., or visit www.amnh.org.
A service charge may apply.

All programs are subject to change.

ENDPAPER

No-Fly Zone

By Robert Zimmerman

For Aleksandr Balandin the smell was quite foul. It was his job, as he moved weightlessly around the Mir space station, to care for six quail chicks. The chicks had recently hatched from the eggs he and Anatoliy Solovyov had carefully monitored for more than two weeks. The two cosmonauts were desperately trying to keep the birds alive.

In zero gravity, though, nothing worked in the usual way. Bird droppings, for instance, didn't do what bird droppings do on Earth: they didn't drop. The cosmonauts had tried to catch the waste by rigging the bird's living area with a fine mesh net. But the droppings kept sticking to the birds, floating behind them like gooey slime. Balandin had to clean the chicks by hand, again and again.

A quail in hand

The trouble was, there was nothing to be done about the awful smell. The space station was orbiting about 300 miles above the Earth, so Balandin and Solovyov couldn't very well throw open a window to clear the air.

I interviewed Balandin in Moscow in 2002, twelve years after his adventures aboard Mir. A soft-spoken man with an easy sense of humor, he told me he found the situation ironic. He and Solovyov had lived and worked on the orbiting space station for nearly half a year. Soon after their arrival, on February 11, 1990, they discovered that the exterior insulation on the spacecraft that had ferried them from Earth was badly torn. The *Soyuz TM-9* was their ticket back, and so they had been forced to make two death-defying space walks to fix the damage. On the first one, both men nearly suffocated when the air supply to their space suits threatened to quit.

But Balandin remembers that, despite the perils the two men faced trying to fix their lifeboat, their attempt to keep the baby quail alive had seemed more daunting. He admitted that his greatest enthusiasm aboard Mir had been caring for the quail. If future space voyagers could breed birds, he reasoned, they would have an inexhaustible supply of food.

The baby-quail saga had begun as one of the experiments scheduled during their mission. Balandin and Solovyov had placed thirty-five quail eggs inside an incubator. Then they spent thirty minutes a day monitoring the eggs. After fourteen days of nail-biting suspense, a healthy chick hatched, becoming the first living creature ever to be born in space. In the next week, five more chicks popped from their eggs.

But setbacks quickly overshadowed this success. As each chick emerged from its egg, it flapped its wings madly, trying (but failing) to control its movements in the weightless atmosphere. To help the birds adapt, the men transferred them to a customized cage. Leg bands tethered each chick, positioning it so that its beak was close to supplies of water and birdseed.

"It didn't work," Balandin said. The chicks' neck muscles seemed too weak to maneuver their heads, to peck at the seeds, or to take in water. With nourishment only inches away, the quail were starving. "So we helped them feed," Balandin continued. "We put seeds in their mouths." Every day, overcoming his aversion to the stench, he opened each bird's mouth and inserted birdseed down its throat.

But Balandin's heartfelt efforts were for naught. In the following weeks all six chicks died. The alien environment of the space station was more than their fragile bodies could handle.

Yet the experiment was not entirely a failure. Balandin's selfless labors illustrate how human efforts to expand into space could make what is now a hostile, barren emptiness into a livable habitat of unimaginable scope—not just for people, but for whatever life we bring along.

Robert Zimmerman writes about the history of space exploration. His most recent book is Leaving Earth: Space Stations, Rival Superpowers, and the Quest for Interplanetary Travel *(Joseph Henry Press, 2003).*

Lighting Technology for eye comfort

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The Balanced Spectrum™ floor lamp brings many of the benefits of natural daylight indoors for glare-free lighting that's perfect for a variety of indoor activities...now available for under $80!

Now at the new low price of $79.95!

The Balanced Spectrum™ floor lamp will change the way you see and feel about your living or work spaces.

Ever since the first human went into a dark cave and built a fire, people have realized the importance of proper indoor lighting. Unfortunately, since Edison invented the light bulb, lighting technology has remained relatively prehistoric. Modern light fixtures do little to combat many symptoms of improper lighting, such as eyestrain, dryness or burning. As more and more of us spend longer hours in front of a computer monitor, the results are compounded. And the effects of indoor lighting are not necessarily limited to physical well being. Many people believe that the quantity and quality of light can play a part in one's mood and work performance. Now, there's a better way to bring the positive benefits of natural sunlight indoors.

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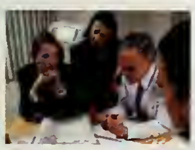

...at work...

...and when you need a source of natural light for close-up tasks.

The Balanced Spectrum™ floor lamp will change the way you see and feel about your living or work spaces. Studies show that sunshine can lift your mood and your energy levels, but as we all know the sun, unfortunately, does not always shine. So to bring the benefits of natural daylight indoors, use the floor lamp that simulates the full spectrum of daylight. You will see with more clarity and enjoyment as this lamp provides sharp visibility for close tasks and reduces eyestrain.

Its 27-watt compact bulb is the equivalent to a 150-watt ordinary light bulb. This makes it perfect for activities such as reading, writing, sewing, needlepoint, and especially for aging eyes.

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- *See with clarity and enjoyment*
- *Creates natural, glare-free light*
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As a commercial photographer, I probably give more attention to lighting than most people and therefore was impressed with the smooth, soft daylight quality of your lamp.

Dennis M.
Richmond, VA

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Grace A.
Margate, FL

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