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contents

features

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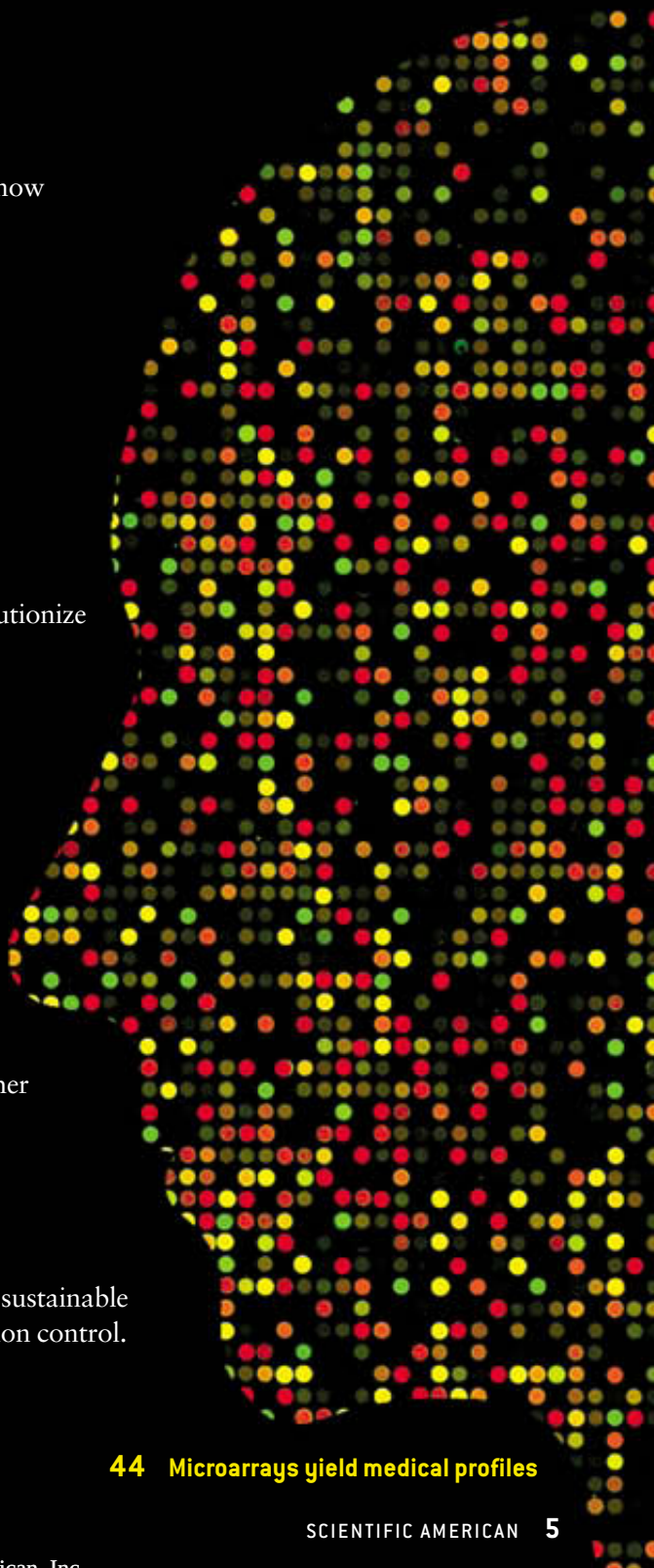


44 Microarrays yield medical profiles

SCIENTIFIC AMERICAN Volume 286 Number 2

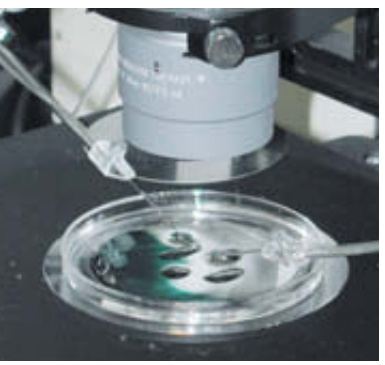
departments

columns

Cover photoillustration by Jana Brenning and TV images by Chip Simons; preceding page: Sara Chen and Aaron Firth; this page, clockwise from top left: Jason Grow; John McFaul; Sara Chen

A Ready-Made Controversy

Several groups have loudly declared their intentions in the past couple of years to attempt human cloning, but the announcement by Advanced Cell Technology in Worcester, Mass., that it had succeeded (as reported in *Scientific American* and elsewhere) still seemed to catch many people off guard. Some of that surprise had less to do with the deed itself than with controversies over whether ACT had accomplished all that it claimed and how the news was spread [*see page 18*]. In retrospect, however, the idea that human cloning would emerge less contentiously looks naive.



CELLULAR manipulation at ACT.

The first, most serious reservations are the scientific ones. ACT acknowledged that its work fell far short of producing a human embryo with stem cells of therapeutic interest and settled instead for a demonstration that human cells can be cloned. Other scientists are skeptical of even that claim, if not openly dismissive of it. Carrying an embryo to only the six-cell stage is no proof of cloning at all, they say, because a few early rounds of cell division can occur in a genetically inert egg cell. ACT might better have waited to publish until more convincing results were in hand. Time will tell whether or not ACT's claim stands up.

ACT is a privately held company and cavalierly acts the part. It has a financial stake in making its experiments succeed and in selling those results to the public. Although ACT published its work in the peer-reviewed literature, some critics feel that experiments of this type would best be left to less self-interested institutions.

Fine—but the law currently forbids the use of government funds for research on human embryos or embryonic stem cells. Given the tremendous stakes—potential riches and scientific immortality—why be surprised that industry would move to fill the vacuum left by federal paralysis? That is what happened two decades ago with in vitro fertilization, a technology advanced by businesses after it was declared off-limits to federal funds. Yet companies do present, promote and protect their discoveries to their own advantage, which is why observers have worried about the increasing privatization of research in the U.S.

In this case, cloning researchers were racing not only one another but the possibility that the government could suddenly outlaw human cloning. This competition also coincides with the rise of online professional journals, which allow quick publication of peer-reviewed results but whose credibility some scientists still accept uneasily. And of course, it also coincides with the skyrocketing interest in scientific and technological subjects shown by the scoop-driven mainstream media, which compete ever more with magazines such as *Scientific American*.

These trends didn't just allow the advent of human cloning to unfold on the margin of acceptability. They pushed it there. They all but guaranteed that the first news of human cloning would come from someone outside the traditional academic mold who was willing to present preliminary results in a scientifically unconventional setting.

If this kind of scientific process is dismaying, what can be done about it? Cloning is not the only science warped by these forces. Perhaps a good place to start would be to lift the government bans on funding for embryonic and stem cell research. Without the influences of private money and secrecy, further work in this area might seem like less of a free-for-all.

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FEATURED STORY

More Tiny Bones to Pick

If you've read the article on page 54 in this issue, then you know something about John Flynn and André Wyss's work. A few years ago these paleontologists discovered in Madagascar a tiny jaw fragment that could upend the current theory of when and where the ancestors of marsupial and placental mammals arose.

Last summer senior online editor Kate Wong traveled to the region with them as they looked for additional fossils. Read more about her experiences in the field with these researchers on the Scientific American Web site.

KATE WONG

- Learn about the expedition leaders in greater depth.
- See photos showing the team at work (*as above*) and the strange animals that inhabit Madagascar today.
- Follow related links to other online sources of information.
- Buy recommended books on the subject.

ASK THE EXPERTS

How do the programs that scan your computer for viruses work?

Geoff Kuenning, professor of computer science at Harvey Mudd College, provides an explanation.

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Letters

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"IN 'DRIVING THE INFO HIGHWAY' [October 2001], Steven Ashley discusses the potential problems of safety and privacy raised by the introduction of telematics into passenger vehicles," writes John A. Dawson of Bala Cynwyd, Pa. "But what of the larger societal transitions that may accompany such a move? Is it not likely that by making driving time more productive and enjoyable, we would increase the vehicle-miles driven on our streets and highways, thereby adding to congestion and travel times? Induced travel and the resulting stimulation of suburban sprawl are the primary reasons that new highways commonly provide only short-term traffic relief. And what would be the effect on mass transit? Would we be encouraging those who now commute by train or bus to switch to a single-occupant vehicle? There are implications here for land use, preservation of older communities, energy consumption, air quality, and further separation of the haves from the have-nots in our society. Encouraging the use of private passenger vehicles may not be an unmitigated good."

Take a trip from the universe to New Orleans to the shower in the October 2001 letters below.

LIFE IN GALACTIC SUBURBIA

We are skeptical of the conclusions reached in "Refuges for Life in a Hostile Universe," by Guillermo Gonzalez, Donald Brownlee and Peter D. Ward. True, we seldom encounter the density waves that cause spiral arms because of our sun's "lucky" orbital frequency. But increasing interstellar density would manifest only if the "hydrogen wall" at the heliopause came to within approximately one astronomical unit (AU) of Earth, which seems unlikely, given that it would require an increase in density of about 10^4. Also, because we live in the galactic suburbs, seldom does a star pass through the Oort cloud, sending comets inward; on average, this happens about once every 25 million years. For most of the stars in the galaxy, however, and all of those in the bulge, such near passages have stripped away Oort clouds entirely, leaving solar systems facing no danger of cometary bombardment. So a majority of stars are safer than ours!

More important, there is no evidence to support the primary predicate of the article—that Earth is the ideal place for life. In the 1930s most scientists believed that the deep ocean was devoid of life because of the extreme pressures and intense cold. With the discovery of a great biomass inside Earth, and microbes tunneling many meters into volcanic rock under the seabed, who can deny that we are just one example of the adaptation of life to its environment? To assume otherwise implies an anthropocentric mechanism yet to be discovered.

HENRY HARRIS
Advanced Concepts Program
Jet Propulsion Laboratory
Pasadena, Calif.

GREG BENFORD
Department of Physics and Astronomy
University of California, Irvine

THE BIG EASY'S ALL WET

South Louisiana ["Drowning New Orleans," by Mark Fischetti] is sinking because for the past 60 years the oil industry has removed billions of barrels of oil and trillions of cubic feet of gas from the underground geologic structures below the I-10 highway. Without the oil and gas, the structures can no longer support the weight above, and they collapse. The ground above sinks, subsides and disappears below the water level.

The oil companies do not want this discussed; they do not want to jeopardize the tremendous investment that they have there. Big oil always diverts

attention to surface issues—levees, river flow, canals in the marsh, saltwater intrusion and so on. Politicians are willing to look the other way because of the large payrolls and significant tax revenue the state enjoys. Surface sinkage exists in other parts of the world where there is major oil and gas extraction. This problem is documented. This problem is kept secret in south Louisiana.

RON RUIZ
New Orleans

SHEA PENLAND OF THE UNIVERSITY OF NEW ORLEANS REPLIES: *An exhaustive study recently published by the U.S. Geological Survey in cooperation with the University of New Orleans Coastal Research Laboratory shows that the oil and gas industry is indeed responsible for roughly one third of the surface problems causing coastal land loss. Numerous studies, however, indicate that the overwhelming subsurface contributor is the compaction of modern sediments deposited over the past several thousand years. By altering the hydrology of the Mississippi River and its delta, humankind has destabilized this wetland surface. Fossil-fuel extraction is a minor contributor to subsurface erosion. Furthermore, such extraction would not simply cause the earth above to "collapse." It would cause subsurface faulting to accelerate, creating localized "hot spots" of minor land loss.*

SHOWER CURTAIN CLING EXPLAINED

In Endpoints, the answer provided by David Schmidt of the University of Massachusetts at Amherst to the question "Why does the shower curtain move toward the water?" is not complete as it is presented. I submit that the buoyancy effect accounts for most of the shower curtain's movement because (1) the movement is significantly reduced when cold water is flowing and (2) if the vortex were the predominant cause, then we would expect that a person in the shower would disrupt the vortex, thus affecting the shower curtain's movement. This, though, is not the case.

DWAYNE ROSENBURGH
Senior Electronic Engineer
U.S. Department of Defense

SCHMIDT REPLIES: *Granted, the buoyancy effect is real. Because the curtain is pulled in by cold flow, however, I was curious to find an additional explanation. Hence, my work investigated a room-temperature shower. As for the complete dominance of the thermal effect, that is debatable. Is the curtain pulled in by a shallow, hot bath?*

TURN DOWN THE SONAR

Low-frequency active (LFA) sonar's source level is about 240 decibels, comparable to a Titan rocket taking off next to your ear ["Sound Judgments," News Scan, by Wendy Williams]. Just testing this and other active sonars has left dead whales across the Canary Islands, Greece and the Bahamas. Low-frequency sound goes much farther than midfrequency sonars, increasing its range of damage.

The U.S. Navy wants to deploy LFA in at least 80 percent of the world's oceans and be forgiven beforehand by the National Marine Fisheries Service (NMFS) for any creatures it kills. It has also asked to be exempted from the Endangered Species Act, apparently believing itself to be above the laws of the land. The NMFS's mandate is to protect marine mammals. Instead the agency has been changing rules to accommodate the navy by increasing the level of sound considered hazardous for whales by a millionfold and watering down the definition of "harassment." LFA is an unnecessary gamble that should be defunded. New passive sonars can do the job and harm nothing.

BENJAMIN WHITE, JR.
International Coordinator
Animal Welfare Institute
Washington, D.C.

THIS OLD HOUSE floats on a barrier island that once protected the Mississippi Delta from the sea.

MAX AGUILERA-HELLWEG

ADVANCES IN MOUSING

The Xerox Star was not an electromechanical rollerball mouse ["Mice and Men," Working Knowledge, by Mark Fischetti]. It was an optical mouse that used two sensors to recognize two-dimensional movements relative to the mouse's being moved. It required a mouse pad that had a printed pattern of dots on its surface (the mouse would even work on a copy of the mouse pad—it was made by Xerox, after all). There was nothing to clean, and the accuracy of the mousing was always excellent. The resolution/responsiveness of the mouse could be changed within the operating-system options.

JOHN HALLY
Fairport, N.Y.

Boundary of Space ▪ Threshold of Flight ▪ Origins of Man

FEBRUARY 1952

TOWARD SPACE—"Long before the first Earth-dweller makes a landfall on the Moon, there will be other firsts, and in a sense, man is even now probing across the borders of space. In a recent experimental flight, the Douglas Skyrocket, a pilot-carrying craft with a rocket motor, rose to an altitude—reportedly 15 miles—where more than 96 per cent of the Earth's atmosphere lay below the pilot's feet. As far as his oxygen supply is concerned, man crosses the borders of space at an altitude of about 10 miles. The pilot of the Douglas Skyrocket crossed this border. In order to do so he had to be encased in an airtight envelope inside his cabin—i.e., he wore a spacesuit."

EUGENICS—"We may attempt to suppress bad genes, not only by controlling reproduction but, better still, by identifying and separating the desirable germ cells from the undesirable ones, which are likely to be present in every individual. We may attempt to improve our endowment of genic varieties by artificial mutation with radiation and chemicals. Mutations are usually toward the worse, but the future may well place specific tools in our hands with which we can change less desirable genic varieties into more desirable ones. Progress in these biological fields very likely will run ahead of our social and political thinking."

FEBRUARY 1902

STONEHENGE—"The work of reraising the Great Monolith at Stonehenge, England, has enabled archaeologists to more reliably estimate the epoch in which these druidical monuments were erected. While making excavations around the monolith, a large number of Neolithic stone implements were unearthed that show every sign of having been used to cut and to square the stones. They all bore marks of hard working. Experts now entertain little doubt that Stonehenge was built in the Neolithic Age, for had it been built in the Bronze or Iron Age, bronze or iron tools would have been used. The introduction of bronze into Britain is generally conceded to have been about 1500 B.C."

WRIGHT GLIDER, 1902

THE WRIGHT STUFF—"Mister Wilbur Wright, of Dayton, Ohio, recently read a most interesting paper before the Western Society of Engineers, entitled 'Some Aeronautical Experiments.' It was the plan of Mr. Wilbur Wright and Mr. Orville Wright to glide from the tops of sandhills. It seemed reasonable that if the body of the operator could be placed in a horizontal position, instead of the upright, as in the machines of Otto Lilienthal, Percy Pilcher and Octave Chanute, the wind resistance could be very materially reduced. The new machine for 1901 was 308 square feet, although so large a machine had never before been deemed controllable. On the seashore of North Carolina, gliding from the top of a sandhill, with the wind blowing 13 miles an hour, the machine sailed off and made an undulating flight of 300 feet. To the onlookers this flight seemed very successful, but to the operator it was known that the full power of the rudder had been required to keep the machine from either running into the ground or rising so high as to lose all headway. The experiments also showed that one of the greatest dangers in machines with horizontal tails had been overcome by the use of the front rudder." [*Editors' note: The Wright brothers' famous powered flyer took to the air in December 1903.*]

FEBRUARY 1852

EVOLUTION "NONSENSE"—"The [anonymous] authors of 'The Vestiges of Creation' have taught the doctrine that life is progressive—that step by step it arose from the lowest conceivable points of life. It is even asserted that the primary man was a dolphin—and all such nonsense. This class of geologists, as a fundamental proof of the correctness of their theory, stated that no animals of a high class of intelligence had ever been found in the Old-Red, or Devonian, sandstone formations. However, this materialist doctrine was proven to be a fixed falsehood at a recent meeting of the British Geological Society. A paper was read on the discovery in the crystalline yellow sandstone of the Old-Red, near Elgin, in the north of Scotland, a series of thirty-four foot-prints of a turtle, and in the same strata, the remains of the skeleton of the oldest fossil reptile yet discovered. It resembles a water salamander and has been named Telerpeton (very old reptile) Elginense."

STEM CELLS

What Clones?

WIDESPREAD SCIENTIFIC DOUBTS GREET WORD OF THE FIRST HUMAN EMBRYO CLONES **BY GARY STIX**

On November 25, 2001, a Massachusetts biotechnology company, Advanced Cell Technology (ACT), reported in an online journal—*e-biomed: The Journal of Regenerative Medicine*—that it was the first to clone human embryos. In a concurrent article in the January *Scientific American*, the researchers explained that their results could "represent the dawn of a new age in medicine by demonstrating that the goal of therapeutic cloning is within reach." Therapeutic cloning—in contrast to reproductive cloning, intended to create a baby—would produce the stem cells needed to treat diabetes, paralysis and other now incurable conditions.

ARGUING THE CASE for therapeutic cloning is Michael D. West of Advanced Cell Technology—seen here in a December Senate hearing.

PAUL J. RICHARDS *AFP Photo*

Many leading scientists, however, say the work should never have been published, because the research failed on several counts to achieve its goals. First, ACT didn't produce any stem cells. But more fundamentally, some investigators questioned the company's basic assertion about having actually cloned human embryos.

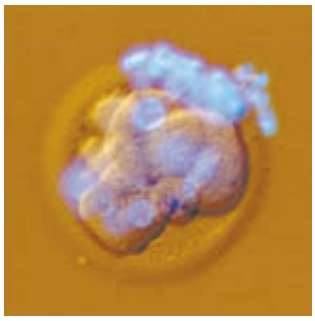
In the experiment, the ACT researchers injected cumulus cells into eggs that had had their nuclei removed. (Cumulus cells nurture eggs in the ovary.) The investigators hoped that the cumulus cells' DNA would launch the process of early embryonic development that leads to a hollow sphere called a blastocyst, which would contain stem cells. Among the eight eggs injected with cumulus cells, two divided until they became four-cell embryos, and one proceeded until it reached six cells. Eleven other eggs injected with the nucleus of a skin cell failed to develop.

According to some biologists, a cloned embryo would attain its true status as an embryo only when the DNA from the cumulus cell that was transferred into the egg began transcription (in which the cell's genes begin to issue instructions to make proteins for embryonic development). An egg contains genetic material (RNA) and proteins that were made during the formation of the egg within the ovary and can support development up to the eight-cell stage without any signals from the DNA in the nucleus.

Thus, the ACT experiment may have been "running on fumes, purely directed by RNA and supported by proteins that were present in the egg," says John Eppig, a developmental and reproductive biologist at Jackson Laboratory in Bar Harbor, Me. Eppig adds that "there's no published information on a cloned human embryo. Whether someone has done it and not published it, your guess is as good as mine. This [result] is not

it." (There was one previous claim of multicell embryo clones, but the findings were not published.)

Eppig is not alone. "It's shocking to me that this would be published and that they would have attempted to publish; it's the total failure of an experiment," says Rudolf Jaenisch, a cloning expert at the Whitehead Institute for Biomedical Research at the Massachusetts Institute of Technology.



STORM CENTRAL: One of ACT's cloned human embryos.

Michael D. West, the president and chief executive of ACT, says that his group has adopted an approach that resembles that of Bob Edwards, the British scientist whose research resulted in 1978 in the first test-tube baby. Edwards published each step of his studies. That, in West's view, helped to foster openness about a controversial procedure. "The reason we decided to publish this was purely because we're promoting the idea of human therapeutic cloning, and we felt it was important to be transparent about where we're at and publish frequently," West states. He explains further that "when we were sure that we had gotten this far and had these results, we felt there was a publishable paper there."

William Haseltine, editor in chief of *e-biomed* and chairman of the biotechnology company Human Genome Sciences, defended the decision to publish. "It was a small but significant first step," he says of the research. The paper, Haseltine describes, went through a standard review process in which "two or more" reviewers, not including him, vetted the paper. He refuses to identify the reviewers, saying only that they did not include editorial board members from ACT.

Haseltine also criticizes scientists for voicing their skepticism in the press instead of writing letters to the journal or attempting to replicate the results. He says that scientists may have made such sharp comments partly because of "deep frustration" over the prohibition against any federally funded research that destroys human embryos: "There are those who would express frustration that they think they can do the work better, and indeed it is possible they could, but [they] cannot do it." He also blames *Scientific American* and *U.S. News and World Report*, which released their articles at the same time as *e-biomed*, for the subsequent frenzy. "Part of the public furor," Haseltine says, "was generated by the weight that the *Scientific American* publication also gave to this story and of course *U.S. News*."

Scientific American editor in chief John Rennie says that he and staff editors debated whether to publish the article. "We were disappointed that it wasn't a more clear-cut demonstration of an embryo that was further along," Rennie says. "But it was still worth doing this." The likelihood of intense public interest in the result as the first documented human cloning demonstration justified the decision, he explains. "It was also our intention to continue to follow the story and provide other points of view on this, including dissenting ones," Rennie elaborates.

Critics of the ACT paper say that the dispute has not helped the case for therapeutic cloning. "In a controversial area you should have at least one part clean and scrutinized, which is the scientific part, and then you can go to the public and discuss all the other considerations, like ethical and moral, ideological and religious [ones]," remarks M.I.T.'s Jaenisch. The U.S. House of Representatives has already voted to ban cloning, whether for therapeutic or reproductive purposes. Last December the Senate declined to take up a measure to place a moratorium on the procedure, but the debate will resume this year.

During a December Senate hearing, West stated that he would be disappointed if ACT couldn't obtain cloned stem cells within six months. In an interview Jose B. Cibelli, the ACT researcher who performed the cloning procedure, also states: "Give me 200 human eggs, and I'll give you cloned human stem cells." Whether such declarations prove to be prescience or braggadocio remains to be seen. But one thing seems certain: one way or another, ACT will find a way to keep its research endeavors squarely in the public eye.

For an expanded version, go to www.sciam.com/explorations/2001/122401clone/

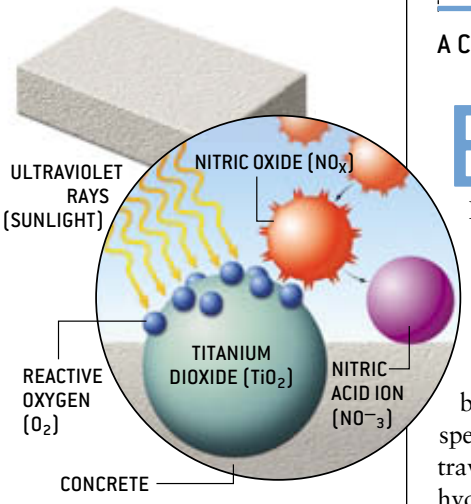
JOSE B. CIBELLI

MIRED IN IRE

Not everyone at *e-biomed*, the online journal that accepted ACT's cloning paper, was happy with its publication. John P. Gearhart of Johns Hopkins University, an editorial board member and a pioneer in stem cell research, told the BBC that he was going to resign from the board over the matter. "I feel very embarrassed and very chagrined by this publication," he said in the interview. This past December the journal's publisher, Mary Ann Liebert, was planning to meet with Gearhart and said she hoped he would change his mind.

PARTHENOGENETICALLY SPEAKING

In addition to their claim of human cloning, researchers at ACT got six of 22 human eggs to form into balls of cells called blastocysts through a process known as parthenogenesis, in which unfertilized eggs are chemically tricked into becoming embryos. Although none of the blastocysts contained stem cells, a new study at ACT suggests that producing them is possible in primates. In an upcoming issue of *Science*, ACT is scheduled to report harvesting stem cells from monkey blastocysts and prompting them to turn into cultures of beating-heart cells, gut epithelial tissue, nerve cells that made dopamine, and other cell types.



EXHAUST POLLUTANT nitric oxide breaks down when sunlight hits the titanium dioxide–coated concrete, releasing reactive oxygen that turns NO_x to nitric acid ions. The alkaline concrete neutralizes the ions, which are washed away by rain.

A REAL GLASS ACT

Glass coated with titanium dioxide can act as self-cleaning windows. Under the sun, the coating breaks down dirt, which can then be washed away by rain. Last August, PPG Industries in Pittsburgh rolled out SunClean, one of the first self-cleaning glass products marketed in the U.S. The windows cost 20 percent more, but you could toss the squeegee.

CHEMISTRY

Paving Out Pollution

A COMMON WHITENER HELPS TO CLEAN THE AIR **BY LINDA WANG**

Buildings, roads and sidewalks have developed an appetite for air pollution. Researchers in Japan and Hong Kong are testing construction materials coated with titanium dioxide—the stuff of white paint and toothpaste—to see how well they can fight pollution.

Better known as a pigment for whiteness, titanium dioxide can clear the air because it is an efficient photocatalyst: it speeds the breakdown of water vapor by ultraviolet light. The results of this reaction are hydroxyl radicals, which attack both inorganic and organic compounds, and turn them into molecules that can be harmlessly washed away with the next rainfall. But it wouldn't work to smear toothpaste on the sidewalk—the titanium dioxide crystals in such applications are too large (about 20 to 250 nanometers wide). The width of the pollution-fighting form is about seven nanometers, offering much more surface area for photocatalysis.

In the early 1970s researchers from the University of Tokyo described titanium dioxide's photocatalytic abilities. Since then, scientists have exploited the compound to kill bacteria on hospital surfaces and to treat contaminated water. Fighting nitrogen oxide on the streets is the latest twist. In Hong Kong, concrete slabs coated with titanium dioxide removed up to 90 percent of nitrogen oxides, most commonly spewed from older cars and diesel trucks and a contributor to smog, acid rain and other environmental headaches. In taking care of the contaminants, a coating of titanium dioxide did in minutes what the environment does in months, says Jimmy Chai-Mei Yu, a chemist at the Chinese University of Hong Kong. Moreover, he adds, because titanium dioxide is a catalyst, it could last forever.

Despite its promise, the compound is no magical cure. "The big problem with titanium dioxide is that it doesn't absorb sunlight very well," says Carl Koval, a chemist at the University of Colorado at Boulder. Only 3 percent of sunlight falls into the range needed for the titanium dioxide to work, points out Adam Heller, a chemical engineer at the University of Texas at Austin. A recent advance by Ryoji Asahi of Toyota Central R&D Laboratories in Nagakute, Japan, boosted the efficiency to 10 percent, but, Heller notes, "it's still a small fraction of the sunlight."

And although titanium dioxide is relatively inexpensive, paving roads and coating buildings with this substance could add up. "The countries with the most air pollution will benefit the most from this technology," Yu observes, "but unfortunately those are the countries that won't be able to afford it."

Linda Wang is a writer based in Chicago.

SARA CHEN

MEDICAL GEOLOGY

Coal Control

TACKLING THE HEALTH DANGERS OF CHINA'S "DIRTY" COAL **BY SARAH SIMPSON**

For the past several decades, cancerous skin lesions and deformed limbs have been all too common among the people of Guizhou Province in southwestern China. Today thousands of the region's residents suffer from arsenic poisoning, with symptoms ranging from freckled skin to squamous cell carcinoma. And more than 10 million are afflicted by fluorosis, which can soften and disfigure teeth and bones.

Only in the past few years have geologists figured out the source of the arsenic and fluorine: coal. Damp, cool autumn weather makes it impossible to dry corn, chili peppers and other crops outside, so families bring them indoors to dry over coal-burning stoves. But it turns out that the coal contains abnormally high concentrations of arsenic

TOXIC SALES: Street vendors in Guizhou Province, China, unknowingly sell coal that is dangerously high in arsenic and other trace elements.

and fluorine. Fluorosis is more common than arsenic poisoning because high-fluorine coal is combined with high-fluorine clay to make briquettes. Now that scientists understand the source of the health problems, they have launched multiple projects to help to alleviate the dangers of "dirty" coal.

The unusual Chinese coals contain upward of 35,000 parts per million (ppm) of arsenic, according to geologist Harvey E. Belkin of the U.S. Geological Survey in Reston, Va., who has analyzed samples from about 25 locations in Guizhou Province. In contrast, coals in the U.S. average about 22 ppm of arsenic. At this level, the U.S. Environmental Protection Agency concludes that arsenic fumes do not pose a compelling health risk.

"The worst mines [in Guizhou Province] have been closed down," Belkin says, but unfortunately, most people who live there don't have an alternative to coal. Wood was once their primary fuel, but the region's forests were largely denuded by the early 1900s. At that time, many people began digging the coal out of the hillsides. Compounding the problem of the contaminated fuel is that most homes have no chimneys; as a result, volatilized elements from the coal collect indoors. Fresh chili peppers contain less than 1 ppm arsenic, for example; peppers dried over indoor coal fires often contain more than 500 ppm arsenic.

U.S. and Chinese scientists have begun mapping the geologic distribution of fluorine and arsenic within regional coal deposits to determine the least harmful sites to establish quarries. "Our focus is not simply to warn people but also to show them that there are reasonably simple solutions," says Robert B. Finkelman, who has directed USGS involvement in the project since 1995. The maps, he says, are now available on CD-ROM.

Finkelman and Belkin are also working with chemist Dan Kroll of Hach Company in Loveland, Colo., to develop a field test kit that residents of Guizhou Province can use to measure the concentrations of dangerous elements in the coal they excavate. Kroll designed a low-tech test that involves an easy-to-follow recipe of crushing the coal, boiling it and adding a few chemicals. The chemical reactions produce arsene gas, which reacts with a paper test strip inside a sealed bottle. The paper turns a shade of yellow, orange or brown, depending on the concentration of arsenic.

Last August, Hach began shipping millions of the groundwater test kits to Bangladesh, where more than a third of the nation's 125 million people are waging an ongoing battle against arsenic contamination of their wells.

"Once the coal kits are field-tested we will raise money to purchase a supply of these kits and get them for free to the people of these villages in China," Finkelman says. If the kits seem to catch on for arsenic tests, Hach may develop cheap test kits to measure fluorine levels as well.

ROBERT B. FINKELMAN *U.S. Geological Survey*

EARTH'S OTHER DIRTY FUGITIVES

Contaminated coal is not the only hazardous earth material that geologists are tackling. They have also shown that roving dust storms from Asia and Africa haul a gang of potential health hazards to the Americas. Hundreds of millions of tons of soil from these eastern continents blow across the oceans every year, carrying with them pesticides, heavy metals, radioactive isotopes, insects and pollen. During the past 18 months, scientists with the U.S. Geological Survey's Center for Coastal and Regional Marine Studies in St. Petersburg, Fla., have discovered that the dust also transports several types of bacteria, viruses and fungi. Inhaling the spores of a windblown fungus in the southwestern U.S. is known to cause valley fever, another name for the sometimes deadly infection coccidioidomycosis.

MEDICINE

Count to 10

FROG EGGS MAY CRACK THE MYSTERY OF HOW ANESTHESIA WORKS **BY LISA MELTON**

For some, even a tooth extraction would be unthinkable without them. Anesthetics have become a mainstay of modern medicine, and every year 27 million people in the U.S. alone benefit from the pain relief, sedation and unconsciousness that they provide. But the rather unnerving reality is that general anesthesia transports us perilously close to death. The dose of anesthetic that puts you to sleep is not much smaller than the dose that can kill you. It is primarily the skill of the anesthesiologist that renders the drugs so safe.

Exactly how anesthetics work has re-

ANESTHESIA USE began in 1846, as shown in this first-ever photograph of surgery using ether, at Massachusetts General Hospital.

NEED TO KNOW: GOING UNDER

Side effects of anesthetics include nausea and vomiting, but it is respiratory depression that is potentially life-threatening. Anesthesiologists carefully monitor patients under anesthesia, making the practice generally safe and the mortality associated with it extremely low: about one in a quarter-million.

mained an enigma since their first use in 1846. Now researchers are homing in on the answer, which could result in a new generation of risk-free anesthetics. "Researchers on both sides of the Atlantic have identified the same target: the GABA type A receptor," explains neuropharmacologist Jeremy J. Lambert of the University of Dundee in Scotland. The receptor, which looks like a squashed doughnut sitting on the cell membrane, grabs onto GABA, or gamma-aminobutyric acid, the brain's major inhibitory neurotransmitter. Each receptor opens up a channel in the membrane and allows certain ions to enter the cell, which then suppress brain activity. But the idea that anesthesia acts on the GABA-A receptor has yet to gain widespread acceptance.

Lambert and his colleagues have taken a big step toward proving the connection between unconsciousness and GABA-A. The team set out to discover which part of the receptor interacts with the anesthetic drug etomidate. Using molecular biology tools, they introduced point mutations into the DNA coding for the human GABA-A receptor and then inserted this modified version into a *Xenopus* (frog) egg.

To the scientists' delight, swapping a single amino acid—out of 2,000 that make up the protein—in an area of the receptor called TM2 (transmembrane domain 2) was enough to make the frog egg cell unresponsive to the anesthetic. The experiment, Lambert concluded in previously published research, demonstrates that anesthetics interact with this important brain receptor in a highly specific fashion.

But it is, of course, a huge leap from an amphibian egg to the human brain, so the team plans to try an experiment on mice. The goal is to genetically engineer mice to carry the mutated GABA-A receptor instead of their own. If these mice stay awake after an injection of anesthetic, then the GABA-A receptor theory will be proved, at least for intravenous anesthetics.

Proof of GABA-A's involvement in anesthesia could lead to the Holy Grail of the operating room: a rapid-onset, readily reversed, risk-free anesthetic. Surprisingly, the key to such an anesthetic may lie in the metabolite of a sex hormone. Scientists have known for some time that a steroid breakdown product of progesterone is a powerful sleep inducer that, in higher doses, can have analgesic, anticonvulsant and even anesthetic properties. The brain produces its own supply of these so-called neurosteroids from either progesterone or cholesterol. And the Dundee team has found that these neurosteroids operate through the same GABA-A receptor as synthetic anesthetics do.

"Neurosteroids have a large safety margin, and unlike the other intravenous anesthetics, they do not depress blood pressure," says Alex S. Evers, whose team at Washington University has also been involved in searching for novel steroids to use as anesthetics. "It is surprising to me that a neurosteroid anesthetic hasn't yet come along."

Lisa Melton is science writer in residence at the Novartis Foundation in London.

STANLEY B. BURNS, M.D./THE BURNS ARCHIVE

AVIATION

Quieting Killer Wakes

AIMING TO BEAT HAZARDOUS TURBULENCE BEHIND PLANES BY STEVEN ASHLEY

The skies over New York City's John F. Kennedy International Airport were clear and relatively calm when American Airlines Flight 587 took off on November 12, 2001. Minutes later the Airbus A300-600 airliner broke up in midflight and dove into the ground—felled perhaps in part by turbulent vortices of air produced by the wings of a Japan Airlines jumbo jet that had just preceded it down the runway.

Engineers are working on ways to detect hazardous wake vortices so pilots can avoid them or to design aircraft that leave safer skies behind them. If implemented, these new technologies could boost the number of planes that airports could handle, thus cutting delays and enabling increased commercial air traffic in coming years.

Because wake vortices can persist in calm air for several minutes (extending for as far as eight miles), the Federal Aviation Administration requires minimum distances between aircraft, based on size. The smaller a following plane is, the more susceptible it is to overturning. Aircraft rated in the "heavy" classification must maintain at least four nautical miles' separation, for example. But such rules limit the number of planes an airfield can accommodate in a given period—a problem sure to be exacerbated by the expected future growth of air traffic.

One technology that might lessen the dangers of wake turbulence is an early-warning system such as Project Socrates (an acronym for *s*ensor for *o*ptically *c*haracterizing *r*emote *t*urbulence *e*manating *s*ound). Socrates would attempt to detect and image unseen wake turbulence and then alert pilots and air traffic controllers. The system, being developed by Flight Safety Technologies (FST) in New London, Conn., and Lockheed Martin in Syracuse, N.Y., relies on lasers that beam light through the air above runways toward ground-based retroreflectors, according to FST president William B. Cotton. Acoustic pressure fluctuations (sound waves) created by air turbulence alter the speed of light locally, he says, which slightly changes the laser beam's transit time. Unfortunately, reliably plucking these faint acoustic fingerprints out of the accompanying noise has proved difficult, so many experts deem this technology unready for near-term application.

Other researchers are focusing on the source—the trailing edges of aircraft wings. This is a highly tricky exercise because vortical flow fields act in a complicated (what scientists call nonlinear) manner, making prediction difficult. Moreover, aircraft actually generate several vortices—off the tail flaps, control surfaces and other areas of air-pressure discontinuity, states Alan J. Bilanin, president of Continuum Dynamics, an engineering consulting firm in Ewing, N.J. "The key to mitigation is to establish a vortex wake consisting of two or more vortical pairs that are unstable and susceptible to rapid breakup," he explains. One does this by redistributing the aerodynamic load along the wingspan or by incorporating the vortices coming off the horizontal stabilizer.

Aerodynamicist Klaus Huenecke of Airbus has developed a "passive" scheme based on so-called designer vortices. The European company hopes to use the technology on its planned A380 superjumbo jet, which is expected to generate strong wakes that may otherwise last 30 percent longer than those of the largest current airliners.

Continuum Dynamics and Boeing go further by introducing "active forcing" of the vortices to induce a wobble, or "waviness," into the flow to hasten breakup even more, dissipating it in perhaps 1.5 to two nautical miles. Continuum Dynamics adds carefully timed flow perturbations from small aerodynamic tabs to break up turbulence. Boeing wants to use existing wing and tail control surfaces that shift up and down about 20 degrees in a coordinated fashion to disrupt the vortical flow.

Bilanin cautions that these systems will take as long as a decade to implement, because they are almost certain to require all-new aircraft designs. Indeed, any alteration to existing aircraft designs entails hard tradeoffs in performance, ride and noise, mechanical complexity, operational and maintenance costs, and safety. In addition, "Nothing will be done in this regard by the manufacturers unless it can be shown that it will enhance sales," he notes. Clearly, it would be hard to justify a technology that will "benefit the guy behind you," as one researcher puts it.

DANGEROUS CURVES: Aircraft wake vortices can throw treacherous air turbulence into the paths of succeeding planes. In this NASA/FAA test, colored smoke makes the swirling airflow visible.

NASA LANGLEY RESEARCH CENTER

CREATING A WAKE VORTEX

Just as a boat leaves a wake, an airplane creates ripples in the air behind it. And just as a canoe paddle forms whirlpools and eddies as it pushes through water (as the fluid swirls around from the rear to the front side), wings create helical wake vortices as they slice through the air to generate lift. "Because of the finite extent of a wing, air rolls off of it in a spiral fashion—inboard to outboard—as it goes from the lower to the upper surface," explains Jeffrey Crouch of Boeing Commercial Airplanes Group in Reston, Wash. Normally invisible, wake vortices can sometimes be seen as contrails, puffy manifestations that form as water vapor from fuel combustion freezes into ice crystals that are entrained in the spiraling airflow.

PHYSICS

Setback for Super-K

DISASTER BLINDS THE WORLD'S LEADING NEUTRINO DETECTOR **BY GRAHAM P. COLLINS**

Beautiful fish-eye-lens photographs of the insides of Japan's Super-Kamiokande neutrino detector have decorated innumerable magazine pages. The images displayed row upon perfect row of photomultiplier tubes like huge glittering crystal eyeballs, the total structure dwarfing any human in the picture. For five years, those "eyeballs" watched for telltale flashes of light signaling a rare neutrino interaction within the detector volume, and the scientific results made headlines. But on November 12, 2001, a disastrous accident—seemingly a chain reaction of implosions that ripped through the array—reduced 7,000 of the 11,000 phototubes to a pile of shards and rubble.

PHOTOMULTIPLIER TUBES installed in the roof of Super-Kamiokande during construction in 1995.

No one knows what started the incident. For the first time since operations began in 1996, the detector had been emptied of its 50,000 tons of ultrapure water for maintenance and replacement of a few hundred phototubes. During the refilling process, with the tank about 80 percent full, the terrible sound of imploding photomultipliers broke out. "It was as if blasting [in the Kamioka mine] was happening underneath me," says Masayuki Nakahata of Tokyo University, who was in the control room atop Super-K at the time.

Super-K's photomultiplier tubes are much like lightbulbs the size of large computer monitors: evacuated glass spheroids, 50 centimeters in diameter. Presumably when one tube imploded, the inrushing water generated a powerful outgoing shock wave that broke other nearby tubes, whose implosions in turn added to a growing maelstrom of surging water and flying shrapnel. Researchers are studying new designs for mounting the phototubes to prevent such a chain reaction.

Kamioka Observatory director Yoji Totsuka vowed to restore Super-K to operation as soon as possible, perhaps within a year. But repairing Super-K will be a mammoth task, and a complete restoration would take years: only about 1,500 replacement photomultiplier tubes are available, and production of these $3,000 devices ceased four years ago. A change in the facility's research focus in 1999, however, may let some corners be cut. Super-K was designed to study naturally produced neutrinos, those generated in the sun and by cosmic rays. By 1998 the facility had gathered conclusive basic evidence of neutrino oscillations, the metamorphosis of neutrinos of one subspecies, or "flavor," to another.

Since 1999 Super-K has been watching for pulses of man-made neutrinos sent to it through 250 kilometers of the earth's crust from the KEK particle accelerator in Tsukuba. The full coverage of 11,000 photomultiplier tubes was necessary for Super-K to identify enough solar neutrinos but exceeds the minimum requirements of the K2K ("KEK to Kamioka") experiment. The beam from KEK carries higher-energy neutrinos, which can be spotted easily even with the surviving tubes spread more sparsely across the detector. The cosmic-ray experiments could also resume, but with reduced efficiency.

Continuing K2K's studies is essential, because the properties of neutrinos hint at novel physics. Over two and a half years of operation, Super-K detected 56 K2K neutrinos, compared with 81 expected in the absence of oscillations, tentatively implying that on the way to Kamioka one third oscillate to a flavor that Super-K cannot detect. K2K was scheduled to run until early 2005. Experiments comparable to K2K elsewhere in the world will not come online until then.

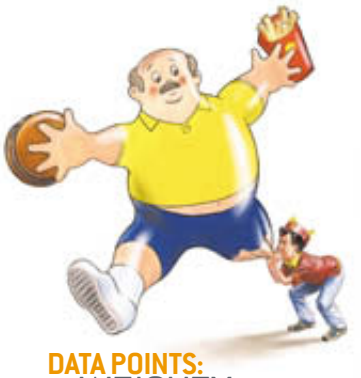
Beyond K2K lies the proposed JHF-Kamioka experiment, which would send a neutrino beam at least 10 times the intensity of K2K's across 300 kilometers from a new accelerator being built in Tokaimura. For that experiment, state-of-the-art detectors are being developed, a process that may be expedited as part of Super-K's recovery. That experiment could also be Super-K's last, as ambitious long-range plans call for construction of Hyper-Kamiokande, which would contain a megaton of water—20 times the capacity of Super-K.

TIME TO REMODEL?

■ **In October researchers at Fermilab in Batavia, Ill., announced that neutrinos and antineutrinos produced at the Tevatron accelerator seem to interact with atomic nuclei slightly more strongly than theory predicts. The result might be a statistical fluke, but if it holds up, it could be a harbinger of subtle new particles and forces lurking beyond the Standard Model of particle physics at high energies.**

■ **A similar hint of post–Standard Model physics was announced last February by researchers at Brookhaven National Laboratory, based on ultraprecise measurements of muons (which are closely related to electrons and to neutrinos). Theorists have since discovered, however, that much of the discrepancy resulted from a bug in a computer program introducing an erroneous minus sign to one term of the theoretical calculations.**

INSTITUTE FOR COSMIC RAY RESEARCH, UNIVERSITY OF TOKYO



DATA POINTS: WEIGHTY MATTERS

Based on the body mass index, obesity has reached epidemic proportions in the U.S., federal health officials say. Being overweight increases the risk of type 2 diabetes, gallbladder disease, coronary problems, hypertension and osteoarthritis.

Percent of adults who were overweight in:

1980: 33%

1999: 35%

Percent who were obese in:

1980: 15%

1999: 27%

Number of states where the obesity rate was greater than 15% in:

1991: 4

1998: 37

State with the greatest percentage of obese people:

Mississippi (22%)

State with the smallest percentage:

Arizona (12.7%)

Annual number of deaths attributed to excess weight and inactivity: 300,000

SOURCES: Centers for Disease Control and Prevention; Journal of the American Medical Association, October 27, 1999. Body mass index (BMI) is calculated as the weight in kilograms divided by the square of the height in meters. Overweight is defined as a BMI of 25 to 29.9; obesity, a BMI above 30.

EVOLUTION

Parts of Speech

We humans may recite Shakespeare while our ape cousins merely grunt their approval of iambic pentameter. But the part of the brain required for our chatter has a longer evolutionary history than previously suspected. A region within Broca's area known as Brodmann's area 44, critical for the power of speech, is larger in the left hemisphere of humans than in the right. A study has now found that the same asymmetry exists in other great ape species: chimpanzees, bonobos and gorillas. Reporting in the November 29, 2001, *Nature*, the Emory University researchers conjecture that the area may have originally been associated with the production of gestures used by apes for communication. This area eventually became used as a source of speech in modern humans. *—Steve Mirsky*

CHIMPANZEES, bonobos and gorillas seem to have a brain area that in humans evolved into our speech centers.

ACOUSTICS

Sonic Womb

An ultrasound scan relies on sound frequencies too high to be heard, but a new study finds that it can raise a racket in the womb by vibrating internal organs—in particular, the fetal ear. Volumes can reach up to 100 decibels in utero, as loud as a subway train. An unborn baby would perceive this sound as a high-pitched tone or chord, although the noise would be more akin to a finger tap near the ear than a shriek cutting the air. The finding may explain why babies wiggle more during ultrasound scans than when resting undisturbed. The authors noted, however, that their study does not suggest a risk to the child. In fact, because the clatter is sharply confined to a pencil-point swath, a fetus should be able to twist easily out of earshot. The researchers, from the Mayo Foundation in Rochester, Minn., presented their findings at the December 2001 meeting of the Acoustical Society of America. *—JR Minkel*

AIDS

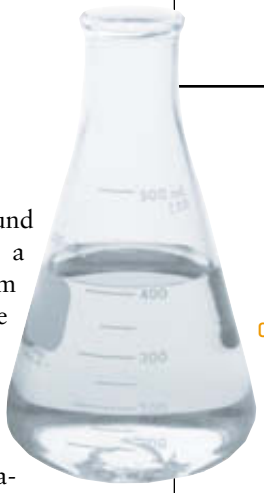
Early Warning

People with HIV usually have to wait four to eight weeks to find out whether the antiviral regimen they are taking is effective. Now researchers think that a single week could be enough. When they culled the records of 124 first-time recipients of HIV drug therapy from three older studies, they found that those whose viral loads dropped by just 80 percent or less after six days almost invariably showed a poor response to treatment. In contrast, those whose virus levels fell by 98 percent or more tended to fare well. This early viral plummet may not always predict a treatment's long-term success, says lead author Michael A. Polis of the National Institute of Allergy and Infectious Diseases, but "without one, we're pretty sure it's going to be a failure." The longer patients receive an ineffective drug combination, the more likely they are to cultivate a strain of the virus resistant to similar agents. The study appears in the November 24, 2001, *Lancet*.—*JR Minkel*

CHEMISTRY

Splitting with Sunshine

High on a chemist's wish list is a material that uses the sun to split water into its constituent hydrogen and oxygen. Through photosynthesis, plants have no problem performing this action, but humans have had trouble duplicating the feat, which would cheaply produce hydrogen gas, a clean fuel. Today's photocatalysts corrode easily or are too inefficient, functioning only in ultraviolet light, which makes up just 4 percent of sunlight (in contrast, the visible spectrum accounts for 43 percent). Researchers in Japan have found that simply adding nickel to a metal oxide (made from indium and tantalum) yields a stable substance that works in the violet region of visible light. The trick now is to boost the material's conversion efficiency by extending the photocatalyst's sensitivity further into the visible spectrum. The December 6, 2001, *Nature* describes the results. *—Philip Yam*



CLEAN FUEL could be had from water if H_2O were efficiently dissociated.

BIOENGINEERING

Into the Maize

Somehow DNA from transgenic corn has found its way into native species located in remote mountain regions of Oaxaca, Mexico. Most samples of the Mexican maize, called *criollo,* had parts of foreign genes. But one had a complete gene from the bacterium *Bacillus thuringiensis,* whose insect-killing abilities are incorporated into many transgenic crops. Just how the DNA found its way into the native plants is not known. Mexico banned the planting of bioengineered maize in 1998, and the closest genetically modified corn ever known to have been planted was 60 miles away—a distance thought to be too far for corn pollen to be carried by wind. The study appears in the November 29, 2001, *Nature.* *—Philip Yam*

ASTRONOMY

Otherworldly Air

Carl Sagan mused that extraterrestrials could easily deduce the existence of cows on Earth: spectroscopic analyses would reveal an anomalous abundance of methane in our atmosphere. Such chemical clues may one day be our first sign of life elsewhere (bovine or otherwise). The technique has just been demonstrated by astronomer David Charbonneau and his colleagues using the Hubble Space Telescope. They took spectra of the star HD 209458 and its Jupiter-like sidekick, which periodically crosses in front of the star and blocks some of the starlight. The apparent dimming is 0.02 percent stronger at 590 nanometers than at other wavelengths, a finding that the team attributes to absorption by sodium—the first convincing detection of an atmosphere on a planet outside our solar system. Researchers doubt that this rather forbidding world is habitable, but a similar technique could look for life on Earth-like planets. See arXiv.org/abs/astro-ph/0111544 for a preprint of the paper. *—George Musser*

GRAZING STARLIGHT provided the first direct evidence of an atmosphere beyond our solar system, as shown in this artist's rendition.

bottom: SOURCES: NASA, D. CHARBONNEAU, T. BROWN, R. NOYES AND R. GILLILAND, ILLUSTRATION BY G. BACON

WWW.SCIAM.COM/NEWS
BRIEF BITS

- **Astronomers have obtained the first image and spectrum of a MACHO, or massive compact halo object, which in this case is a dwarf star 600 light-years away and less than 10 percent the mass of the sun. MACHOs are a particular breed of dark matter. /120701/3.html**
- **By punching holes through their cell walls, viral enzymes can rapidly kill bacteria, including antibiotic-resistant strains, before they infect body cells. /120701/2.html**
- **Long thought to contribute only a desirable "mouth feel," fat may actually have a taste, which might help researchers develop diet foods that taste more like their fatty counterparts. /120501/3.html**
- **Experimental psychologists have found that athletes might avoid choking in the crunch by practicing under high-pressure conditions. /121701/2.html**

BY THE NUMBERS

Assembling the Future

HOW INTERNATIONAL MIGRANTS ARE SHAPING THE 21ST CENTURY **BY RODGER DOYLE**

The 150 million people who live outside the country of their birth make up less than 2.5 percent of the world population, but they have an importance far beyond their numbers. Some international migrants are refugees or students, but those with the most impact are economic migrants, drawn to places such as Los Angeles, where the wages may be three times greater than those in Mumbai (Bombay). These migrants tend to be young and willing to work for low wages. Though traditionally unskilled, a growing number are highly educated.

Immigration is now the major contributor to demographic change in many developed countries. In the U.S., according to the latest U.S. Census Bureau projection, the population will grow by 129 million in the period from 2000 to 2050, but if immigration stops, it would go up by just 54 million. Western Europe's population is 42 percent greater than that of the U.S., but its projected immigration is only about half that of the U.S.; as a consequence, the region is expected to lose 28 million people over the next 50 years. Japan, which has close to zero net migration, is projected to lose 26 million by 2050. (Deaths will start outrunning births in western Europe and Japan around the middle of this decade.)

During the past six years, the U.S. received 27 percent of the world's international migrants, compared with 9 percent by Germany, the second most popular destination. (Western Europe as a whole, however, took in 21 percent.) One fourth of all migrants to the U.S. went to California; favorite cities, in order of the number of foreign-born, are Los Angeles, New York City, San Francisco, Miami and Chicago.

International migrants primarily come from developing countries, with China at 14 percent and Mexico at 8 percent being the largest sources. A few developing countries—Afghanistan, Bosnia, Liberia and Rwanda—have had significant influxes in recent years, but these reflect mainly the movement of refugees. Most developing countries had negative net migration.

In the past few years, every European country with considerable immigration has had a reaction against foreign workers, according to social scientist Christopher Jencks of Harvard University. Some Asian countries hit hard by recession in the late 1990s tried to repatriate migrant workers. Thus far the U.S. shows no signs of reinstituting the extremely restrictive immigration laws of the past, a major reason being the dependence of many industries on a supply of foreign labor. Indeed, the AFL-CIO, once an opponent of high immigration quotas, has reversed position and is now attempting to organize immigrants. This change in attitude, among other reasons, leads Jencks to conclude that a substantial reversal of the current liberal policies is unlikely.

That would be good news for employers and for the affluent, who can continue to buy goods and services on the cheap. The economy as a whole will benefit to the extent that cheap labor helps to control inflation. But there is a specter haunting immigration: Can the U.S. economy really provide decent wages for the 46 million workers expected in the next 50 years? They may depress not only the wages of traditionally disadvantaged groups, such as blacks and Hispanics, but also the wages of American middle-class professionals, particularly if the U.S. continues to relax the rules for entry of high-tech workers.

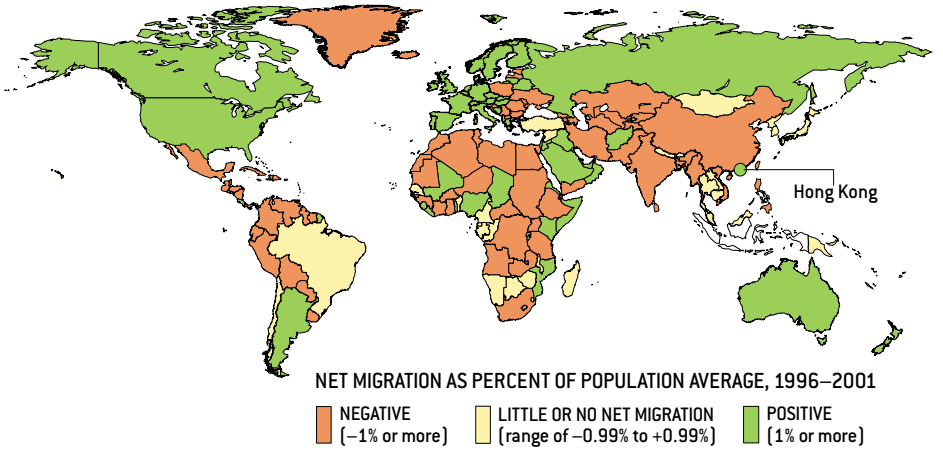
Rodger Doyle can be reached at rdoyle2@adelphia.net

FAST FACTS: ON THE MOVE

Most active in world migration (average annual net migration in thousands, 1996–2001):

U.S.	960
Germany	311
Afghanistan	289
Russia	247
Canada	186
Rwanda	141
Liberia	137
Hong Kong	116
Bosnia	107
Italy	107
Singapore	105
Bangladesh	–100
Kazakhstan	–141
Congo	–180
Iran	–211
Pakistan	–213
Mexico	–284
China	–508

SOURCE: U.S. Bureau of the Census estimates and projections. Many of the smaller countries are classified as having little or no net migration. This is believed to be more or less the case, although fully reliable data for these countries are not available.



RODGER DOYLE

Down with the Bad, Up with the Good

A biotech firm develops a vaccine to raise good cholesterol levels By THOMAS MAEDER

Una S. Ryan had a childhood dream of making discoveries that saved people's lives, but a productive career in vascular biology never quite got her there. "I spent many years in research and wrote a lot of papers, but in my 40s I realized that I hadn't cured anyone yet," Ryan says. When Avant Immunotherapeutics in Needham, Mass., offered her a job as chief scientific officer in 1993, she leaped at the opportunity.

Originally named T Cell Sciences, Avant had focused on developing vaccines to decrease the body's pathological response against some of its own molecules, a phenomenon that occurs in autoimmune diseases such as multiple sclerosis and rheumatoid arthritis. During an early brainstorming session, Ryan, now the company's CEO, challenged the scientific staff to propose novel therapeutic targets; her hope was to revitalize Avant's languishing research program by bringing together seemingly incongruous problems and technologies. "Put together an immunology company and someone who wants to cure vascular disease," Ryan says, "and you have a new direction."

BRAINSTORMING of Charles W. Rittershaus and Una S. Ryan led to Avant's HDL vaccine program.

One staff member suggested searching for peptide drugs that would raise the amount of high-density lipoprotein (HDL, referred to as good cholesterol) in the blood. A well-known risk factor for cardiovascular disease—the number-one killer in the U.S.—is elevated levels of serum cholesterol that gets bound to low-density lipoprotein (a complex known as LDL, or bad cholesterol), which deposits fatty plaque in the arteries. But equally menacing are low concentrations of HDL, which serves to transport cholesterol back from these deposits to the liver for repackaging or elimination in bile.

Charles W. Rittershaus—"the resident inventor here," Ryan calls him—thought that Avant might attack the problem not with peptides but by using the company's established expertise. "It came to me that we could make an immune response or a vaccine [that would raise HDL]," Rittershaus recounts. "That was kind of naive at the time, but we decided to pursue it." Naive and also, in a lot of people's eyes, absurd. "Who in their right mind would think you'd use immunology to treat a disease of eating too many doughnuts and sitting on your rear end?" Ryan asks.

Existing cholesterol-reducing treatments include dietary restriction of total cholesterol intake or the long-term use of drugs such as statins or fibrates to lower LDL or niacin to increase HDL. None of these drugs addresses the problem completely—even in combination they are better at lowering LDL than at raising HDL—and all have troubling side effects. Moreover, people who feel healthy lack motivation to take potent drugs as prevention against intangible future risks, resulting in poor patient compliance.

In the late 1980s epidemiological studies in Japan identified several families with unusually high levels of HDL, low levels of LDL, and a correspondingly small incidence of cardiovascular disease. This profile was linked to mutations in a gene coding for cholesteryl ester transfer protein (CETP). HDL transports cholesterol from the arteries back to the liver. But it also transfers cholesterol back to LDL as part of a complex cycle presumably intended to maintain a certain concentration and distribution of cholesterol. In moderate amounts, cholesterol is needed for the biosyn-

JASON GROW

thesis of cell membranes, hormones and other essential substances. The molecule that shuttles cholesterol from HDL to LDL is CETP.

Pharmaceutical scientists recognized that CETP presented an attractive target for an antiatherosclerosis drug. A number of large companies, including Bayer, Pfizer and Japan Tobacco, inaugurated screening programs to identify small molecules that would block its activity. Rather than addressing HDL or LDL separately, as earlier researchers had done, the teams decided that jamming the transfer process would automatically and favorably shift the overall balance by keeping cholesterol in HDL and depleting the amount transferred to LDL. All of that work focused on drugs, not vaccines, however—until Avant came along. "The people here didn't know blood vessels or cholesterol," Ryan says. "But they did know antigens and T cells and immunology. There was originally huge opposition to this idea from investors and some people in the company, but it's now a major part of what we do." For a long time the board advised against calling the new treatment a vaccine at all. "They told us, 'Just say you're putting a medicine in twice a year instead of twice a day. Then you can charge more and won't have the stigma of calling it a vaccine,'" Ryan observes.

To create a CETP vaccine, Avant had to accomplish what the body does by mistake in autoimmune diseases. T cells, a type of lymphocyte, recognize very specific antigens, segments of molecules against which the immune system mounts an attack. The immune system ordinarily shuts down the T cell responses to the body's own molecules, which is how it differentiates "other" from "self." A vaccine against CETP had to trick the immune system into attacking a target it usually ignored. Moreover, this target needed to be unique to the CETP molecule, so that a kind of immunological "friendly fire" would not accidentally attack other proteins. Fortunately, Alan R. Tall, an atherosclerosis researcher at Columbia University, had previously identified a 16-amino-acid region of the CETP molecule that was crucial to the molecule's function and distinct from any stretch in other natural proteins.

To elicit a response to this self-antigen, Rittershaus and his colleagues needed to couple it to something that virtually everyone's immune system recognizes as a threat. Almost all Americans have been vaccinated against tetanus, so they created a 31-amino-acid peptide that combined Tall's 16 CETP residues, along with 14 from tetanus toxin, and an amino acid that linked two copies of this peptide into a very stable and antigenic hairpin-shaped molecule. Avant's strategy worked. Through some immunological quirk—a sort of guilt by association—this type of hybrid antigen, which Avant called the CETi-1 vaccine, elicits a robust immune response to both tetanus and the linked CETP fragment. In rabbits the CETi-1 vaccine raised HDL by 42 percent, lowered LDL by 24 percent and reduces the area of atherosclerotic lesions by an encouraging 40 percent.

At this point the skeptics' qualms about the vaccine strategy vanished. "The breakthrough was when the animals didn't die," Ryan says. "We were clearly good rabbit doctors. The next wave of acceptance came when the FDA allowed us to go into the clinic."

Scientists at Avant didn't know blood vessels or cholesterol. But they did know antigens and T cells and immunology.

Avant has completed human safety studies and is now in phase II clinical trials to determine the optimal vaccine dose. Company researchers feel confident about the vaccine's safety and efficacy profile because of the original Japanese epidemiological data. "Small cohorts of humans walk around with low CETP activity and live long and healthy lives," says Lawrence J. Thomas, a senior scientist at Avant. "So the experiment has been done for us in nature."

Avant is not alone in taking a self-antigen vaccine approach to treating disease. Elan Pharmaceuticals in South San Francisco is developing an immunotherapy to stimulate the immune system to recognize and attack the amyloid plaques that are implicated in Alzheimer's disease. Aphton Corporation in Miami has various products in clinical trials, including contraceptives and drugs to treat cancer.

Using a vaccine for the prevention of atherosclerosis has two potential advantages over drug-based therapies. First, as long as the target is accurately identified, Rittershaus says, "the immune system can be exquisitely specific," which may translate into fewer side effects than with conventional treatments. Second, current cholesterol-lowering drugs must be taken on a daily basis, whereas Avant is aiming at a vaccine that would be given once every six months, which could increase compliance and lower costs. If this works, you might be able to get your flu shot and your HDL shot at the same time. SA

Thomas Maeder is a science writer who lives in Narberth, Pa.

Intellectual Improprieties

A leading gadfly picks some of the worst patents of all time By STEVE DITLEA

How badly does the patent office err? Gregory Aharonian has made his reputation by lambasting the U.S. Patent and Trademark Office (PTO) for issuing patents without making a thorough search of the existing literature to determine the novelty of a proposed invention—a key criterion for granting a patent [see "Patent Pamphleteer," December 2001]. Aharonian's Web site, www.bustpatents.com, includes an archive of bad patents, which lists dozens of patents declared invalid by the PTO or the courts.

SCIENTIFIC AMERICAN asked Aharonian for his short list of the worst patents ever. What follows is his selection of four "really, really bad patents. Probably not the worst ever," Aharonian notes, "but quite close."

Three-dimensional pie charts. The PTO issued a patent in 1996 for a method of creating enhanced pie charts on a computer, a technique that was first published in computer journals as far back as the 1970s. "This [patent] is a classic example of a simple software technique for which the PTO was unable to find relevant prior art [previous inventions] to invalidate the claims," Aharonian says. "It demonstrates the PTO's need for more extensive libraries of books and journals, as well as the need to provide more time for the examiners to search through such materials." Quite often PTO examiners look only at listings of abstracts of journals to determine whether a claim is original. But a lot of software techniques are not described in these databases. (U.S.: 5,491,779: "Three-Dimensional Presentation of Multiple Data Sets in Unitary Format with Pie Charts"; Richard D. Bezjian.)

Training manuals. Using training manuals in education is routine. But the technique in this 1998 patent merely describes how an experienced person can teach a novice by using an illustrated publication, such as a training manual. "The technique is so common as to be something that probably isn't written about because it's too trivial," Aharonian observes. The practice of patenting such basic business methods has increasingly come under fire. (U.S.: 5,851,117: "Building Block Training Systems and Training Methods"; Keith A. Alsheimer and others.)

Effectiveness of an ad. Advertising agencies often ask a panel of people to compare one advertisement against another. A patent issued in 1999 outlines a system for garnering feedback on the effectiveness of a new advertisement or broadcast commercial by comparing it with a control advertisement. "Haven't ad agencies done this for decades?" Aharonian asks. "Again, a common trivial practice regularly described in academic journals on marketing and advertising. Another prior art breakdown for a nonnovel patent." (U.S.: 5,991,734: "Method of Measuring the Creative Value in Communications"; Thomas J. Moulson.)

Gene profiling. To ascertain the effect of a chemical in drug testing, researchers habitually expose cells to potentially toxic substances. A 1998 patent was granted for a method of exposing cells to toxins—and measuring how they affect the cells. "This is an overly broad, trivial patent that many in the biotech industry don't like," Aharonian says. "It is the broadness of the claims in light of prior art that makes this patent bad. It shows that the problems of prior art that are common in the software and electronics fields affects other fields, such as biotech." (U.S.: 5,811,231: "Methods and Kits for Eukaryotic Gene Profiling"; Spencer B. Farr and others.) SA

Steve Ditlea is a journalist based in Spuyten Duyvil, N.Y. He has been covering technology since 1978.

JOHN McFAUL

The Gradual Illumination of the Mind

The advance of science, not the demotion of religion, will best counter the influence of creationism By MICHAEL SHERMER

In one of the most existentially penetrating statements ever made by a scientist, Richard Dawkins concluded that "the universe we observe has precisely the properties we should expect if there is, at bottom, no design, no purpose, no evil and no good, nothing but blind, pitiless indifference."

Facing such a reality, perhaps we should not be surprised at the results of a 2001 Gallup poll confirming that 45 percent of Americans believe "God created human beings pretty much in their present form at one time within the last 10,000 years or so"; 37 percent prefer a blended belief that "human beings have developed over millions of years from less advanced forms of life, but God guided this process"; and a paltry 12 percent accept the standard scientific theory that "human beings have developed over millions of years from less advanced forms of life, but God had no part in this process."

In a forced binary choice between the "theory of creationism" and the "theory of evolution," 57 percent chose creationism against only 33 percent for evolution (10 percent said that they were "unsure"). One explanation for these findings can be seen in additional results showing that just 34 percent considered themselves to be "very informed" about evolution.

We need to employ a proactive strategy of science education and evolution explanation.

Although such findings are disturbing, truth in science is not determined democratically. It does not matter what percentage of the public believes a theory. It must stand or fall on the evidence, and there are few theories in science that are more robust than the theory of evolution. The preponderance of evidence from numerous converging lines of inquiry (geology, paleontology, zoology, botany, comparative anatomy, genetics, biogeography, and so on) points to the same conclusion—evolution is real. The 19th-century philosopher of science William Whewell called this process of independent lines of inquiry converging together to a conclusion a "consilience of inductions." I call it a "convergence of evidence." Whatever you call it, it is how historical events are proved.

The reason we are experiencing this peculiarly American phenomenon of evolution denial (the doppelgänger of Holocaust denial, using the same techniques of rhetoric and debate) is that a small but vocal minority of religious fundamentalists misread the theory of evolution as a challenge to their deeply held religious convictions. Given this misunderstanding, their response is to attack the theory. It is no coincidence that most evolution deniers are Christians who believe that if God did not personally create life, then they have no basis for belief, morality and the meaning of life. Clearly for some, much is at stake in the findings of science.

Because the Constitution prohibits public schools from promoting any brand of religion, this has led to the oxymoronic movement known as "creation science" or, in its more recent incarnation, "intelligent design" (ID). ID (aka God) miraculously intervenes just in the places where science has yet to offer a comprehensive explanation for a particular phenomenon. (ID used to control the weather, but now that we understand it, He has moved on to more difficult problems, such as the origins of DNA and cellular life. Once these problems are mastered, then ID will no doubt find even more intractable conundrums.) Thus, IDers would have us teach children nonthreatening theories of science, but when it comes to the origins of life and certain aspects of evolution, children are to learn that "ID did it." I fail to see how this is science—or what, exactly, IDers hope will be taught in these public schools. "ID did it" makes for a rather short semester.

To counter the nefarious influence of the ID creationists, we need to employ a proactive strategy of science education and evolution explanation. It is not enough to argue that creationism is wrong; we must also show that evolution is right. The theory's founder, Charles Darwin, knew this when he reflected: "It appears to me (whether rightly or wrongly) that direct arguments against Christianity and theism produce hardly any effect on the public; and freedom of thought is best promoted by the gradual illumination of men's minds which follows from the advance of science." SA

Michael Shermer is founding publisher of Skeptic *magazine (www.skeptic.com) and author of* The Borderlands of Science.

BRAD HINES

Telecom's Man of the Moment

Heir to a famed military and political legacy, Michael K. Powell tries to make his mark on the federal agency that regulates cell phones, television and the Internet By JULIE WAKEFIELD

Washington, D.C.—It is casual Friday at the Federal Communications Commission. Michael K. Powell, the nation's communications czar, is dressed in a cardigan sweater and a preppy dark turtleneck. This studied informality contrasts with the seriousness with which Powell regards the chairmanship's job that President George W. Bush entrusted him with last January. "The FCC's portfolio is breathtaking," Powell notes. "We oversee the entire telephone, wireless telephone, wireless, satellite, cable, television, great chunks of what we call the Internet—all of which are amid the most profound revolutions in history."

TOM WOLFF

MICHAEL POWELL: COMMUNICATIONS CZAR

- **Work ethic: Dedicated, but weekends belong to family: wife Jane and sons Jeffrey, 12, and Bryan, 7.**
- **Fanatic about: Washington Redskins.**
- **Favorite escape: Relaxing on his boat.**
- **Core belief: "American competitive policy says we don't care about companies—we care about consumer welfare."**

The lot of the $950-billion communications industry hangs on the signals emanating from the eighth-floor office of the agency's glistening glass and brick headquarters, a short jog from Congress and the White House. CEOs and lobbyists faithfully trek to pay homage to Powell as part of the $125 million spent annually on lobbying by the communications industry. "A day in the life of the FCC," Powell admits, "is listening to company after company argue for policy changes in their self-interest."

Recently celebrating his first anniversary as chairman, the 38-year-old Republican has established himself as a free-marketer but not a dogmatic one. Unsatisfied with the agency's hitherto knee-jerk, piecemeal policy, Powell intends to shake things up. He has initiated policy reviews on everything from cross-media ownership to how the radio-frequency spectrum should be allocated. "It really stresses me that we don't have a coherent, cogent vision of what we're doing here," he says. "We're just running around reacting to the latest activity, latest transaction." His critics, however, accuse him—much as they do his father, Secretary of State Colin L. Powell—of promoting the status quo, in the son's case an agenda of more deregulation and mergers.

Michael Powell is not your average political appointee. His clout extends to both sides of the congressional aisle. "When he first came to the FCC [in 1997 as a Clinton appointee to an open Republican seat], he may have had a nepotism cloud hanging over him, but it dissipated very, very fast," says Andrew Jay Schwartzman, president and CEO of the Media Access Project, a public-interest law firm not shy about criticizing Powell's policies. "He is an unbelievably talented, smart guy."

His appointment to the FCC is the perfect marriage of law and technology for this self-described

gadget freak who catapulted through the legal ranks. On graduating from Georgetown University Law Center in 1993, he landed several prestigious clerkships and did a stint as chief of staff of the Department of Justice's antitrust division under Joel I. Klein during the Microsoft antitrust case.

Powell's presence at the FCC stems in part from an accident that almost killed him. Raised in the patriotic culture that pervades military posts, he had always dreamed of following in his father's footsteps in the army. After studying government at the College of William and Mary on an ROTC scholarship, he was commissioned as a second lieutenant. But a jeep accident on the German Autobahn in 1987 almost pulverized his pelvis, ending his military career. A steel lattice now fuses his upper and lower body. The accident brought him a certain clarity, however. Four months after leaving the hospital, he married his best friend, Jane, a college sweetheart. After a brief Pentagon desk job for then Secretary of Defense Dick Cheney, Powell embarked on a second career in law with an eye on politics.

GROUND-ZERO TOUR after September 11 let Powell and New York governor George Pataki see emergency efforts, including those to restore critical telecom services.

The experience shaped him in other ways as well. "I'm not afraid to do risky or hard things, because my ego doesn't hang on this work," Powell says. "If you can divorce who you are from what you do, which is what Dad taught me to do, you can conquer anything, in the sense that you're not afraid of anything." Fearlessness is in order at the FCC. The 68-year-old agency, whose biggest charge used to be enforcing "decency" standards on the airwaves, is now central to reviving a tech sector that has fallen on especially hard times. The fallout from the September 11 attacks has only broadened the challenges, as Powell observed during a visit to ground zero in New York City a week after the tragedy.

Not surprisingly, Powell is advancing a mantra of "less regulation, more competition" to cure telecom's woes. Although he's skeptical that high-speed Internet access, or broadband, will become a panacea, he believes that it has practically infinite possible applications that will benefit the world, and he has made accelerating its deployment his foremost objective.

Contentiousness surrounds the question of how best to get broadband connections such as digital subscriber line (DSL) technology to the masses at reasonable rates. At the heart of the policy battle is how to overhaul the 1996 Telecommunications Act, passed to split up the local phone monopoly controlled by the regional Bell operating companies. The law strives to open up the Bell networks by leasing portions of the wires to new companies to offer competing services, but it has been slow to foster a competitive playing field. Powell chides the way the act is structured, which he interprets as, "Oh, by the way, companies, go build your own gallows: we want you to spend a lot of money to make it easy for your competitors to use your equipment to compete against you."

The implementation of the 1996 act will continue to preoccupy Powell for the duration of his time as commissioner. But he thinks it's much too late for the additional reform packages being debated in Congress: "The horse has already left the barn. Anytime you do a massive law, you're going to spend four years in litigation over what the law means." Powell urges patience.

Open-access concerns extend beyond broadband. Consumers Union, based in Yonkers, N.Y., is among the watchdogs that worry that Powell's hands-off approach—which he shares with previous FCC chairmen—won't do enough to safeguard the public interest in the face of increasing media mergers, consolidated cable ownership and the like. Powell suggests that media ownership of one company by another and the so-called digital convergence of television, computers and a range of media may further the public interest. "Some of the values and objectives that we herald can be advanced by combinations—not undermined," he says. Convergence will enable more "localism"—the ability to tailor content to regional needs—because of the efficiencies that can be obtained by combining different media, Powell notes.

His critics, though, assert that he has to clearly articulate his policy goals. The trouble is that "he doesn't distinguish between diversity in the sense of variety of content and diversity in the sense of independence of voices and opinions," Media Access's Schwartzman contends. "The test we're looking for is whether he'll try to use technology to promote the [media] diversity goals he talks about."

"Mike is a not a person who sits in anybody's pocket," observes David J. Farber, the FCC's former chief technologist. But he must still prove himself. "Politically, he has a Teflon-like invincibility, which he has yet to use," Farber adds. The long-term viability of Michael Powell, who is already rumored to aspire to higher government office, may require that he lose a bit of his father's fabled caution and become more of a risk taker. SA

Julie Wakefield is a science writer based in Washington, D.C.

FEDERAL COMMUNICATIONS COMMISSION

THE NETWORK IN EVERY ROOM

BY W. WAYT GIBBS

Information is power, or so it is often said. Now the reverse is also true: a new technology coming to market this winter allows information to be communicated at high speed over the existing power lines in a building. Connecting all the network-aware devices in a house—at first just computers and printers but in the future telephones, entertainment components and even appliances—will soon be a simple matter of plugging them in. If one of the devices on the home network is a cable modem or DSL (digital subscriber line) router, then all the outlets in the house can tap into the Internet as well as the power grid.

Engineers have suspected for years that there might be clever ways to force into dual duty all the uncountable miles of copper wiring that reach into nearly every room in the industrial world. Indeed, the first U.S. patent on a method to use the power wires for communications was issued in 1899. But many early attempts slammed into immovable technical obstacles. After several embarrassing failures by well-known firms such as Nortel Networks and Siemens AG, a few European utilities have at last begun to offer their customers phone and Internet service over power lines. The American, Canadian and Japanese power grids use a different design that makes it far too costly for utilities to compete with DSL and cable, however [*see box on page 40*].

Meanwhile other technologies have arrived that can link up machines inside a building without stringing cables through the walls. The new power-line networking standard will have to compete with HomePNA, for example, which works through telephone jacks. Another challenger, known formally as 802.11b and colloquially as Wi-Fi, communicates via radio waves.

Both HomePNA and Wi-Fi have enjoyed only a lukewarm reception among homeowners, says Kurt Scherf, who tracks the home networking industry for Parks Associates in Dallas. Of the 26 million or so households in the U.S. that have multiple computers, Scherf says, "there are probably 5.5 million already networked, and about 80 to 90 percent of those use Ethernet." At 100 megabits a second, an Ethernet network transmits at 10 times the speed of HomePNA and Wi-Fi, but it must use special cables.

Wi-Fi is still relatively expensive (about $400 for a base station and two adapters), and many potential users are worried about neighbors eavesdropping on the e-mails they send and the Web sites they browse. Rightly so, Scherf says: "There is an encryption option for almost all wireless network devices, but most users don't know how to turn it on." The biggest limitation of HomePNA is that apartments and older homes often have only one or two phone jacks.

Power outlets, in contrast, are ubiquitous. And practically any machine you'd want to connect needs electricity anyway. Because power-line communications equipment doesn't require radio transducers, it can be less expensive as well as more secure than Wi-Fi. The trick is making it reliable and fast. Previous standards for sending data over electrical wiring—X-10,

Thanks to ingenious engineering, computers and appliances can now communicate through the electrical wiring in a house

SCOTT GRIMANDO

Communicating over power lines is like transcribing a symphony played over stadium loudspeakers, during the Super Bowl, while wearing earmuffs.

CEBus and LonWorks have been the most popular—top out at roughly 10 kilobits a second. HomePlug Powerline Alliance, a consortium of some 90 electronics and computer companies, knew it had to find a way to increase that speed 1,000-fold.

A Silk Purse from a Spider's Web

THAT CHALLENGE APPEALED to Larry W. Yonge, vice president for research at Intellon in Ocala, Fla. A communications engineer, Yonge had founded a satellite dish company that boomed for several years but ultimately succumbed to competition from cable. When he joined Intellon in 1996, his sole task was to solve the power-line network problem. "It wasn't immediately obvious that it could be done," he recalls. "We had to design a whole system from scratch."

Even engineers used to dealing with interference say that power lines are a truly horrendous medium for communications. "We have designed a very efficient system to transmit electrical energy at 60 hertz," says William E. Blair of the Electrical Power Research Institute in Palo Alto, Calif. "But if you take the same wires and try to put communications signals on them, it's a disaster." Rather like trying to transcribe the exact score of a symphony—as it is played over the loudspeakers at a packed football stadium, on a windy night, during the final minutes of a tied Super Bowl game, while wearing earmuffs.

For the noise of the crowd, substitute hair dryers, light dimmers, fluorescent lamps, vacuum cleaners and a cacophony of similar appliances that send spikes of static coursing back through the wires. In much the same way that a public-address system distorts the sound of music, the house wiring itself filters out some frequencies preferentially, altering the signal in erratic ways. The data stream ricochets off unused outlets and other sudden changes in the resistance of the wire, setting up standing waves and resonating feedback.

Like earmuffs, the home's main circuit breaker dampens signals because it splits the wiring into nearly separate sections. In newer houses that have so-called dual-phase power, a message put on the "hot" wire often has to travel up the street to a distribution transformer hanging on a utility pole, then zip back on the "ground" wire in order to reach a different part of the building. By the time it reaches the target outlet, the signal can be faint indeed.

Compounding these problems, the shape and size of the power network change unpredictably whenever a switch is thrown. Turn on the lights or plug in an extension cord, and the voltage, resistance and current fluctuate.

To top it all off, Blair adds, the long, looping electrical circuits act as antennas: they pick up a variety of radio signals that can interfere with the data signal. But if the data signal is boosted too much to overcome the noise, the wires will also transmit radio signals of their own. "So you get interference in everything else," Blair explains, "like a buzz in your stereo and static on your television."

Yonge and his assistants worked around these problems in various ways. They decided to use much higher frequencies than anyone had tried before, above four megahertz. Appliances generate less noise in that part of the electromagnetic spectrum. And multimegahertz signals tend to pass relatively smoothly from one side of the circuit breaker (or distribution transformer) to the other. Off go the earmuffs.

The engineers also elected to use a very wide swath of spectrum, from 4.5 megahertz up to 21 megahertz, which they then divided into 84 channels. Much like the technique used by digital cellular phones, this approach allows devices to send data with less power and thus less pollution of the radio environ-

Power, Gas and Web

Utilities are becoming ISPs, but not in North America

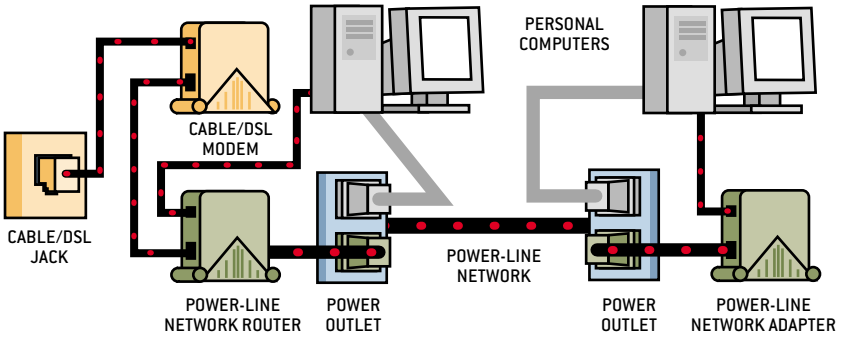
Beyond its use in home networks, electrical wiring can now connect entire neighborhoods to the Internet—but only in certain parts of the world. That is because it is not just the shape of a power plug that differs from country to country; the structure of the power grid differs as well. In most of Europe, Asia and South America, a single large transformer serves hundreds of buildings. The U.S., Canada and Japan, among others, use smaller pole-top transformers that connect to only three to six homes.

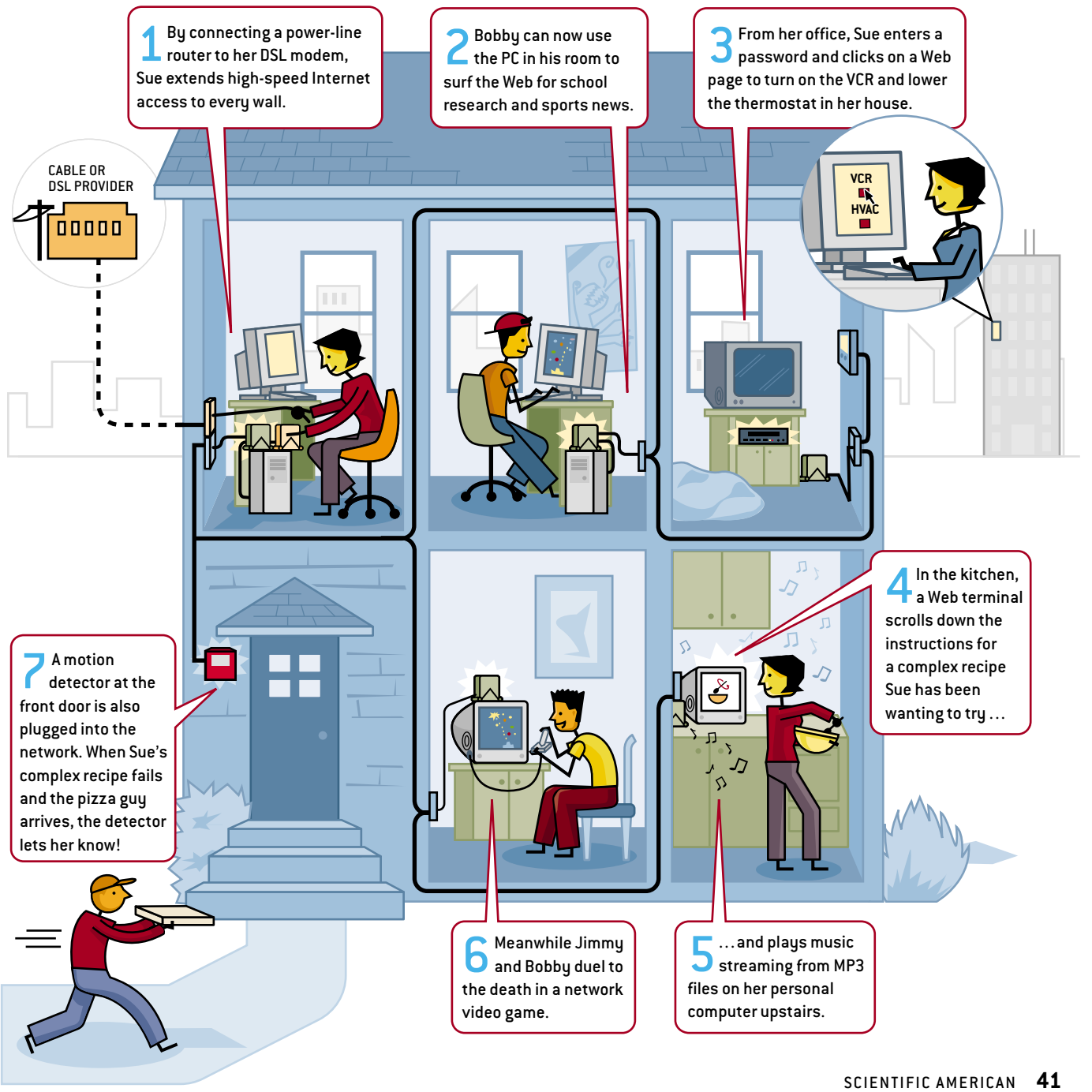
Unfortunately for utilities that want to provide Internet services via their wires, transformers act like big filters that erase information-bearing ripples from the current. "You can put a bypass amplifier around each transformer," says William E. Blair of the Electric Power Research Institute in Palo Alto, Calif., "but it breaks the economics to put dozens on each circuit, as you would have to do in the U.S. Europeans can have one very good bypass amplifier at a substation that routes the signals around the transformer to 200 or 300 homes. That's cost-effective."

Indeed, last summer RWE Powerline, a utility subsidiary based in Essen, Germany, began offering two-megabit-a-second service for about 35 euro ($31) a month. It uses adapters made by the Swiss firm Ascom, which reports that Freiburg Electric Enterprises in Switzerland is also rolling out Internet service and that field trials are under way in nine other European countries, Hong Kong, Singapore and Brazil. —*W.W.G.*

PLUGGING INTO A HOME NETWORK: JUST ADD POWER

THE FIRST POWER-LINE networking products to hit the market early in 2002 will connect only to computers, printers, scanners and other devices that accept USB or Ethernet connections. But the HomePlug standard will work as well with future household appliances modified to communicate through their power cords.

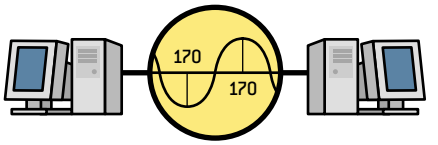




GRAPHIC BY XPLANE (WWW.XPLANE.COM)

DEALING WITH NOISE: ADAPT AND EVADE

POWER LINES inside a house are designed to carry a current that alternates more or less smoothly between –170 volts and +170 volts (averaging 120 volts). Communications signals—small voltage variations added to that sine wave—can get clobbered by numerous sources of noise and interference.

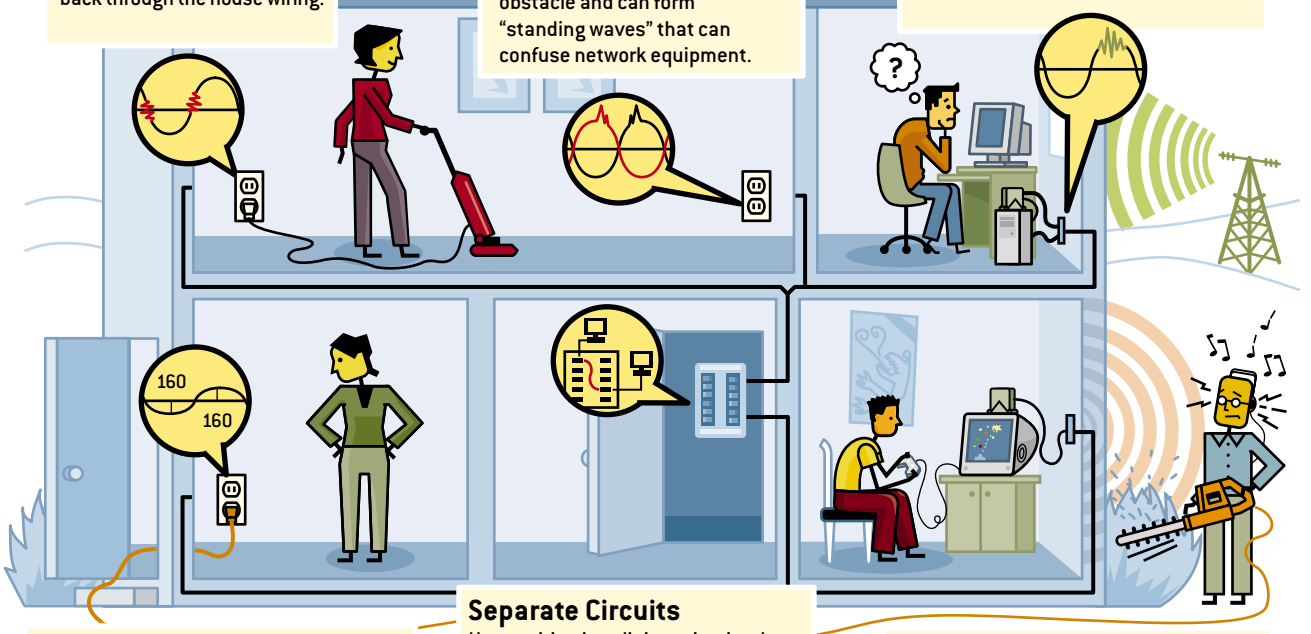


IDEAL AC POWER VOLTAGE

Motor Noise
Vacuum cleaners, blenders and other motors sweep brushes across magnets, producing static as a side effect. The static is conducted back through the house wiring.

Reflection
Sudden changes in the resistance of a circuit, such as a termination at an unused outlet, act like a wall to communications signals. They bounce off the obstacle and can form "standing waves" that can confuse network equipment.

Radio Interference
The electrical wiring in a house acts like a large antenna that can pick up signals from radio and television towers or amateur radio operators nearby.



Changes in Size and Shape
Turning on a light switch or plugging in an extension cord changes the size and character of the electrical network, causing brief dips or surges in power levels.

Separate Circuits
Home wiring is split into circuits that connect only at the main breaker or at a transformer down the street. Signals between machines on different circuits must jump those hurdles.

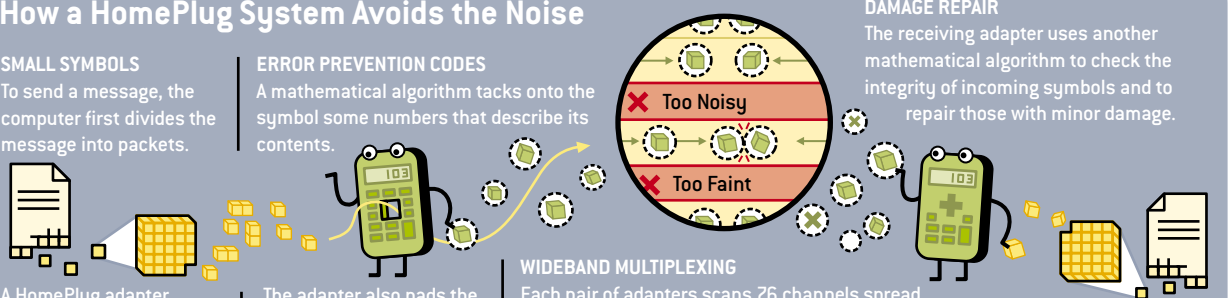
Stray Transmissions
One way to cope with noise is to increase the signal power. But doing so increases stray radio noise transmitted by the antennalike wiring.

How a HomePlug System Avoids the Noise

SMALL SYMBOLS
To send a message, the computer first divides the message into packets.

ERROR PREVENTION CODES
A mathematical algorithm tacks onto the symbol some numbers that describe its contents.

DAMAGE REPAIR
The receiving adapter uses another mathematical algorithm to check the integrity of incoming symbols and to repair those with minor damage.



A HomePlug adapter plugged into the wall receives the packets and subdivides each one into "symbols" small enough to fit between bursts of noise.

The adapter also pads the symbol with a guard interval that protects the data from collisions with reflected echoes of itself and other symbols.

WIDEBAND MULTIPLEXING
Each pair of adapters scans 76 channels spread across a wide band of spectrum from 4.5 to 21 megahertz. They block those that are too noisy or faint. Symbols are sent simultaneously on all clear channels, but at low power to minimize stray radio transmissions.

The adapter then reassembles the symbols into a packet, and the target computer stitches the packets into a copy of the original message.

GRAPHIC BY XPLANE (WWW.XPLANE.COM)

"What makes it all work is a complexity of signal processing that considerably exceeds anything ever used before." *—Oleg Logvinov, president of Enikia*

ment. They blocked off the eight channels that would be most likely to interfere with amateur radio operators to head off any complaints to the Federal Communications Commission.

"But we spent most of our effort trying to deal with noise on the power line," Yonge says. "That was the hardest problem." The engineers needed a transmission technique that could adapt to rapidly changing conditions on the line. They found one in so-called orthogonal frequency division multiplexing (OFDM), which is used in Europe for digital television broadcasts.

Bending with the Wind

OFDM IS SIMPLER than its intimidating name suggests [*see illustration on opposite page*]. Unlike FM radio, in which each channel carries a different program, OFDM allows a HomePlug device to send a data message using all 76 independent channels at once. Before two HomePlug adapters start exchanging data, they send each other test signals on every channel and block off those that are too noisy or faint. "That channel map is updated every few seconds," Yonge explains. So the speed of communication rises and falls as needed for as long as the conversation continues.

That takes care of the wind, to continue our analogy, but it cannot completely compensate for echoes and sudden outbursts of noise. To get around the echoes, each packet of data put on the network is padded with a guard interval, a brief pause that allows the reverberations to die down. And every digital payload is preprocessed to add extra error-checking information. If the message is corrupted en route, the receiver can use the added numbers to mathematically reconstruct the damaged bits.

"What makes it all work is a complexity of signal processing that considerably exceeds anything ever used before in mainstream wireless or wired communications," says Oleg Logvinov, president of Enikia, a power-line communications company in Warren, N.J. "But the number of logic gates you can pack into a chip today is enough to conquer complexity." Indeed, Intellon's chip is nearly as complex as a first-generation Pentium processor but is custom-designed to handle just this one task.

In simulations, Yonge recalls, the system worked great. But the real test came last spring, when Intellon sent engineers out to test its prototype equipment in more than 25 companies and 500 homes of various sizes and vintages around the world. The consortium members had set a high criterion for success, says William E. Earnshaw, Intellon's head of engineering. "They wanted it to work at full capacity in 80 percent of the homes and at two thirds of full speed in the rest." The technology passed easily, Earnshaw reports. "You can plug a vacuum cleaner in right next to the modem, and it will still work," Yonge boasts.

In November, Linksys and Phonex Broadband became the first to announce retail devices that will work with PCs, printers and any other peripherals that support a USB network connection. Other manufacturers are not far behind. According to Linksys, prices will be similar to those for Wi-Fi gear but a bit higher than HomePNA. "Most every room has at least two outlets," notes Karen Sohl of Linksys, "so the power-line adapters are more convenient than phone-line products" and thus may command a slightly higher price. The cost of the equipment will fall over time, says Tom Reed, president of HomePlug and manager of emerging technologies at Radio Shack. Because power-line adapters do not need as much analog circuitry, they will always be cheaper to make than wireless devices.

Power-line communications also have a security advantage over wireless, Reed points out. The signals will propagate to other homes on the same transformer—typically three to six houses in the U.S. (or all the units in an apartment building). But the chips automatically come with encryption turned on, unlike Wi-Fi. Cracking the 56-bit ciphers isn't impossible, but it isn't easy.

Scherf of Parks Associates perceives two critical tests ahead for the technology. The first is a competing standard being developed by the Consumer Electronics Association. That effort appears to be at least a year away from completion. By the time it arrives, Yonge says, HomePlug will be rolling out version 2, which will increase speeds to 100 megabits a second. But two incompatible standards could sow confusion, nonetheless.

Second, and probably not coincidentally, the companies that make audio, video and telephone components remain on the sidelines. That may delay some of the most appealing applications for power-line communications. "You could plug a cable or satellite video receiver into any outlet in the home and then plug your TV in anywhere and move it around at will," Reed muses. "Or you could add a virtual second phone line. Say you grew up in Omaha: with voice-over IP [Internet telephony] you could get a local phone number in Omaha that connects over the Internet to ring an IP phone plugged into the wall in your house in California. And when you move to Boston, the number stays the same."

It will take clever business innovations to make such dreams profitable. But thanks to the innovations of clever engineers, the technology now seems plausible. SA

MORE TO EXPLORE

HomePlug Standard Brings Networking to the Home. Steve Gardner et al. in *Communication Systems Design,* Vol. 6, No. 12; December 2000. Available online at **www.csdmag.com/main/2000/12**

HomePlug Powerline Alliance: **www.homeplug.org**

HomePNA: **www.homepna.org**

Wi-Fi: **www.wi-fi.org**

THE MAGIC OF MICROARRAYS

Research tools known as DNA microarrays are already clarifying the molecular roots of health and disease and speeding drug discovery. They could also hasten the day when custom-tailored treatment plans replace a one-size-fits-all approach to health care

BY STEPHEN H. FRIEND AND ROLAND B. STOUGHTON

DOT PATTERNS EMERGE when DNA microarrays analyze tissue samples. Individual differences in those patterns could one day help doctors match treatments to the unique needs of each patient.

MOST PEOPLE STRICKEN with a cancer called diffuse large B cell lymphoma initially respond well to standard therapy. Yet in more than half of cases, the cancer soon roars back lethally. Physicians have long assumed that the reason some individuals succumb quickly while others do well is that the disease actually comes in different forms caused by distinct molecular abnormalities. But until two years ago, investigators had no way to spot the patients who had the most virulent version and thus needed to consider the riskiest, most intensive treatment.

Then a remarkable tool known as a DNA microarray, or DNA chip, broke the impasse. It enabled a team of researchers from the National Institutes of Health, Stanford University and elsewhere to distinguish between known long- and short-term survivors based on differences in the overall pattern of activity exhibited by

hundreds of genes in their malignant cells at the time of diagnosis. That achievement should lead to a diagnostic test able to identify the patients in greatest danger.

DNA microarrays, first introduced commercially in 1996, are now mainstays of drug discovery research, and more than 20 companies sell them or the instruments or software needed to interpret the information they provide. The devices are also beginning to revolutionize how scientists explore the operation of normal cells in the body and the molecular aberrations that underlie medical disorders. The tools promise as well to pave the way for faster, more accurate diagnoses of many conditions and to help doctors personalize medical care—that is, tailor therapies to the exact form of disease in each person and select the drugs likely to work best, with the mildest side effects, in those individuals.

Tiny Troupers

THE ARRAYS COME IN several varieties, but all assess the composition of genetic material in a tissue sample, and all consist of a lawn of single-stranded DNA molecules (probes) that are tethered to a wafer often no bigger than a thumbprint. These chips also capitalize on a very handy property of DNA: complementary base pairing.

DNA is the material that forms the more than 30,000 genes in human cells—the sequences of code that constitute the blueprints for proteins. It is built from four building blocks, usually referred to by the first letter of their distinguishing chemical bases: A, C, G and T. The base A in one strand of DNA will pair only with T (A's complement) on another strand, and C will pair only with G.

Hence, if a DNA molecule from a tissue sample binds to a probe having the sequence ATCGGC, an observer will be able to infer that the molecule from the sample has the complementary sequence: TAGCCG. RNA, which is DNA's chemical cousin, also follows a strict base-pairing rule when binding to DNA, so the sequence of any RNA strand that pairs up with DNA on a microarray can be inferred as well.

Complementary base-pairing reactions have been integral to many biological tests for years. But amazingly, DNA microarrays can track tens of thousands of those reactions in parallel on a single chip. Such tracking is possible because each kind of probe—be it a gene or a shorter sequence of code—sits at an assigned spot within a checkerboardlike grid on the chip and because the DNA or RNA molecules that get poured over the array carry a fluorescent tag or other label that can be detected by a scanner. Once a chip has been scanned, a computer converts the raw data into a color-coded readout.

Scientists rely on DNA microarrays for two very different purposes. So-called genotype applications compare the DNA on a chip with DNA in a tissue sample to determine which genes are in the sample or to decipher the order of code letters in as yet unsequenced strings of DNA. Frequently, however, investigators these days use the devices to assess not merely the presence or sequence of genes in a sample but the expression, or activity level, of those genes. A gene is said to be expressed when it is transcribed into messenger RNA (mRNA) and translated into protein. Messenger RNA molecules are the mobile transcripts of genes and serve as the templates for protein synthesis.

Gene Hunters

RESEARCHERS have employed the genotype approach to compare the genes in different organisms (to find clues to the evolutionary history of the organisms, for example) and to compare the genes in tumors with those in normal tissues (to uncover subtle differences in gene composition or number). One day gene comparisons performed on DNA chips could prove valuable in medical practice as well.

Carefully designed arrays could, for instance, announce the precise cause of infection in a patient whose flulike symptoms (such as aches, high fever and breathing difficulty) do not point to one clear culprit. A surface could be arrayed with DNA representing genes that occur only in selected disease-causing agents, and a medical laboratory could extract and label DNA from a sample of infected tissue (perhaps drawn from the person's nasal passages). Binding of the patient's DNA to some gene sequence on the chip would indicate which of the agents was at fault. Similarly, chips now being developed could signal that bioterrorists have released specific types of anthrax or other exotic germs into a community.

For better or worse, gene-detecting microarrays could also identify an individual's genetic propensity to a host of disorders. Most genetic differences in people probably take the form of single nucleotide polymorphisms, or SNPs (pronounced "snips"), in which a single DNA letter substitutes for another. A chip bearing illness-linked gene variants could be constructed to reveal an individual's SNPs and thus predict the person's likelihood of acquiring Alzheimer's disease, diabetes, specific cancers and so on. Those people at greatest risk could then receive close

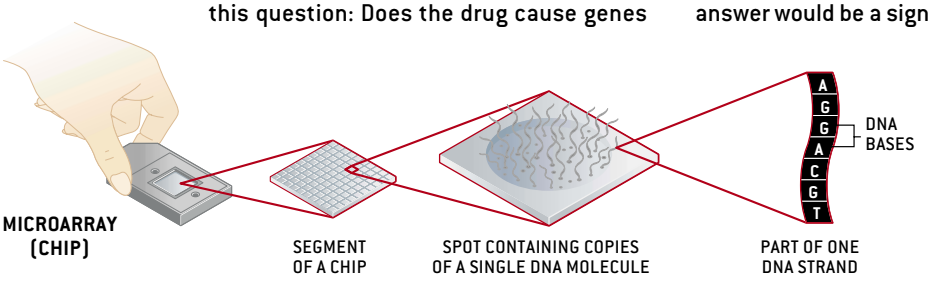
Overview/*Microarrays*

- DNA microarrays, also known as DNA or gene chips, can track tens of thousands of molecular reactions in parallel on a wafer smaller than a microscope slide. The chips can be designed to detect specific genes or to measure gene activity in tissue samples.
- These properties are proving immensely valuable to cell biologists, to scientists who study the roots of cancer and other complex diseases, and to drug researchers. Microarrays are also under study as quick diagnostic and prognostic tools.
- Protein arrays, which have great promise as diagnostic devices and as aids to biological research, are being developed as well.
- The research and diagnostic information provided by DNA chips and protein arrays should eventually help physicians provide highly individualized therapies.

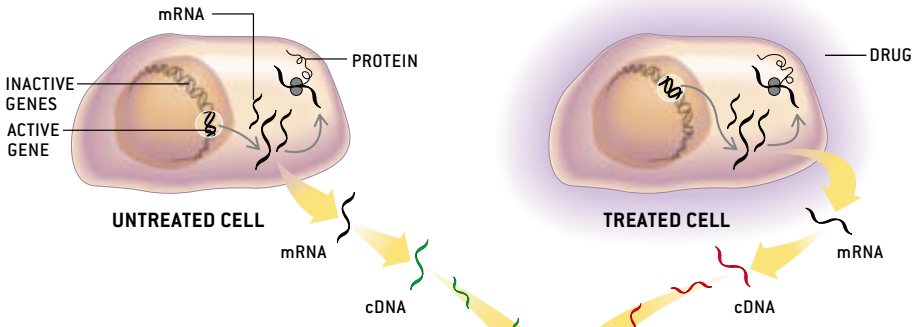
DENNIS GALANTE PHOTOGRAPHY (*preceding pages*)

HOW ARRAYS WORK

TO DETERMINE QUICKLY whether a potential new drug is likely to harm the liver, a researcher could follow the steps below, asking this question: Does the drug cause genes (the blueprints for proteins) in liver cells to alter their activity in ways that are known to cause or reflect liver damage? A "yes" answer would be a sign of trouble.

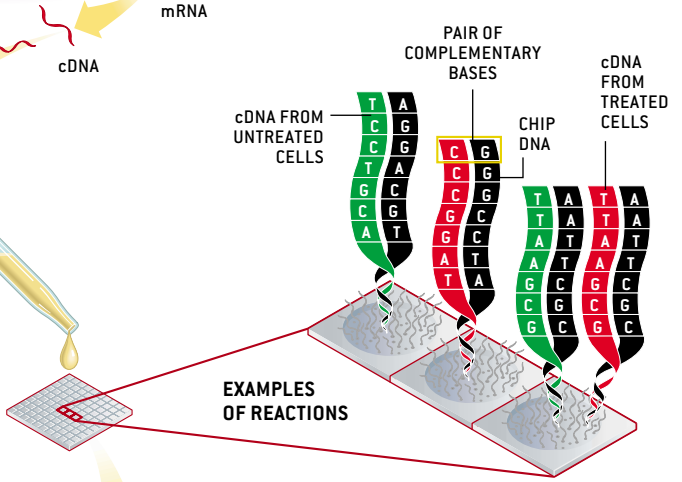


1 Construct or buy a microarray, or chip, containing single-stranded DNA representing thousands of different genes, each assigned to a specified spot on the one-by-three-inch or smaller device. Have every spot include thousands to millions of copies of a DNA strand.

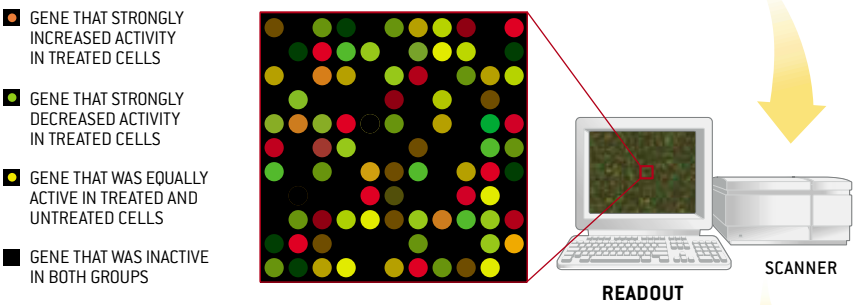


2 Obtain two samples of liver cells; apply the drug to one sample. Then, from each sample, collect molecules of messenger RNA (mRNA)—the mobile copies of genes and the templates for protein synthesis in cells.

3 Transcribe the mRNA into more stable complementary DNA (cDNA) and add fluorescent labels—green to cDNAs derived from untreated cells, red to those from treated cells.

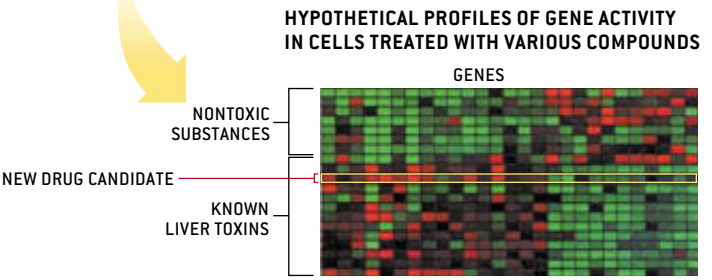


4 Apply the labeled cDNAs to the chip. Binding occurs when cDNA from a sample finds its complementary sequence of bases on the chip (*detail at right*). Such binding means that the gene represented by the chip DNA was active, or expressed, in the sample.



5 Put the chip in a scanner. Have a computer calculate the ratio of red to green at each spot (to quantify any changes in gene activity induced by the drug) and generate a color-coded readout.

6 Determine whether any genes responded strongly to the drug in ways known to promote or reflect liver damage. Or compare the overall expression pattern produced by strong responders with the patterns produced when those genes react to known liver toxins (*right*). Close similarity would indicate that the new candidate was probably toxic as well. In the diagram, each box represents a single gene's response to a compound.



JARED SCHNEIDMAN DESIGN

monitoring, intensive preventive care and early intervention. Whether these kinds of tests would appeal to the public is an open question, though; the downside of such knowledge can be increased anxiety and the potential for discrimination by employers and insurers.

Other valuable information provided by SNP chips would pose no threat to people's mental state, employability or insurability. The gene variants we possess influence how our bodies process the medicines we take, which in turn influences the effectiveness of the drugs and the intensity of their side effects. Chips that highlighted our unique genetic sensitivities would help physicians choose the drugs that work best and pose the fewest dangers in each of us. SNP chips displaying genetic mutations that increase the aggressiveness of tumors might also help pathologists determine whether benign-looking tumors are actually fiercer than they seem based on microscopic analyses. Both types of arrays are already being investigated for use in medical care.

Choice Expressions

AS EXCITING AS such applications are, it is the other major use of arrays—expression profiling—that has increasingly captivated researchers over the past few years. Laboratory workers produce these profiles by measuring the amounts of different mRNAs in a tissue sample. Generally, the more copies of mRNA a cell makes, the more copies of protein it will make, so the quantities of the various mRNAs in a sample can indirectly indicate the types and amounts of proteins present. Proteins are often of interest because they control and carry out most activities in our bodies' cells and tissues. Chips that directly measure protein levels are being developed [*see box on page 52*], but constructing them remains challenging.

By using the genome as a sensor pad to detect activity changes in a cell's various genes, scientists can gain exquisitely detailed "snapshots" of how a cell's functions have been altered by drugs or disease states. At times, knowing the overall on-off pattern of gene activity in a sample can actually be more useful than knowing which particular genes turn on and off in response to some influence. In those cases, as will be seen, the pattern serves as a shorthand "signature" reflecting the molecular state of a sample under some specific condition.

Expression profiling has proved invaluable on many fronts. Cell biologists like it because knowledge of the proteins that predominate after a tissue is exposed to different conditions can provide insight into how the tissue normally compensates for disruptions and what goes wrong when diseases develop.

These scientists are also using expression arrays to learn the functions of genes that have been discovered as a result of the recent sequencing of nearly all the DNA in the nucleus of the human cell. Several techniques that do not involve microarrays can reveal the jobs performed by newly discovered genes (or, more properly, by the proteins those genes encode), but those approaches do not always work well or quickly. In what has come to be called the guilt-by-association application, expression arrays can help fill in the blanks, even in the absence of any prior clues to a gene's role in the body.

This method derives from the awareness that no gene is an island. If genes in a tissue switch on and off together in response to some influence—say, a drug, an infection or an induced gene mutation—workers can surmise that those like-acting genes operate in the same regulatory pathway; that is, the genes work together or in series to induce a cellular response. Investigators can reasonably guess, then, that the jobs of any originally mysterious genes in the group resemble those of genes whose responsibilities are already understood.

Drug Discovery Tools

DRUG RESEARCHERS, too, take advantage of the guilt-by-association method—to discover proteins not previously known to operate in biological pathways involved in diseases. Once those proteins are found, they can be enlisted as targets for the development of new and better medicines.

In one example, Peter S. Linsley, our colleague at Rosetta Inpharmatics, wanted to identify fresh targets for drugs that might combat inflammatory illnesses, in which the immune system perversely damages parts of the body. He therefore asked which genes in white blood cells of the immune system increase and decrease their protein production in parallel with the gene for a protein called interleukin-2 (IL-2), which is strongly implicated in inflammatory disorders.

He got the answer by producing expression profiles for white blood cells exposed to various chemicals and then having a computer run a sophisticated pattern-matching program to pinpoint a set of genes that consistently switched on or off when the IL-2 gene was activated. This set included a gene whose function in the body had not been determined by other means. At about the same time, investigators at the Pasteur Institute in

AN ARRAY OF COMPANIES

The following are just some of the companies that sell or are developing array-related products and services:

DNA MICROARRAYS

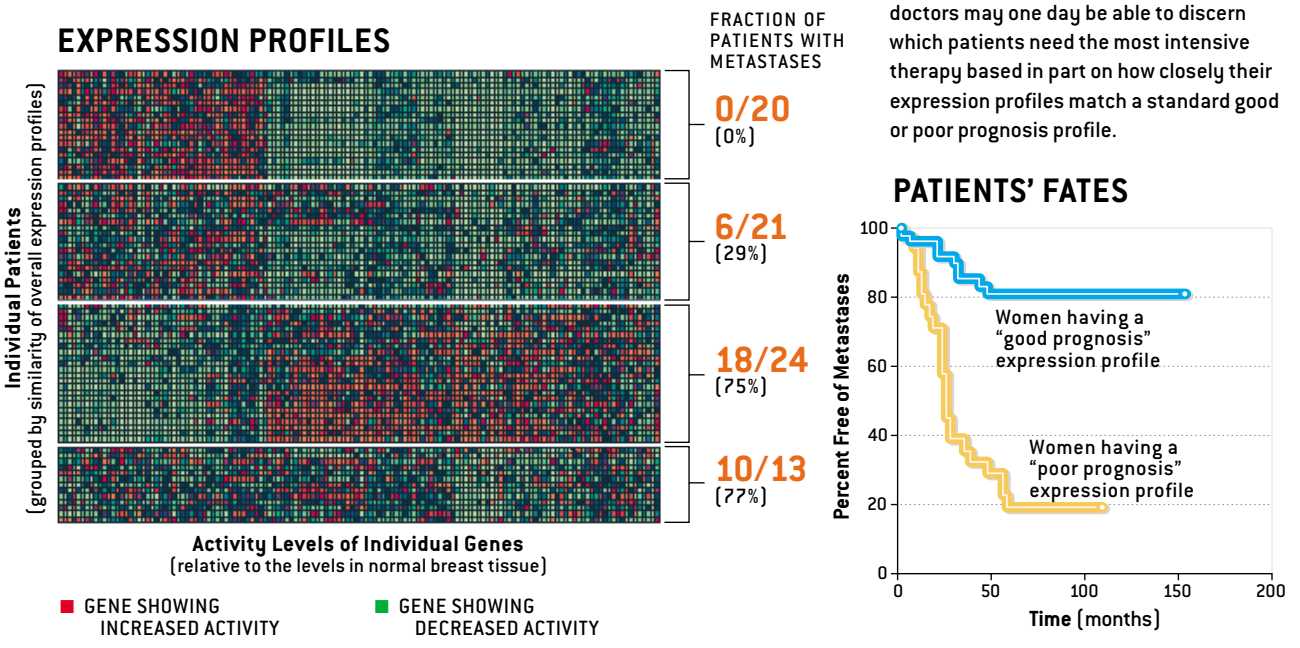
Affymetrix, *Santa Clara, Calif.*
Agilent Technologies, *Palo Alto, Calif.*
Amersham Biosciences, *Piscataway, N.J.*
Axon Instruments, *Union City, Calif.*
BioDiscovery, *Marina del Rey, Calif.*
Clontech, *Palo Alto, Calif.*
Genomic Solutions, *Ann Arbor, Mich.*
Mergen, *San Leandro, Calif.*
Motorola Life Sciences, *Northbrook, Ill.*
Nanogen, *San Diego, Calif.*
Partek, *St. Peters, Mo.*
PerkinElmer, *Boston, Mass.*
Rosetta Inpharmatics, *Kirkland, Wash.*
Spotfire, *Cambridge, Mass.*
Virtek Vision International, *Ontario, Canada*

PROTEIN ARRAYS

Biacore International, *Uppsala, Sweden*
Biosite Diagnostics, *San Diego, Calif.*
Ciphergen, *Fremont, Calif.*
Large Scale Biology, *Germantown, Md.*

PREDICTING CANCER'S COURSE

WORK AT ROSETTA INPHARMATICS and the Netherlands Cancer Institute suggests that microarrays can help distinguish cancer patients with different prognoses. After determining the activity (expression) levels of genes in small, localized breast tumors from young women who were followed for at least five years after surgery, the researchers found that the expression profiles—the overall patterns of activity across a selection of genes in the tumors—differed among the patients (*left*). A mathematical analysis (*right*) then revealed that patients whose expression profiles resembled a "poor prognosis" signature (the average pattern in tumors that metastasized) were much more likely to suffer a quick recurrence than were patients whose profiles resembled a "good prognosis" signature (the typical pattern in tumors that did not spread). If such results are confirmed by others, doctors may one day be able to discern which patients need the most intensive therapy based in part on how closely their expression profiles match a standard good or poor prognosis profile.



Paris independently confirmed, with other methods, that this gene operates in the IL-2 pathway. Together the findings suggest that the protein encoded by the gene could be a good target for anti-inflammatory drugs.

Pharmaceutical scientists use expression profiling in a different way: to pick out—and eliminate—drug candidates that are likely to produce unacceptable side effects. Workers who want to determine whether a given compound could damage the heart, for example, can compile a compendium of expression profiles for heart cells exposed to existing drugs and other chemicals. If they also treat heart cells with the drug candidate under study, they can ask a computer to compare the resulting signature with those in the compendium. A signature matching those produced by substances already known to disrupt cardiac cells would raise a red flag.

A compendium of expression profiles can also help explain why a drug produces particular side effects. A pressing question today, for instance, is why protease inhibitors, which are lifesavers to people infected with HIV (the virus that causes AIDS), can lead to high cholesterol and triglyceride levels in the blood, strange redistributions of body fat, and insulin resistance. Aware that the liver influences the production and breakdown of lipids (the group that includes cholesterol and triglycerides) and of lipid-containing proteins, we and others at Rosetta, in collaboration with Roger G. Ulrich and his team at Abbott Laboratories, decided to see whether one protease inhibitor—ritonavir—produced some of its side effects by acting on the liver.

With an array representing about 25,000 rat genes, we produced expression profiles of rat liver tissue exposed to an assortment of compounds that can be toxic to the liver. After that, we grouped the compounds according to similarities of expression signatures across some 2,400 genes that responded strongly to those substances. Next we delivered ritonavir to rat livers and compared the resulting expression profiles with those generated earlier.

THE AUTHORS

STEPHEN H. FRIEND and *ROLAND B. STOUGHTON* are colleagues at Rosetta Inpharmatics in Kirkland, Wash., which was founded in 1996 to develop molecular profiling methods involving computers and DNA microarray technology. Merck & Co. acquired the company last year. Friend is vice president of basic research at Merck and president of Rosetta. He was a pediatric oncologist and molecular biologist at Harvard University before becoming director of molecular pharmacology at the Fred Hutchinson Cancer Research Center and co-founding Rosetta. Stoughton, who has a Ph.D. in physics, is senior vice president for informatics at Rosetta. Before turning his attention to biotechnology, he worked on developing signal-processing and pattern-recognition tools for geophysics and astrophysics.

DATA DISPLAY BY HONGYUE DAI *Rosetta Inpharmatics*; GRAPH BY SARA CHEN

Protein Arrays—A New Option

by N. Leigh Anderson and Gunars Valkirs

LIKE DNA MICROARRAYS, protein-based chips—which array proteins instead of DNA molecules on a small surface—can measure the levels of proteins in tissues. In fact, they do the job more directly and, some evidence says, more accurately. Protein arrays also stand alone in being able to reveal which of thousands of proteins in a tissue interact with one another.

All these properties make protein arrays quite appealing to biological researchers. But the average person would most likely be intrigued for a different reason. Hope is high that such chips will dramatically expand the number of conditions that doctors can diagnose quickly in their offices.

These devices should be very useful as diagnostic tools in part because, unlike DNA microarrays, they can glean information from blood plasma, which is easy to obtain. Most medical disorders—from infectious diseases to heart or kidney damage—leave identifiable traces in the blood, in the form of secreted or leaked proteins. Moreover, in a single test, the arrays might measure many or all of the proteins known to flag the presence of medical problems. In contrast, standard diagnostic tests detect only one or a few disease-specific proteins at a time.

The design of protein arrays resembles that of DNA chips. Hundreds to thousands of distinct proteins sit (in millions of copies) at specified spots in a grid on a wafer-thin plate. Binding of proteins from a blood sample to proteins on a chip reveals the nature and quantities of the sample proteins.

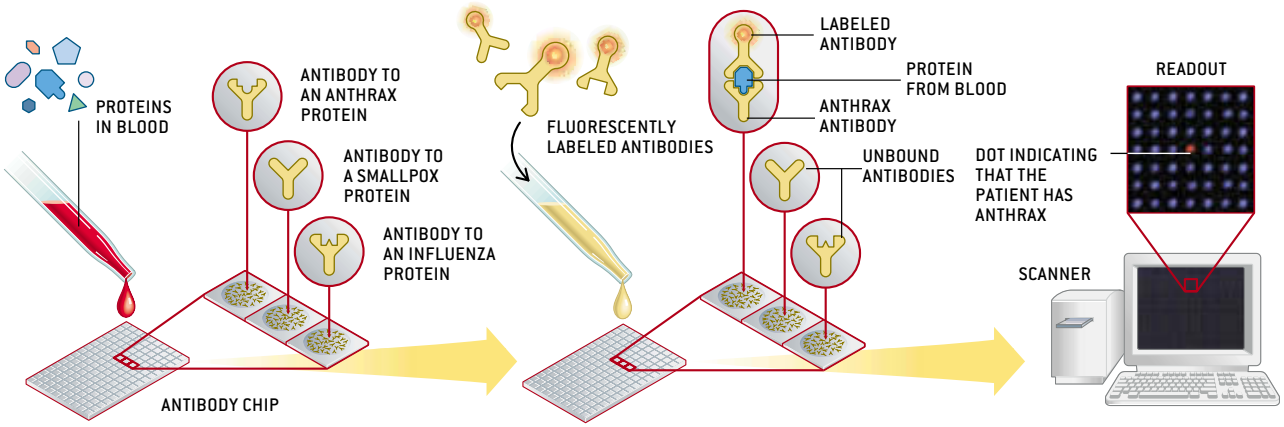
The kinds of proteins displayed on the chips can vary depending on the questions being asked. But the chips closest to commercialization (initially for use by researchers) rely on the remarkable immune system molecules called antibodies—each of which recognizes and binds to one specific protein or, more precisely, to a specific segment of a protein. Some of these antibody chips work by what is called the sandwich method: proteins recognized by a chip get sandwiched between two different antibodies, one that grabs the protein and a second that attaches a fluorescent label to the snagged molecule (*diagram below*).

For antibody-based arrays to deliver fully on their potential for advancing research and diagnostics, scientists will have to topple at least two major impediments. One is the need for techniques that mass-produce many different antibodies at once, and not just any antibodies—those that bind tightly to one target, so as to reveal even small quantities in a sample. This problem is already being surmounted. The second obstacle is more fundamental. Medical science has so far uncovered only dozens of the perhaps thousands of proteins able to signal the presence or progress of a disease. Until chipmakers know which proteins to look for, they will be able to seek only a limited number of disease markers in a tissue sample. Fortunately, droves of investigators are now hunting for new disease-specific proteins. As advances in antibody manufacture and protein discovery converge, they will yield a second generation of protein arrays that could well transform both medical research and clinical practice.

N. Leigh Anderson and Gunars Valkirs collaborate on protein array research. Anderson is chief scientific officer at Large Scale Biology Corporation in Germantown, Md. Valkirs is chief technology officer at Biosite Diagnostics in San Diego, Calif.

A PROTEIN ARRAY IN ACTION

DOCTORS MIGHT ONE DAY use a "sandwich assay" to identify the infectious agent responsible for a patient's illness. Is it a common flu bug or a new, deadly variety? Might the tuberculosis bacterium be at fault—or even anthrax, smallpox or Q fever microorganisms unleashed by bioterrorists? Following the steps below would reveal the answer.



1 Apply blood from a patient to a chip, or array, consisting of antibodies assigned to specific squares on a grid. Each square includes multiple copies of an antibody able to bind to a specific protein from one organism and so represents a distinct disease-causing agent.

2 Apply fluorescently labeled antibodies able to attach to a second site on the proteins recognizable by the antibodies on the chip. If a protein from the blood has bound to the chip, one of these fluorescent antibodies will bind to that protein, enclosing it in an antibody "sandwich."

3 Feed the chip into a scanner to determine which organism is present in the patient's body. In this case, the culprit is shown to be a strain of anthrax.

JARED SCHNEIDMAN DESIGN

Ritonavir, we learned, leads to activation of genes that are usually quieted in response to a well-known lipid-lowering agent; ritonavir also decreases the production of proteins that normally assemble into proteosomes, structures that break down no-longer-useful proteins, including lipid-containing types. These findings suggest that ritonavir raises lipid levels in the liver—and hence in the blood—in part by elevating the liver's synthesis of lipids and inhibiting its breakdown of lipid-containing proteins. Further study of exactly how ritonavir interacts with the lipid- and proteosome-producing pathways will provide ideas for reducing its side effects.

Treatment Tailors

HAVING AN ENLARGED arsenal of drugs, and more drugs with fewer side effects, would be a great outcome of the molecular profiling made possible by DNA array studies. But many physicians are hoping for an even better result: rapid diagnostic tools that would divide patients with similar symptoms into separate groups that would benefit from different treatment plans. As the lymphoma study mentioned at the start of this article demonstrated, cancer specialists in particular desperately need ways to identify patients who require maximally aggressive treatment from the beginning.

Research into breast cancer by our group at Rosetta, working with collaborators from the Netherlands Cancer Institute in Amsterdam, demonstrates how expression arrays can help [*see box on page 49*]. In this case, we wanted to invent a test able to determine which young patients with early-stage breast cancer (with no evidence of cancer in the lymph nodes) need systemic drug therapy to prevent tumor spread (metastasis) after surgery and which do not. Although current guidelines recommend systemic treatment for about 90 percent of these women, a good many of them would probably avoid distant metastases even if they did not have such treatment. Unfortunately, standard tools cannot single out the women at greatest risk.

We began by generating expression profiles for tumors from close to 100 women under age 55 whose clinical course had been followed for more than five years after surgery. We initially worked with a microarray representing 25,000 human genes. In the end, we found that one particular signature produced by about 70 genes strongly indicated that metastases would soon appear. In addition, the opposite pattern was strongly indicative of a good prognosis. Clearly, some tumors are programmed to metastasize before they grow to a size smaller than half a dime, whereas other, larger masses are programmed not to spread.

Our results have to be confirmed by others before expression profiling can become a routine part of breast cancer workups. Within two years, many medical centers will probably begin to test expression profiling as a guide to therapy, not just for breast cancer but for other types as well. Other diseases need improved diagnostic tools, too. Expression profiling might help distinguish subgroups of patients with such disorders as asthma, diabetes or obesity who have special treatment needs. Those applications are now under study.

Before microarrays can live up to their full potential as research and diagnostic tools, several roadblocks have to be toppled. The chips, scanners and other accoutrements remain expensive (engendering "array envy" in many underfunded academics). Presumably, however, costs will drop with time.

Yet even if prices fall, the technologies may prove infeasible, at least initially, for doctors' offices or standard medical laboratories. Few physicians or technicians have the equipment and the skill to prepare tissue samples properly for use with arrays. What is more, to diagnose, say, liver disease based on changes in gene expression in liver cells, a doctor would ideally need to obtain tissue from the liver. But that organ is not readily accessible.

These problems loom large right now but are probably surmountable with ingenuity. At times, for instance, accessible tissues might function as acceptable stand-ins for inaccessible ones. Moreover, in some instances, microarrays themselves may not have to be used; they might provide the research information needed for devising new diagnostic tests, which can then take other forms.

As the operations of cells and the entire body become better understood, physicians will be able to make more precise diagnoses, to offer patients more sophisticated therapies (possibly including gene therapies), and to tailor these interventions to an individual's genetic background and current state of physiological functioning. By the year 2020, health maintenance organizations and their ilk could conceivably keep *in silico* models of the personal molecular states of their subscribers—virtual simulations that could be updated constantly with microarray and other data from doctor visits and with new scientific information about cell biology. Perhaps some subscribers won't like that idea and will forgo a rate discount—and quite possibly the best care—in return for a feeling of privacy. Those who go along with the program, though, will probably delay the effects of aging more successfully and lead healthier lives. SA

MORE TO EXPLORE

The Chipping Forecast. Supplement to *Nature Genetics,* Vol. 21, pages 1–60; January 1999.

Genomics, Gene Expression and DNA Arrays. David Lockhart and Elizabeth Winzeler in *Nature,* Vol. 405, pages 827–836; June 15, 2000.

Experimental Annotation of the Human Genome using Microarray Technology. D. D. Shoemaker et al. in *Nature,* Vol. 409, pages 922–927; February 15, 2001.

Web sites listing links and publications on microarrays can be found at:

http://bioinformatics.phrma.org/microarrays.html

http://industry.ebi.ac.uk/~alan/MicroArray/

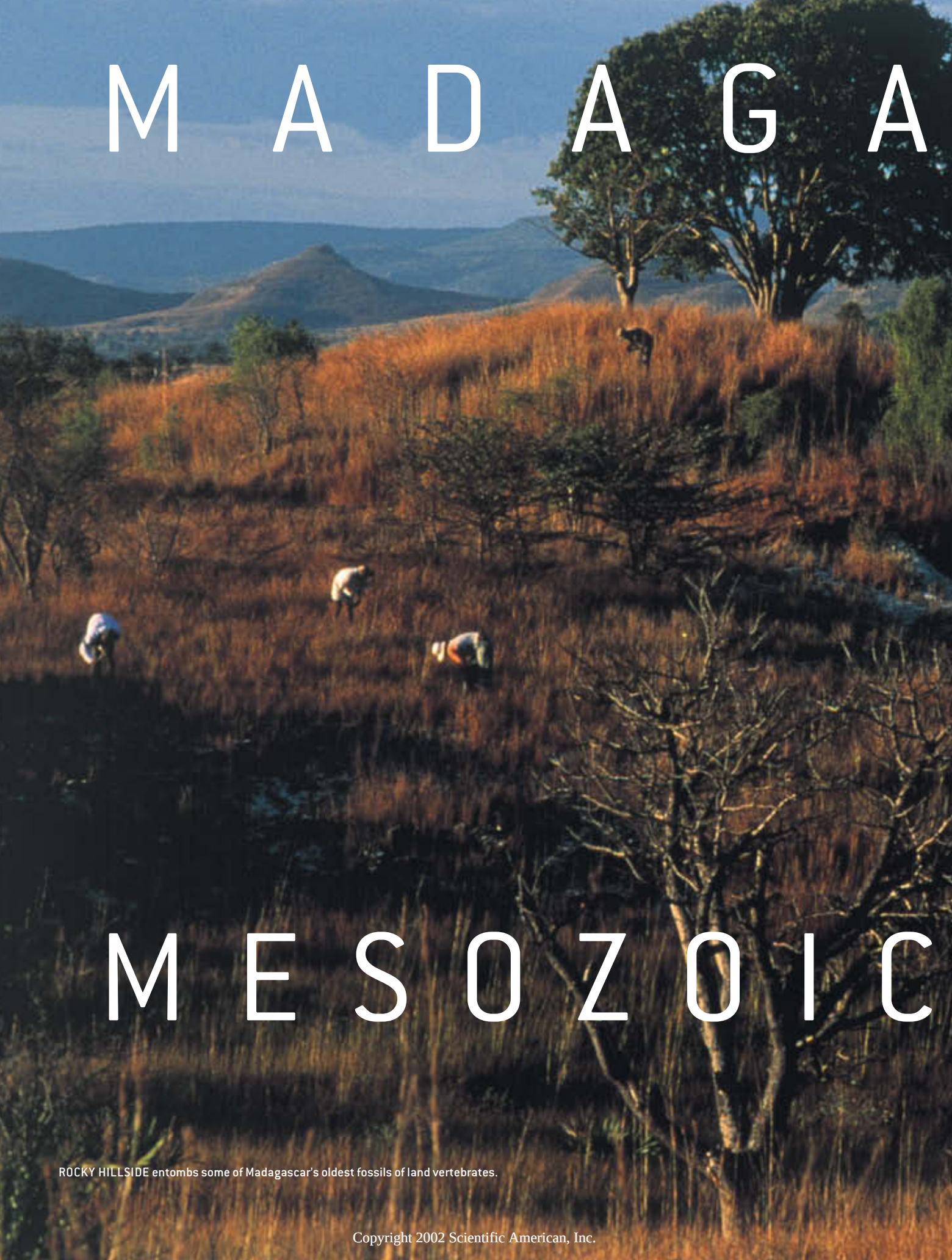
www.rii.com/publications/default.htm

http://ihome.cuhk.edu.hk/~b400559/2001j_mray.html

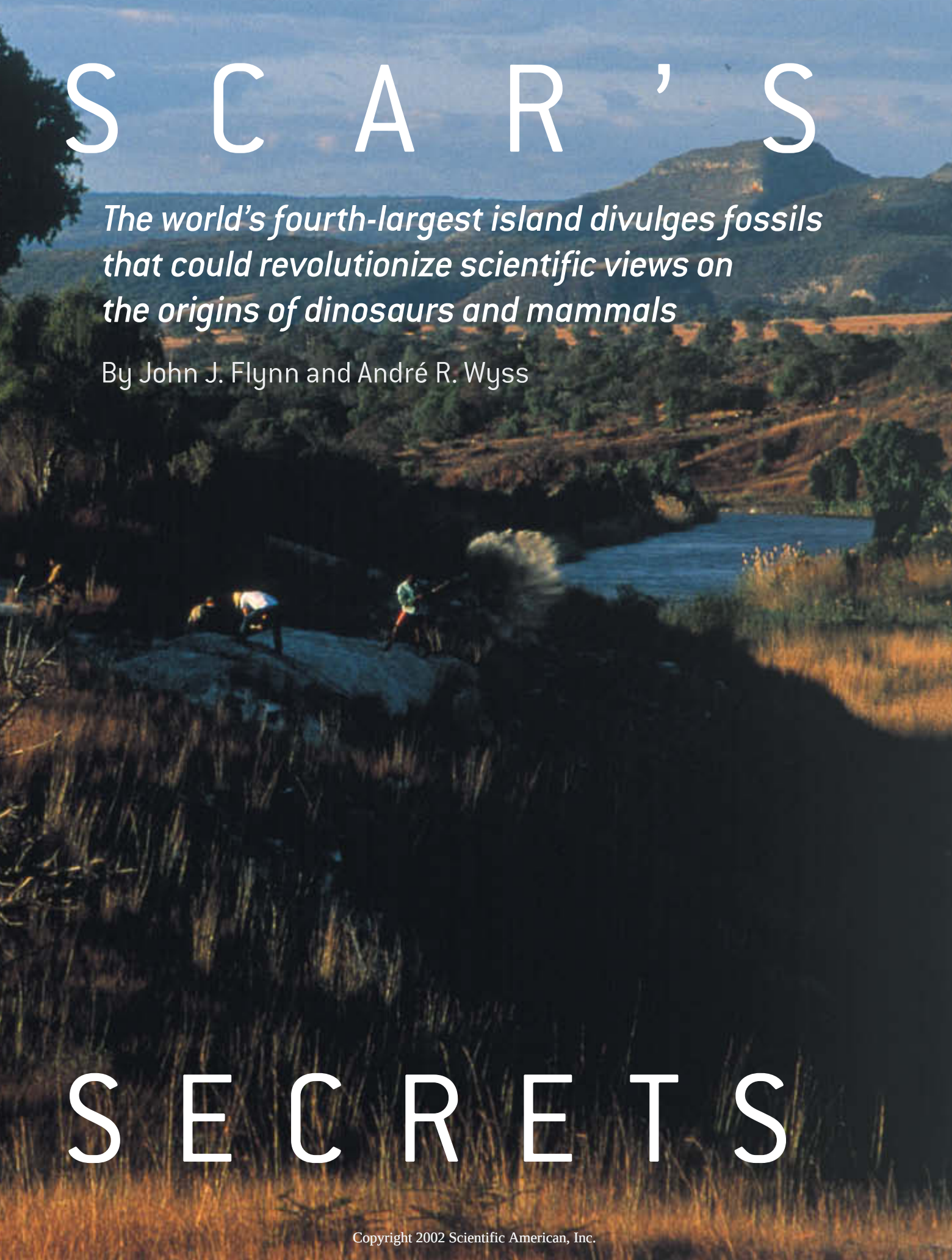
www.biologie.ens.fr/en/genetiqu/puces/links.html#news

MADAGA

MESOZOIC



ROCKY HILLSIDE entombs some of Madagascar's oldest fossils of land vertebrates.



SCAR'S SECRETS

The world's fourth-largest island divulges fossils that could revolutionize scientific views on the origins of dinosaurs and mammals

By John J. Flynn and André R. Wyss

THREE WEEKS INTO our first fossil-hunting expedition in Madagascar in 1996, we were beginning to worry that dust-choked laundry might be all we would have to show for our efforts. We had turned up only a few random teeth and bones—rough terrain and other logistical difficulties had encumbered our search. With our field season drawing rapidly to a close, we finally stumbled on an encouraging clue in the southwestern part of the island. A tourist map hanging in the visitor center of Isalo National Park marked a local site called "the place of animal bones." We asked two young men from a neighboring village to take us there right away.

Our high hopes faded quickly as we realized the bleached scraps of skeletons eroding out of the hillside belonged to cattle and other modern-day animals. This site, though potentially interesting to archaeologists, held no promise of harboring the much more ancient quarry we were after. Later that day another guide, accompanied by two dozen curious children from the village, led us to a second embankment similarly strewn with bones. With great excitement we spotted two thumb-size jaw fragments that were undoubtedly ancient. They belonged to long-extinct, parrot-beaked cousins of the dinosaurs called rhynchosaurs.

The rhynchosaur bones turned out to be a harbinger of a spectacular slew of prehistoric discoveries yet to come. Since then, the world's fourth-largest island has become a prolific source of new information about animals that walked the land during the Mesozoic era, the interval of the earth's history (from 250 million to 65 million years ago) when both dinosaurs and mammals were making their debut. We have unearthed the bones of primitive dinosaurs that we suspect are older than any found previously. We have also stirred up controversy with the discovery of a shrewlike creature that seems to defy a prominent theory of mammalian history by being in the "wrong" hemisphere. These exquisite specimens, among numerous others collected over five field seasons, have enabled us to begin painting a picture of ancient Madagascar and to shape our strategy for a sixth expedition this summer.

Much of our research over the past two decades has been aimed at unraveling the history of land-dwelling animals on the southern continents. Such questions have driven other paleontologists to fossil-rich locales in South Africa, Brazil, Antarctica and India. Rather than probing those established sites for additional finds, we were lured to Madagascar: the island embraces vast swaths of Mesozoic age rocks, but until recently only a handful of terrestrial vertebrate fossils from that time had been discovered there. Why? We had a hunch that no one had looked persistently enough to find them.

Persistence became our motto as we launched our 1996 expedition. Our team consisted of a dozen scientists and students from the U.S. and the University of Antananarivo in Madagascar. Among other benefits, our partnership with the country's leading university facilitated the acquisition of collecting and exporting permits—requisite components of all paleontological fieldwork. Before long, however, we ran headlong into logistical obstacles that surely contributed to earlier failures to find ancient fossils on the island. Mesozoic deposits in western Madagascar are spread over an area roughly the size of California. Generations of oxcarts and foot travel have carved the only trails into more remote areas, and most of them are impassable by even the brawniest four-wheel-drive vehicles. We had to haul most of our food, including hundreds of pounds of rice, beans and canned meats, from the capital. Fuel shortages sometimes seriously restricted mobility, and our work was even thwarted by wildfires, which occur frequently and rage unchecked. New challenges often arose unexpectedly, requiring us to adjust our plans on the spot.

NEITHER REPTILE NOR MAMMAL, this leopard-size traversodontid had the stout incisors and wide cheek teeth needed to grasp and grind vegetation as it browsed in Madagascar about 230 million years ago.

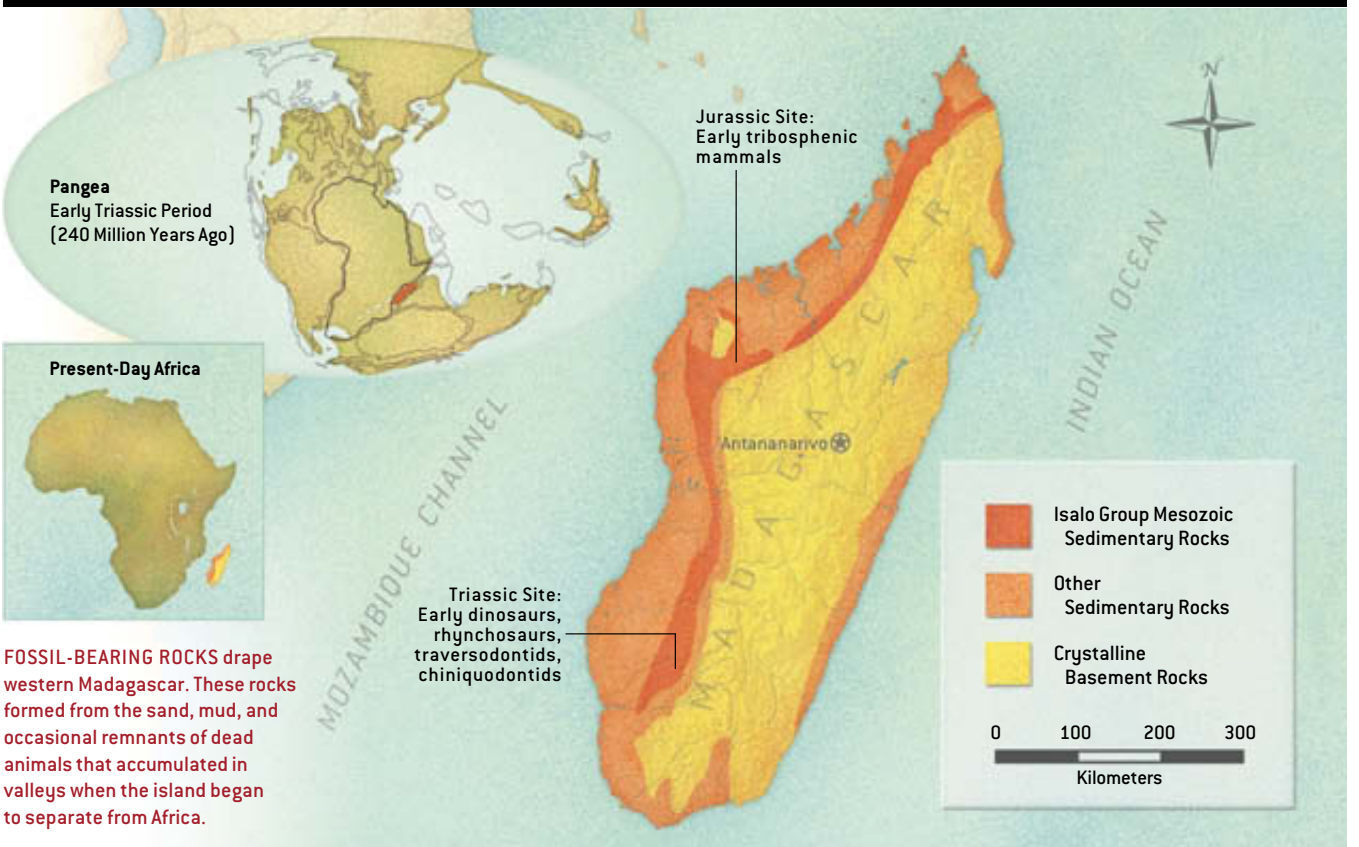
MARIA STENZEL *National Geographic Image Collection* [*preceding two pages*]; JOHN WEINSTEIN *The Field Museum* [*this page*]

Ancient Luck

PERHAPS THE MOST DAUNTING obstacle we faced in prospecting such a large region was deciding where to begin. Fortunately, we were not planning our search blindly. The pioneering fieldwork of geologists such as Henri Besairie, who directed Madagascar's ministry of mines during the mid-1900s, provided us with large-scale maps of the island's Mesozoic rocks. From those studies we knew that a fortuitous combination of geologic factors had led to the accumulation of a thick blanket of sediments over most of Madagascar's western lowlands—and gave us good reason to believe that ancient bones and teeth might have been trapped and preserved there.

At the dawn of the Mesozoic era 250 million years ago, it would have been possible to walk from Madagascar to almost anywhere else in the world. All of the planet's landmasses were united in the supercontinent Pangea, and Madagascar was nestled between the west coast of what is now India and the east coast of present-day Africa [*see map on opposite page*]. The world was a good deal warmer than at

MADAGASCAR THEN AND NOW



FOSSIL-BEARING ROCKS drape western Madagascar. These rocks formed from the sand, mud, and occasional remnants of dead animals that accumulated in valleys when the island began to separate from Africa.

present—even the poles were free of ice. In the supercontinent's southern region, called Gondwana, enormous rivers coursed into lowland basins that would eventually become the Mozambique Channel, which today spans the 250 miles between Madagascar and eastern Africa.

These giant basins represent the edge of the geologic gash created as Madagascar began pulling away from Africa more than 240 million years ago. This seemingly destructive process, called rifting, is an extremely effective way to accumulate fossils. (Indeed, many of the world's most important fossil vertebrate localities occur in ancient rift settings—including the famous record of early human evolution in the much younger rift basins of east Africa.) The rivers flowing into the basins carried with them mud, sand, and occasionally the carcasses or bones of dead animals. Over time the rivers deposited this material as a sequence of vast layers. Continued rifting and the growing mass of sediment caused the floors of the basins to sink ever deeper. This depositional process persisted for nearly 100 million years, until the basin floors thinned to the breaking point and molten rock ascended from the planet's interior to fill the gap as new ocean crust.

Up to that point nature had afforded Madagascar three crucial ingredients required for fossil preservation: dead organisms, holes in which to bury them (rift basins), and material to cover them (sand and mud). But special conditions were also needed to ensure that the fossils were not destroyed during the subsequent 160 million years. Again, geologic circumstances proved fortuitous. As the newly separated landmasses of Africa and Madagascar drifted farther apart, their sediment-laden coastlines rarely experienced volcanic eruptions or other events that could have destroyed buried fossils. Also key for fossil preservation is that the ancient rift basins ended up on the western side of the island, which today is dotted with dry forests, grasslands and desert scrub. In a more humid environment, such deposits would have eroded away or would be hidden under dense vegetation like the kind that hugs much of the island's eastern coast.

Initially Madagascar remained attached to the other Gon-

THE AUTHORS

JOHN J. FLYNN and *ANDRÉ R. WYSS* have collaborated for nearly 20 years. Their expeditions have taken them to the Rocky Mountains, Baja California, the Andes of Chile, and Madagascar. Together they also study the evolutionary history of carnivores, including dogs, cats, seals, and their living and fossil relatives. Flynn is MacArthur Curator of Fossil Mammals at the Field Museum in Chicago, associate chair of the University of Chicago's committee on evolutionary biology doctoral program, and adjunct professor at the University of Illinois at Chicago. Wyss is a professor of geological sciences at the University of California, Santa Barbara, and a research associate at the Field Museum.

The authors thank the National Geographic Society, the John C. Meeker family and the World Wildlife Fund for their exceptional support of this research.

SARA CHEN

dwanan landmasses: India, Australia, Antarctica and South America. It did not attain islandhood until it split from India about 90 million years ago. Sometime since then, the island acquired its suite of bizarre modern creatures, of which lemurs are the best known. For more than a century, researchers have wondered how long these modern creatures and their ancestors have inhabited the island. Illuminating discoveries by another team of paleontologists indicate that almost all major groups of living vertebrates arrived on Madagascar since sometime near the end of the Mesozoic era 65 million years ago [see "Modern-Day Mystery," on page 62]. Our own probing has focused on a more ancient interval of Madagascar's history—the first two periods of the Mesozoic era.

Pay Dirt

ONE OF THE JOYS of working in little-charted terrain has been that if we manage to find anything, its scientific significance is virtually assured. That's why our first discoveries near Isalo National Park were so exciting. The same evening in 1996 that we found the rhynchosaur jaw fragments, University of Antananarivo student Léon Razafimanantsoa spotted the six-inch-long skull of another interesting creature. We immediately identified the animal as a peculiar plant eater, neither mammal nor reptile, called a traversodontid cynodont.

The rhynchosaur jaws and the exquisite traversodontid skull—the first significant discoveries of our ongoing U.S.-Malagasy project—invigorated our expedition. The first fossil is always the hardest one to find; now we could hunker down and do the detailed collecting work necessary to begin piecing together an image of the past. The white sandstones we were excavating had formed from the sand carried by the rivers that poured into lowlands as Madagascar unhinged from Africa. Within these prehistoric valleys rhynchosaurs and traversodontids, both four-legged creatures ranging from three to 10 feet in length, probably grazed together much the same way zebras and wildebeests do in Africa today. The presence of rhynchosaurs, which are relatively common in coeval rocks around the world, narrowed the date of this picture to sometime within the Triassic period (the first of three Mesozoic time intervals), which spans from 250 million to 205 million years ago. And because traversodontids were much more diverse and abundant during the first half of the Triassic than during the second, we thought initially that this scene played out sometime before about 230 million years ago.

During our second expedition, in 1997, a third type of animal challenged our sense of where we were in time. Shortly after we arrived in southwestern Madagascar, one of our field assistants, a local resident named Mena, showed us some bones that he had found across the river from our previous localities. We were struck by the fine-grained red rock adhering to the bones—everything we had found until that point was buried in the coarse white sandstone. Mena led us about half a mile north of the rhynchosaur and traversodontid site to the bottom of a deep gully. Within a few minutes

Tiny Bones to Pick

Paleontologists brave wildfires, parasites and scorching temperatures in search of ancient mammal fossils

By Kate Wong

THE THREE LAND ROVERS pause while John Flynn consults the device in his hand. "Is the GPS happy?" someone asks him. Flynn concludes that it is, and the caravan continues slowly through the bush, negotiating trails usually traversed by oxcart. We have been driving since seven this morning, when we left Madagascar's capital city, Antananarivo. Now, with the afternoon's azure sky melting into pink and mauve, the group is anxious to locate a suitable campsite. A small cluster of thatched huts comes into view, and Flynn sends an ambassador party on foot to ask the inhabitants whether we may camp in the area. By the time we reach the nearby clearing, the day's last light has disappeared and we pitch our tents in the dark. Tomorrow the real work begins.

The expedition team of seven Malagasies and six Americans, led by paleontologists Flynn and André Wyss of the Field Museum in Chicago and the University of California at Santa Barbara, respectively, has come to this remote part of northwestern Madagascar in search of fossils belonging to early mammals. Previous prospecting in the region had revealed red and buff-colored sediments dating back to the Jurassic period—the ancient span of time (roughly 205 million to 144 million years ago) during which mammals made their debut. Among the fossils unearthed was a tiny jaw fragment with big implications.

Conventional wisdom holds that the precursors of modern placental and marsupial mammals arose toward the end of the Jurassic in the Northern Hemisphere, based on the ages and locations of the earliest remains of these shrewlike creatures, which are characterized by so-called tribosphenic molars. But the Malagasy jaw, which Flynn and Wyss have attributed to a new genus and species, *Ambondro mahabo,* possesses tribosphenic teeth and dates back some 167 million years to the Middle Jurassic. As such, their fossil suggests that tribosphenic mammals arose at least 25 million years earlier than previously thought and possibly in the south rather than the north.

No one has disputed the age of *A. mahabo,* but not everyone agrees that the finding indicates that tribosphenic mammals originated in the south. Fossil-mammal expert Zhexi Luo of the Carnegie Museum of Natural History in Pittsburgh and several of his colleagues recently

FOUR-INCH-LONG MAMMAL *Ambondro mahabo* lived in Madagascar about 167 million years ago.

suggested that *A. mahabo* and a similarly surprising fossil beast from Australia named *Ausktribosphenos nyktos* might instead represent a second line of tribosphenic mammals—one that gave rise to the egg-laying monotremes. But Flynn and Wyss counter that some of the features that those researchers use to link the Southern tribosphenic mammals to monotremes may be primitive resemblances and therefore not indicative of an especially close evolutionary relationship.

As with so many other debates in paleontology, much of the controversy over when and where these mammal groups first appeared stems from the fact that so few ancient bones have ever been found. With luck, this season's fieldwork will help fill in some of the gaps in the fossil record. And recovering more specimens of *A. mahabo* or remains of previously unknown mammals could bolster considerably Flynn and Wyss's case for a single, Southern origin for the ancestors of modern placentals and marsupials.

The next morning, after a quick breakfast of bread, peanut butter and coffee, we are back in the vehicles, following the GPS's trail of electronic bread crumbs across the grassland to a fossil locality the team found at the end of last year's expedition. Stands of doum palms and thorny Mokonazy trees dot the landscape, which the dry season has left largely parched. By the time we reach our destination, the morning's pleasant coolness has given way to a rather toastier temperature. "When the wind stops, it cooks," remarks William Simpson, a collections manager for the Field Museum, coating his face with sunscreen. Indeed, noontime temperatures often exceed 90 humid degrees Fahrenheit.

Flynn instructs the group to start at the base of the hillside and work up. Meanwhile he and Wyss will survey the surrounding area, looking for additional exposures of the fossil-bearing horizon. "If it's something interesting, come back and get me," he calls. Awls in hand and eyes inches from the ground, the workers begin to scour the gravel-strewn surface for small bones, clues that delicate mammal fossils are preserved below. They crawl and slither in pursuit of their quarry, stopping only to swig water from sun-warmed bottles. Because early mammal remains are so minute (*A. mahabo*'s jaw fragment, for example, measures a mere 3.6 millimeters in length), such sleuthing rarely leads to instant gratification. Rather the team collects sediments likely to contain such fossils and ships that material back to the U.S. for closer inspection. Within a few hours, a Lilliputian vertebra and femur fragment turn up—the first indications that the fossil hunters have hit pay dirt. "It's a big Easter egg hunt," Wyss quips. "The eggs are hidden pretty well, but we know they're out there."

By the third day the crew has identified a number of promising sites and bagged nearly a ton of sediment for screen washing. Members head for a dammed-up stream that locals use to water their animals. Despite the scorching heat, those working in the water must don heavy rubber boots and gloves to protect against the parasites that probably populate the murky green pool. They spend the next few hours sifting the sediments through screen-bottomed baskets and buckets. Wyss spreads the resulting concentrate on a big blue plastic tarp to dry. Volunteers at the Field Museum will eventually look for fossils in this concentrate under a microscope, one spoonful at a time, but Wyss has a good feeling about the washed remains already. "You can actually see bone in the mix," he observes. The haul that yielded *A. mahabo,* in contrast, offered no such hints to the naked eye.

JURASSIC AGE jaw fragment of *A. mahabo* features specialized molars that are unique to tribosphenic mammals.

Hot and weary from the screen washing, the researchers eagerly break for lunch. Under the shade of a Mokonazy tree, they munch their sardine, Gouda and jalapeño sandwiches, joking about the bread, which, four days after leaving its bakery in Antananarivo, has turned rather tough. Wyss ceremoniously deposits a ration of jelly beans into each pair of upturned palms. Some pocket the treats for later, others trade for favorite flavors, and a few ruefully relinquish their sweets, having lost friendly wagers made earlier.

Usually lunch is followed by a short repose, but today nature has a surprise in store. A brushfire that had been burning off in the distance several hours ago is now moving rapidly toward us from the northeast, propelled by an energetic wind. The crackling sound of flames licking bone-dry grass crescendos, and ashen leaf remnants drift down around us. We look on, spellbound, as cattle egrets collect in the fire's wake to feast on toasted insects, and birds of prey circle overhead to watch for rodents flushed out by the flames. Only the stream separates us from the blaze, but reluctant to abandon the screen washing, Flynn and Wyss decide to wait it out. Such fires plague Madagascar. Often set by farmers to encourage new grass growth, they sometimes spread out of control, especially in the tinderbox regions of the northwest. Indeed, the explorers will face other fires that season, including one that nearly consumes their campsite.

An hour later the flames have subsided, and the team returns to the stream to finish the screening quickly. Banks once thick with dry grass now appear naked and charred. Worried that the winds might pick up again, we pack up and go to one of the team's other fossil localities to dig for the rest of the afternoon.

Following what has already become the routine, we return to camp by six. Several people attend to the filtering of the drinking water, while the rest help to prepare dinner. During the "cocktail hour" of warm beer and a shared plate of peanuts, Flynn and Wyss log the day's events and catalogue any interesting specimens they've collected. Others write field notes and letters home by the light of their headlamps. By nine, bellies full and dishes washed, people have retired to their tents. Camp is silent, the end of another day's efforts to uncover the past.

Kate Wong is a writer and editor for ScientificAmerican.com

FRANK IPPOLITO (*opposite page*); JOHN J. FLYNN AND SUSANA MAGALLON *The Field Museum* (*above*)

we spotted the bone-producing layer from which his unusual specimens had rolled. A rich concentration of fossils was entombed within the three-foot-thick layer of red mudstones, which had formed in the floodplains of the same ancient rivers that deposited the white sands. Excavation yielded about two dozen specimens of what appeared to be dinosaurs. Our team found jaws, strings of vertebrae, hips, claws, an articulated forearm with some wrist bones, and other assorted skeletal elements. When we examined these and other bones more closely, we realized that we had uncovered remains of two different species of prosauropods (not yet formally named), one of which appears to resemble a species from Morocco called *Azendohsaurus*. These prosauropods, which typically appear in rocks between 225 million and 190 million years old, are smaller-bodied precursors of the long-necked sauropod dinosaurs, including such behemoths as *Brachiosaurus*.

saurs with more ancient kinds of animals, plus the lack of younger groups, suggests that the Malagasy prosauropods are as old as any dinosaur ever discovered, if not older.

Only one early dinosaur site—at Ischigualasto, Argentina—contains a rock layer that has been dated directly; all other early dinosaur sites with similar fossils are thus estimated to be no older than its radioisotopic age of about 228 million years. (Reliable radioisotopic ages for fossils are obtainable only from rock layers produced by contemporaneous volcanoes. The Malagasy sediments accumulated in a rift basin with no volcanoes nearby.) Based on the fossils present, we have tentatively concluded that our dinosaur-bearing rocks slightly predate the Ischigualasto time span. And because prosauropods represent one of the major branches of the dinosaur evolutionary tree, we know that the common ancestor of all dinosaurs must be older still. Rocks from before about 245 million years ago have been moderately well sampled around the world, but none of them has yet yielded dinosaurs. That means the search for the common ancestor of all dinosaurs must focus on a relatively poorly known and ever narrowing interval of Middle Triassic rocks, between about 240 million and 230 million years old.

We had unearthed a collection of fossils NOT KNOWN TO COEXIST ANYWHERE ELSE.

When we discovered that dinosaurs were foraging among rhynchosaurs and traversodontids, it became clear that we had unearthed a collection of fossils not known to coexist anywhere else. In Africa, South America and other parts of the world, traversodontids are much less abundant and less diverse once dinosaurs appear. Similarly, the most common type of rhynchosaur we found, *Isalorhynchus,* lacks advanced characteristics and thus is inferred to be more ancient than the group of rhynchosaurs that is found with other early dinosaurs. What is more, the Malagasy fossil assemblage lacks remains of several younger reptile groups usually found with the earliest dinosaurs, including the heavily armored, crocodilelike phytosaurs and aetosaurs. The occurrence of dino-

INSPECTING THE ROCKS UP CLOSE, author Flynn (*right*) and William Simpson work to ensure that no scraps of bone have been overlooked.

Mostly Mammals

DINOSAURS NATURALLY ATTRACT considerable attention, being the most conspicuous land animals of the Mesozoic. Less widely appreciated is the fact that mammals and dinosaurs sprang onto the evolutionary stage at nearly the same time. At least two factors account for the popular misconception that mammals arose only after dinosaurs became extinct: Early mammals all were chipmunk-size or smaller, so they don't grab the popular imagination in the way their giant Mesozoic contemporaries do. In addition, the fossil record of early mammals is quite sparse, apart from very late in the Mesozoic. To our delight, Madagascar has once again filled in two mysterious gaps in the fossil record. The traversodontid cynodonts from the Isalo deposits reveal new details about close mammalian relatives, and a younger fossil from the northwest side of the island poses some controversial questions about where and when a key advanced group of mammals got its start.

The Malagasy traversodontids, the first known from the island, include some of the best-preserved representatives of early cynodonts ever discovered. ("Cynodontia" is the name applied to a broad group of land animals that includes mammals and their nearest relatives.) Accordingly, these bones provide a wealth of anatomical information previously undocumented for these creatures. These cynodonts are identified by, among other diagnostic features, a simplified lower jaw that is dominated by a single bone, the dentary. Some

MARIA STENZEL *National Geographic Image Collection (this page);* FRANK IPPOLITO (*opposite page*)

LIVING IN MIXED COMPANY

PALEONTOLOGISTS DID NOT KNOW until recently that the unusual group of ancient animals shown above—prosauropods (*1*), traversodontids (*2*), rhynchosaurs (*3*) and chiniquodontids (*4*)—once foraged together. In the past six years, southwestern Madagascar has become the first place where bones of each particular type of animal have been unearthed alongside the others, in this case from Triassic rocks about 230 million years old. Then the region was a lush, lowland basin that was forming as the supercontinent Pangea began to break up. The long-necked prosauropods here, which represent some of the oldest dinosaurs yet discovered, browse on conifers while a parrot-beaked rhynchosaur prepares to sip from a nearby pool. The prosauropod teeth were spear-shaped and serrated—good for slicing vegetation; rhynchosaurs were perhaps the most common group of plant eaters in the area at that time. Foraging among these large reptiles are the peculiar traversodontids and chiniquodontids. Both types of creatures are early members of the Cynodontia, a broad group that includes today's mammals. The grinding cheek teeth of the traversodontids suggest they were herbivores; the chiniquodontids sport the sharp, pointed teeth of carnivores. *—J.J.F. and A.R.W.*

specimens include both skulls and skeletons. Understanding the complete morphology of these animals is crucial for resolving the complex evolutionary transition from the large cold-blooded, scale-covered animals with sprawling limbs (which dominated the continents prior to the Mesozoic) to the much smaller warm-blooded, furry animals with an erect posture that are so plentiful today.

Many kinds of mammals, with many anatomical variations, now inhabit the planet. But they all share a common ancestor marked by a single, distinctive suite of features. To determine what these first mammals looked like, paleontologists must examine their closest evolutionary relatives within the Cynodontia, which include the traversodontids and their much rarer cousins, the chiniquodontids (also known as probainognathians), both of which we have found in southwestern Madagascar. Traversodontids almost certainly were herbivorous, because their wide cheek teeth are designed for grinding. One of our four new Malagasy traversodontid species also has large, stout, forward-projecting incisors for grasping vegetation. The chiniquodontids, in contrast, were undoubtedly carnivorous, with sharp, pointed teeth. Most paleontologists agree that some chiniquodontids share a more recent common ancestor with mammals than the herbivorous traversodontids do. The chiniquodontid skulls and skeletons we found in Madagascar will help reconstruct the bridge between early cynodonts and true mammals.

Not only are Madagascar's Triassic cynodonts among the best preserved in the world, they also sample a time period that is poorly known elsewhere. The same is true for the youngest fossils our expeditions have uncovered—those from a region of the northwest where the sediments are about 165 million years in age. (That date falls within the middle of the Jurassic, the second of the Mesozoic's three periods.) Because these sediments were considerably younger than our Triassic rocks, we allowed ourselves the hope that we might find remains of an ancient mammal. Not a single mammal had been recorded from Jurassic rocks of a southern landmass at that point, but this did nothing to thwart our motivation.

Once again, persistence paid off. During our 1996 field season, we had visited the village of Ambondromahabo after hearing local reports of abundant large fossils of the sauropod dinosaur *Lapparentosaurus*. Sometimes where large animals are preserved, the remains of smaller animals can also be found—though not as easily. We crawled over the landscape, eyes held a few inches from the ground. This uncomfortable but time-tested strategy turned up a few small theropod dinosaur teeth, fish scales and other bone fragments, which had accumulated at the surface of a small mound of sediment near the village.

These unprepossessing fossils hinted that more significant items might be buried in the sediment beneath. We bagged about 200 pounds of sediment and washed it through mosquito-net hats back in the capital, Antananarivo, while waiting to be granted permits for the second leg of our trip—the

Madagascar's Triassic cynodonts are among the BEST PRESERVED IN THE WORLD.

Modern-Day Mystery

MADAGASCAR IS FAMOUS for its 40 species of lemurs, none of which occurs anywhere else in the world. The same is true for 80 percent of the island's plants and other animals. This biotic peculiarity reflects the island's lengthy geographic isolation. (Madagascar has not been connected to another major landmass since it separated from India nearly 90 million years ago, and it has not been joined with its nearest modern neighbor, Africa, since about 160 million years ago.) But for decades the scant fossil evidence of land-dwelling animals from the island meant that little was known about the origin and evolution of these unique creatures.

While our research group was probing Madagascar's Triassic and Jurassic age rocks, teams led by David W. Krause of the State University of New York at Stony Brook were unearthing a wealth of younger fossils in the island's northwestern region. These specimens, which date back some 70 million years, include more than three dozen species, none of which is closely related to the island's modern animals. This evidence implies that most modern vertebrate groups must have immigrated to Madagascar after this point.

The best candidate for a Malagasy motherland is Africa, and yet the modern faunas of the two landmasses are markedly distinct. Elephants, cats, antelope, zebras, monkeys and many other modern African mammals apparently never reached Madagascar. The four kinds of terrestrial mammals that inhabit the island today—rodents, lemurs, carnivores and the hedgehoglike tenrecs—all appear to be descendants of more ancient African beasts. The route these immigrants took from the mainland remains unclear, however. Small clinging animals could have floated from Africa across the Mozambique Channel on "rafts" of vegetation that broke free during severe storms. Alternatively, when sea level was lower these pioneers might have traveled by land and sea along a chain of currently submerged highlands northwest of the island.

Together with Anne D. Yoder of Northwestern University Medical School and others, we are using the DNA structure of modern Malagasy mammals to address this question. These analyses have the potential to reveal whether the ancestors of Madagascar's modern mammals arrived in multiple, long-distance dispersal events or in a single episode of "island hopping." *—J.J.F. and A.R.W.*

leg to the southwest that turned up our first rhynchosaur jaws and traversodontid skull.

During the subsequent years back in the U.S., while our studies focused on the exceptional Triassic material, the tedious process of sorting the Jurassic sediment took place. A dedicated team of volunteers at the Field Museum in Chicago—Dennis Kinzig, Ross Chisholm and Warren Valsa—spent many a weekend sifting through the concentrated sediment under a microscope in search of valuable flecks of bone or teeth. We didn't think much about that sediment again until 1998, when Kinzig relayed the news that they had uncovered the partial jawbone of a tiny mammal with three grinding teeth still in place. We were startled not only by the jaw's existence but also by its remarkably advanced cheek teeth. The shapes of the teeth document the earliest occurrence of Tribosphenida, a group encompassing the vast majority of living mammals. We named the new species *Ambondro mahabo,* after its place of origin.

The discovery pushes back the geologic range of this group of mammals by more than 25 million years and offers the first glimpse of mammalian evolution on the southern continents during the last half of the Jurassic period. It shows that this subgroup of mammals may have evolved in the Southern Hemisphere rather than the Northern, as is commonly supposed. Although the available information does not conclusively resolve the debate, this important addition to the record of early fossil mammals does point out the precarious nature of long-standing assumptions rooted in a fossil record historically biased toward the Northern Hemisphere [see "Tiny Bones to Pick," by Kate Wong, on page 58].

Planning Persistently

ALTHOUGH OUR TEAM has recovered a broad spectrum of fossils in Madagascar, scientists are only beginning to describe the Mesozoic history of the Southern continents. The number of species of Mesozoic land vertebrates known from Australia, Antarctica, Africa and South America is probably an order of magnitude smaller than the number of contemporaneous findings from the Northern Hemisphere. Clearly, Madagascar now ranks as one of the world's top prospects for adding important insight to paleontologists' knowledge of the creatures that once roamed Gondwana.

Often the most significant hypotheses about ancient life on the earth can be suggested only after these kinds of new fossil discoveries are made. Our team's explorations provide two cases in point: the fossils found alongside the Triassic prosauropods indicate that dinosaurs debuted earlier than previously recorded, and the existence of the tiny mammal at our Jurassic site implies that tribosphenic mammals may have originated in the Southern, rather than Northern, Hemisphere. The best way to bolster these proposals (or to prove them wrong) is to go out and uncover more bones. That is why our primary goal this summer will be the same as it has been for our past five expeditions: find as many fossils as possible.

Our agenda includes digging deeper into known sites and surveying new regions, blending risky efforts with sure bets.

INTO THE SUNSET: Authors Flynn (*right*) and Wyss ride back to camp after a long day's digging in southwestern Madagascar.

No matter how carefully formulated, however, our plans will be subject to last-minute changes, dictated by such things as road closures and our most daunting challenge to date, the appearance of frenzied boomtowns.

During our first three expeditions, we never gave a second thought to the gravels that overlay the Triassic rock outcrops in the southwestern part of the island. Little did we know that those gravels contain sapphires. By 1999 tens of thousands of people were scouring the landscape in search of these gems. The next year all our Triassic sites fell within sapphire-mining claims. Those areas are now off limits to everyone, including paleontologists, unless they get permission from both the claim holder and the government. Leaping that extra set of hurdles will be one of our foremost tasks this year.

Even without such logistical obstacles slowing our progress, it would require uncountable lifetimes to carefully survey all the island's untouched rock exposures. But now that we have seen a few of Madagascar's treasures, we are inspired to keep digging—and to reveal new secrets. SA

MORE TO EXPLORE

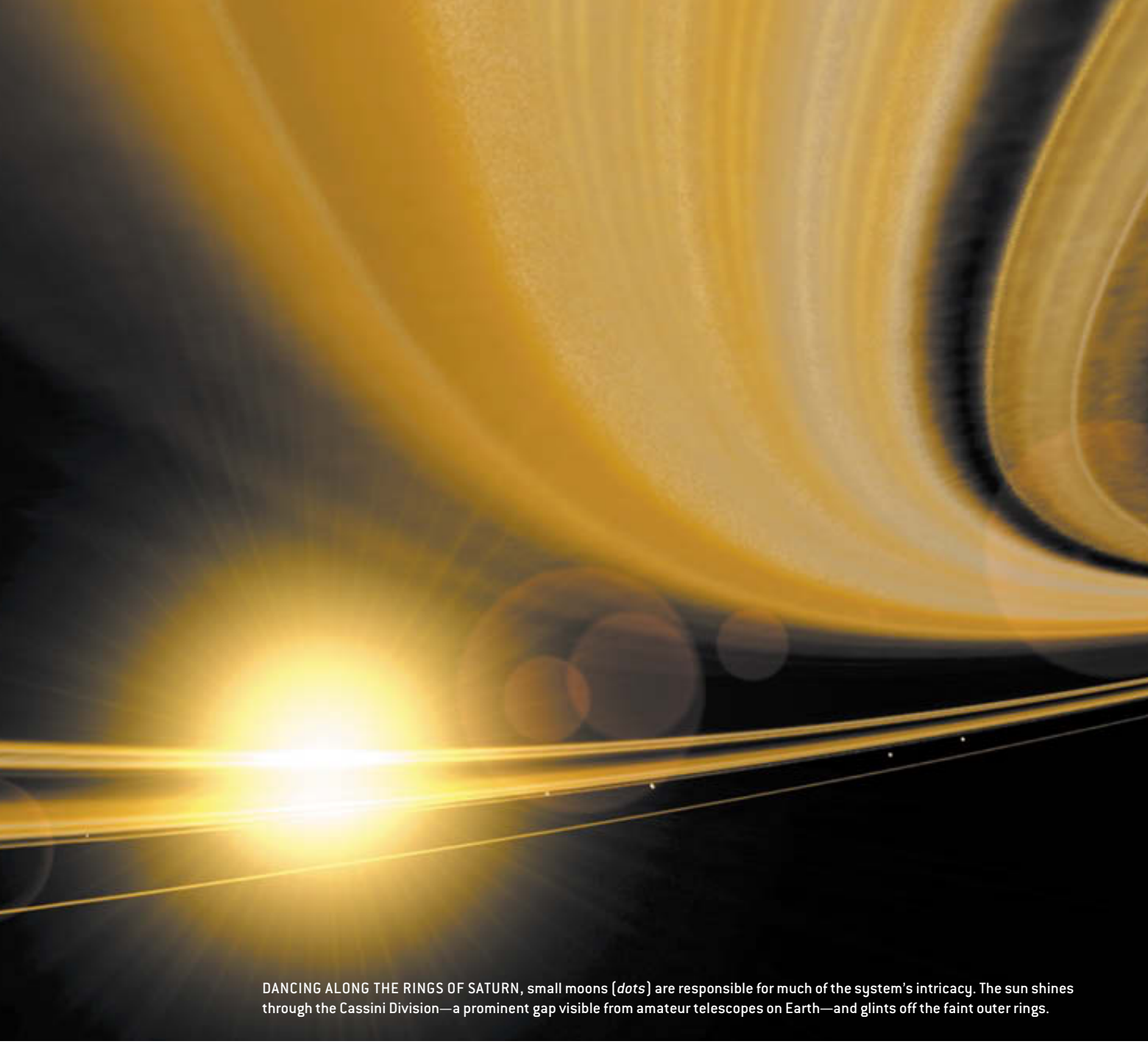
Madagascar: A Natural History. Ken Preston-Mafham. Foreword by Sir David Attenborough. Facts on File, 1991.

Natural Change and Human Impact in Madagascar. Edited by Steven M. Goodman and Bruce D. Patterson. Smithsonian Institution Press, 1997.

A Middle Jurassic Mammal from Madagascar. John J. Flynn, J. Michael Parrish, Berthe Rakotosaminimanana, William F. Simpson and André R. Wyss in *Nature,* Vol. 401, pages 57–60; September 2, 1999.

A Triassic Fauna from Madagascar, Including Early Dinosaurs. John J. Flynn, J. Michael Parrish, Berthe Rakotosaminimanana, William F. Simpson, Robin L. Whatley and André R. Wyss in *Science,* Vol. 286, pages 763–765; October 22, 1999.

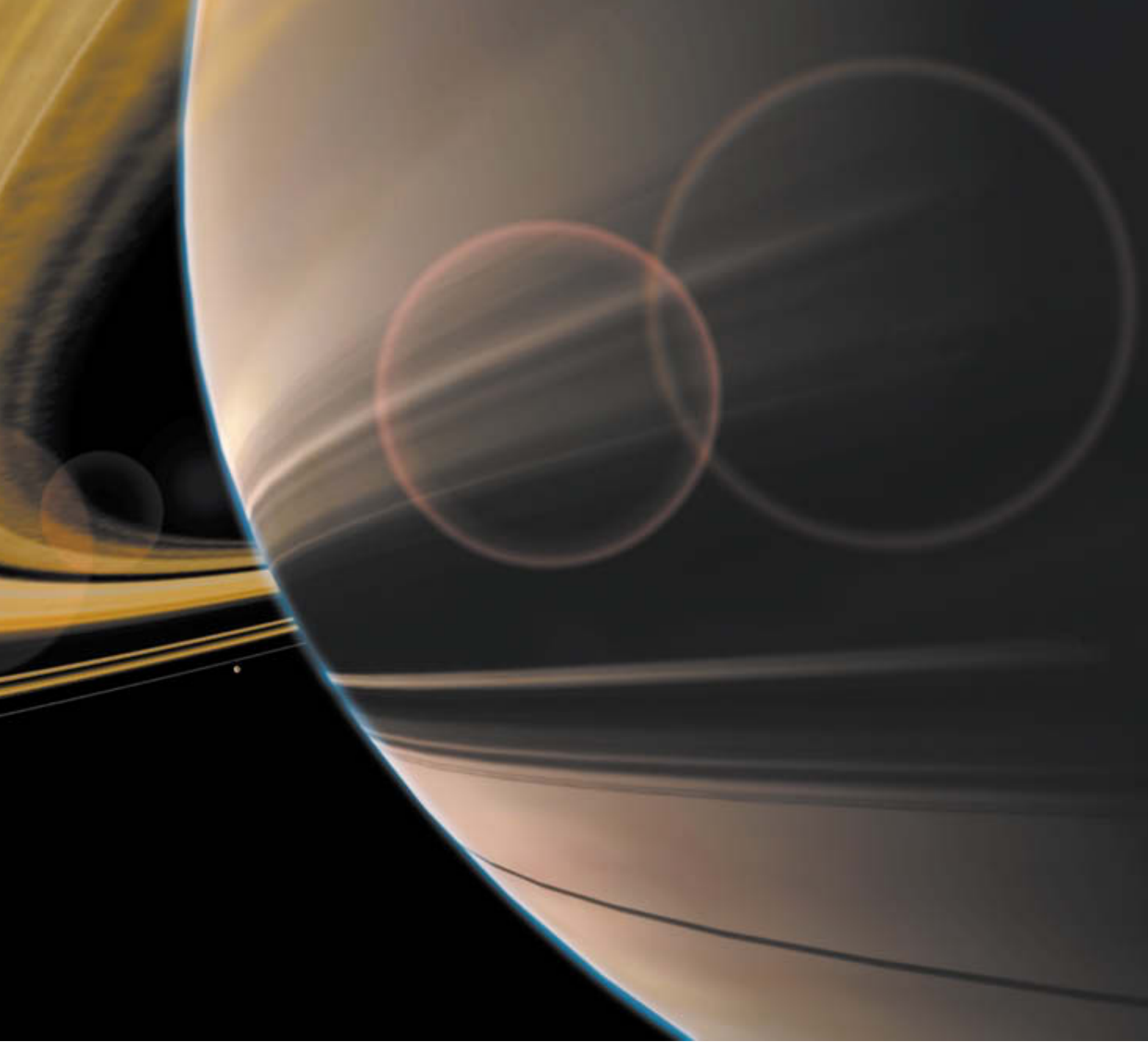
MARIA STENZEL *National Geographic Image Collection*



DANCING ALONG THE RINGS OF SATURN, small moons (*dots*) are responsible for much of the system's intricacy. The sun shines through the Cassini Division—a prominent gap visible from amateur telescopes on Earth—and glints off the faint outer rings.

Bejeweled

By Joseph A. Burns, Douglas P. Hamilton and Mark R. Showalter



Worlds

What an impoverished universe it would be if Saturn and the other giant planets lacked rings. Planetary scientists are finally working out how gravity has sculpted these elegant ornaments

Much of the modern world's economy is based on inventions made possible by 19th-century physicist James Clerk Maxwell, father of electromagnetism and pioneer of thermodynamics. In terms of raw economic benefit, though, not much can be said for another of Maxwell's favorite subjects: the rings of Saturn. Apart from inspiring the sales of executive desk toys, planetary rings do not contribute conspicuously to the material wealth of nations. And yet that does not blunt their appeal. In his 1857 Adams Prize essay, Maxwell wrote:

> There are some questions in Astronomy to which we are attracted … on account of their peculiarity … [rather] than from any direct advantage which their solution would afford to mankind…. I am not aware that any practical use has been made of Saturn's Rings … [b]ut when we contemplate the Rings from a purely scientific point of view, they become the most remarkable bodies in the heavens, except, perhaps, those still less *useful* bodies—the spiral [galaxies]…. When we have actually seen that great arch swung over the equator of the planet without any visible connection, we cannot bring our minds to rest.

A century and a half later Saturn's rings remain a symbol of all that is exotic and wondrous about the universe. Better observations have only heightened their allure. The findings of the past two decades have so overturned previous knowledge that essentially a new ring system—one much more complex and interesting than theory, observation or imagination had suggested—has been revealed.

Other giant planets besides Saturn have rings, and no two systems look alike. Rings are strange, even by the standards of astronomy. They are sculpted by processes that can be feeble and counterintuitive. For example, in rings, gravity can effectively repel material. We now appreciate that rings, once thought to be static, are continually evolving. We have seen the vital symbiosis between satellites and rings. Most important, we have recognized that planetary rings are more than just exquisite phenomena. Like Maxwell, modern scientists see analogies between rings and galaxies; in a very fundamental way, rings may also afford a glimpse into the solar system's ancient beginnings.

Saturn's rings, initially spied in 1610 by Galileo Galilei and interpreted as a planet-encircling hoop five decades later by Christiaan Huygens, stood alone for more than three and a half centuries. Then, in a span of just seven years, rings were discovered around the other three giant planets. Uranus's were detected first, in 1977. James L. Elliot, then at Cornell University, monitoring a star's brightness as Uranus crossed in front of it, noticed the signal blinking on and off. He inferred that a series of narrow bands, slightly elliptical or inclined, circumscribe the planet [see "The Rings of Uranus," by Jeffrey N. Cuzzi and Larry W. Esposito; SCIENTIFIC AMERICAN, July 1987]. In 1979 the Voyager 1 spacecraft sighted Jupiter's diaphanous rings. Finally, in 1984, a technique like Elliot's detected pieces of rings—but not full rings—around Neptune.

Those heady days passed, and ring research stagnated until the mid-1990s. Since then, a new era of ring exploration has begun. Observations have poured in from the Hubble Space Telescope, ground-based telescopes and the Galileo probe in orbit about Jupiter [see "The Galileo Mission to Jupiter and Its Moons," by Torrence V. Johnson; SCIENTIFIC AMERICAN, February 2000]. Saturn's faintest rings and satellites became visible in 1995 and 1996, when the positions of Earth and Saturn made the system appear edge-on, thereby reducing the glare from the main rings. And in July 2004 the Cassini spacecraft will begin its four-year tour of the Saturnian system.

Four-Ring Circus

ALTHOUGH THE FOUR known ring systems differ in detail, they share many general attributes. They are all richly textured, made up of multiple concentric rings often separated by gaps of various widths. Each ring is composed of innumerable par-

THE AUTHORS

JOSEPH A. BURNS, DOUGLAS P. HAMILTON and *MARK R. SHOWALTER* started working together at Cornell University, where Burns is a professor and Hamilton and Showalter were graduate students. Burns studied naval architecture in college but then got caught up in the excitement of the space age and changed fields. He is now I. P. Church Professor of Engineering and Astronomy. Hamilton, a professor at the University of Maryland, received the 1999 Urey Prize of the American Astronomical Society for his studies of the celestial mechanics of dust. Showalter is a researcher at Stanford University, where he oversees NASA's archive of planetary ring data. All three authors are deeply involved in space missions to the outer planets.

PRECEDING PAGES: DON DIXON; OPPOSITE PAGE: DON DIXON (*drawing*); NASA/JPL (*spacecraft images*)

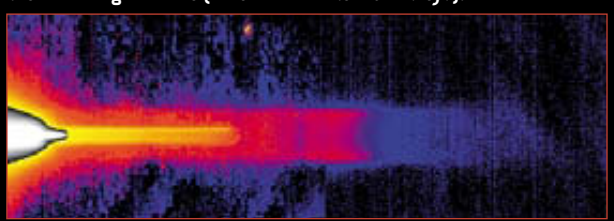
Jupiter

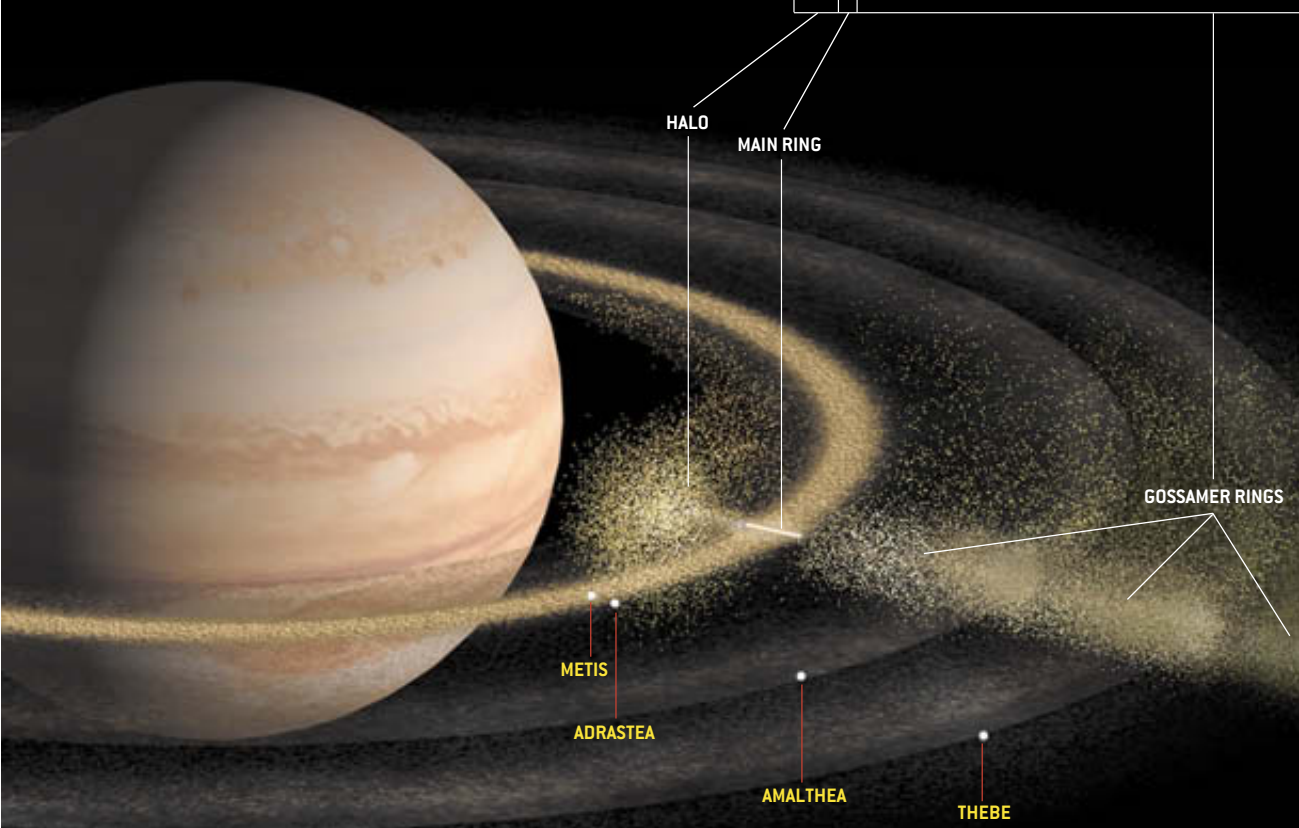
The largest planet in the solar system has rings of puzzling subtlety. They are composed of finer particles and are less flattened than the rings around other planets.

This mosaic by the Galileo spacecraft shows Jupiter in eclipse, highlighting its upper atmosphere and rings.

A tenuous, puffy halo rises up from the main ring's inner edge.

Faint gossamer rings (*yellow, red and blue bands*) extend beyond the main ring and halo (*black-and-white blob at left*).





Saturn

Saturn's rings, the most baroque, seem to get more complicated the closer scientists look. The famous Voyager images may pale in comparison to what the Cassini spacecraft finds in 2004.

A RING (*artist's conception*)

In at least one place, the meter-size snowballs are cleared away by satellites.

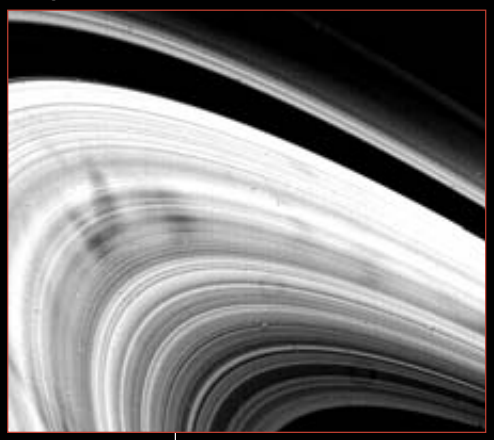
ENCKE GAP

Pried open by the tiny satellite Pan.

F RING

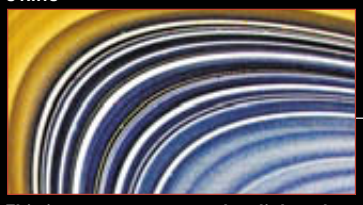
The multiple strands are knotted by the tugs of two nearby satellites.

B RING



The "spokes" are fleeting smudges made of levitating dust grains. The innumerable ringlets remain unexplained.

C RING



This image exaggerates the slight color differences between the C ring (*blue*) and B ring (*gold*).

DON DIXON (*drawings*); NASA/JPL (*spacecraft images*)

ticles—chunks of rock and ice—that independently circle the central planet while gently jostling one another. Rings fall into two general categories based on how densely packed the particles are, as described by the optical depth, a measure of the exponential decay of light as it penetrates perpendicularly through the ring. For the densest rings, such as Saturn's main rings (designated A and B) and the Uranian rings (designated by numbers and Greek letters), the optical depth can be as high as 4, which means that a mere 2 percent of the light leaks through. The most tightly packed of these rings contain particles that range from a few centimeters to several meters in diameter.

Particles in a dense ring system collide frequently, often several times during each orbit around the planet. In the process, energy is lost and angular momentum is redistributed. Because particles nearer to the planet move at a higher speed than do particles farther out, collisions hold back the inner particles (which then fall toward the planet) and push forward the outer ones (which then move away from the planet). Thus, a ring tends to spread radially. But the spreading takes time, and in this regard, a ring may be thought of as a viscous fluid that slowly diffuses inward and outward. Saturn's rings have an effective kinematic viscosity like that of air.

The energy loss, combined with angular-momentum redistribution, causes a dense ring system to flatten. Whatever its initial shape, the system quickly becomes a thin, near-equatorial disk. Saturn's rings are only tens of meters from top to bottom even though they stretch across several hundred thousand kilometers; they are proportionally as thick as a sheet of tissue paper spread over a football field. A similar effect flattens the debris disks around stars and the gaseous disks of spiral galaxies.

Another consequence of dense packing is to strengthen the particles' own mutual gravitational attraction. This may be why Uranus's rings are slightly out of round: their self-gravity resists the tendency to smear into a circular band.

At the other extreme, the faintest known rings, such as Jupiter's rings and Saturn's outermost rings, have optical depths between 10^{-8} and 10^{-6}. Particles are as spread out as baseball outfielders. Because they collide infrequently, they tend not to settle into a flat disk. As we know from how these rings scatter light, the particles are fine dust, typically microns in size, comparable to the size of smoke particles. So these structures are literally smoke rings. The particles display unusual dynamics because, being so small, they are significantly affected by electromagnetic and radiation forces in addition to gravity.

Neptune's rings do not fall into this neat dichotomy; their optical depth lies between the two extremes. The Neptunian system is anomalous in other respects as well. Its densest ring is not a smooth band; it contains discontinuous arcs that together encompass less than a tenth of the circumference. Without some confinement mechanism at work, these structures should spread fully around the planet in about a year. Yet recent Hubble images and ground-based observations find that the positions of the arcs have shifted little in the past 15 years.

RESONANCE between a satellite and a ring particle means that their two orbits are choreographed: in this case, the particle goes around exactly twice in the time it takes the satellite to trundle around once. Because the bodies always encounter each other at the same position, gravitational tugs can add up.

Lords of the Rings

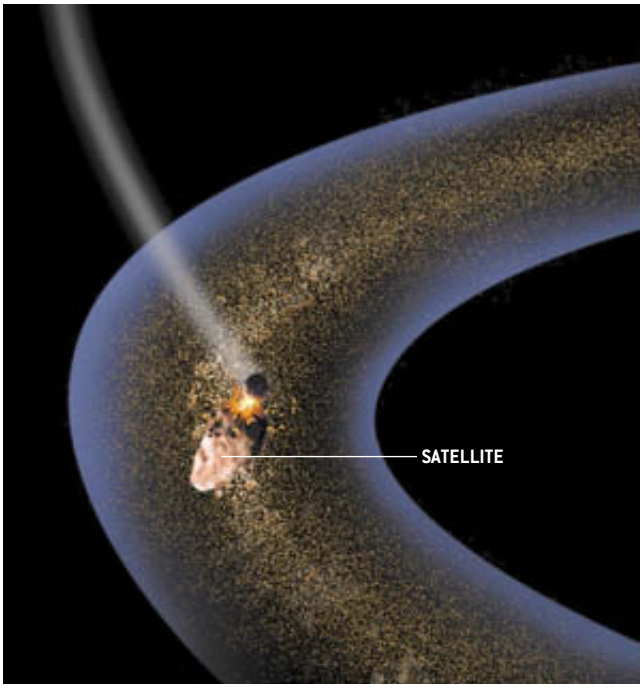
ALL DENSE RING systems nestle close to their planets, extending no farther than the so-called Roche limit, the radius within which the planet's tidal forces overwhelm the tendency of ring particles to agglomerate into larger bodies. Just outside the Roche limit is a zone where small, irregularly shaped moons can coexist with the rings. The interactions between rings and ring moons are implicated in many of the strangest aspects of rings.

For example, Saturn's E ring reaches across a broad region that encompasses the satellites Mimas, Tethys, Dione and Rhea, peaking in brightness at the orbit of the smooth, icy moon Enceladus. The narrow F ring, a tangle of several lumpy strands, sits isolated just beyond Saturn's A ring and also is straddled by two moons, Pandora and Prometheus. Correlations of satellite positions and ring features occur in the Jovian, Uranian and Neptunian systems as well.

Explaining how satellites wield such power has been the major advance in ring science over the past two decades. Three basic processes appear to be at work. The first is the orbital resonance, a tendency of gravitational forces to be magnified at positions where a particle's orbital period matches an integer ratio (say, $m:n$) of a satellite's orbital period. For instance, a particle at the outer edge of Saturn's B ring is in a 2:1 resonance with Mimas, meaning that it goes around the planet precisely twice for each lap the satellite completes. In another example, the exterior boundary of Saturn's A ring is in a 7:6 resonance with the satellites Janus and Epimetheus.

DON DIXON

Orbits that lie near resonant locations suffer unusually large distortions because the gentle tugs of moons are repeated systematically and therefore build up over time. Resonances are stronger for particles in orbits near a moon, but when the orbits are too close, different resonances vie for control, and motions become chaotic. Resonances are strongest when $m = n + 1$ (for example, 2:1 or 43:42) and weaken rapidly as m and n differ more and more. Throughout Saturn's enormous rings, only a few dozen ring locations respond to strong satellite resonances.



IF SOMETHING SLAMS into a satellite, material flies off and becomes part of a ring. Conversely, the satellite steadily sweeps up material. The balance of these competing effects determines the size of faint rings.

The outcome of these resonant perturbations varies. Strong ones clear material, accounting for the outer edges of Saturn's A and B rings. In some places, gaps are opened. Such a resonance may account for Neptune's discontinuous ring. Analogous resonances explain the distribution of material in the asteroid belt, for which the sun plays the role of the planet and Jupiter plays the role of the satellite.

Elsewhere in the A ring, resonances generate waves. If the satellite has an elliptical orbit, the result is a spiral wave, a miniature version of the pinwheel pattern of our galaxy. If the satellite has a tilted orbit, the result is a series of vertical bending waves, an out-of-plane corrugation—small ripples in a cosmic carpet.

Although resonances typically involve satellites, any force that repeats periodically at an integer ratio of the orbital period—such as lumpy planetary gravitational fields or variable electromagnetic forces—will be similarly effective. The Jovian system has become infamous for such resonances. Inward of a radius of 120,000 kilometers, the ring abruptly puffs up from a flat disk to a thick torus. A ring particle at that radius orbits three times for every two planetary spins; thus, the planet's tilted magnetic field pushes it ever upward. Still closer to the planet, at a radius of 100,000 kilometers, the brightness of the Jovian ring drops sharply. That happens to be the location of the 2:1 electromagnetic resonance. Particles that drift to this position are spread so thinly that they vanish against the giant planet's glare.

The second basic way that satellites govern ring structures is by influencing the paths of ring particles. The gravitational interaction of a satellite and a nearby particle is somewhat counterintuitive. If these two bodies were isolated in deep space, their close encounters would be symmetrical in space and time. The particle would approach the satellite, accelerate, zip around, emerge on the other side and decelerate (assuming it did not collide). The departure leg would be the mirror image of the inbound path (a hyperbola or parabola). Although the particle would have changed direction, it would eventually return to its original speed.

Ringmaster

IN A RING SYSTEM, however, a satellite and particle are not isolated—they are in orbit around a third object, the planet. Whichever body is nearer to the planet orbits faster. Suppose it is the particle. During the close encounter, the gravity of the satellite nudges the particle into a new orbit. The event is asymmetrical: the particle moves closer to the satellite, and the gravitational interaction of the two bodies strengthens. So the particle is unable to regain the velocity it once had; its orbital energy and angular momentum have decreased. Technically, that means its orbit is distorted from a circle to an ellipse of slightly smaller size; later, collisions within the ring will restore the orbit to a circle, albeit a shrunken one.

The net effect is that the particle is pushed inward. Its loss is the satellite's gain, although because the satellite is more massive, it moves proportionately less. If the positions are reversed, so are the roles: with the satellite on the inside, the particle will be pushed outward and the satellite inward. In both cases, the attractive gravity of a satellite appears to *repulse* ring material. None of Newton's laws have been broken; this bizarre outcome occurs when two bodies in orbit around a third interact and lose energy. (It is completely different from the "repulsive" gravity that occurs in theories of the expanding universe.)

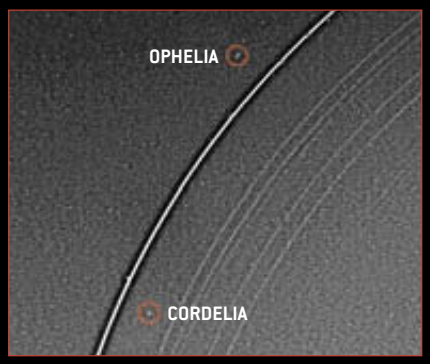
Like resonances, this mechanism can pry open gaps in rings. The gaps will grow until the satellite's repulsive forces are counterbalanced by the tendency of rings to spread during collisions. Such gaps are present within Saturn's A, C and D rings, as well as throughout the Cassini division, a zone that separates the A and B rings.

Conversely, the process can squeeze a narrow ring. Satellites on either side of a strand of material can shepherd that material, pushing back any particles that try to escape. In 1978 Peter Goldreich and Scott D. Tremaine, then both at the California Institute of Technology, hypothesized the shepherding process to explain the otherwise puzzling stability of the threadlike rings of Uranus [see "Rings in the Solar System," by James B. Pollack and Jeffrey N. Cuzzi; SCIENTIFIC AMERICAN, November 1981]. The satellites Cordelia and Ophelia keep Uranus's ε ring corralled. Saturn's F ring appears to be herded by Prometheus and Pandora. To be sure, most of the visible gaps and narrow

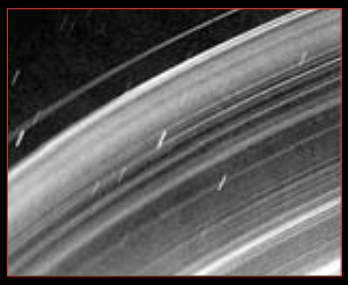
DON DIXON

Uranus

What makes the rings of Uranus so odd is that most of them are slightly elliptical and tilted. Somehow they have resisted the forces that would have circularized and flattened them.

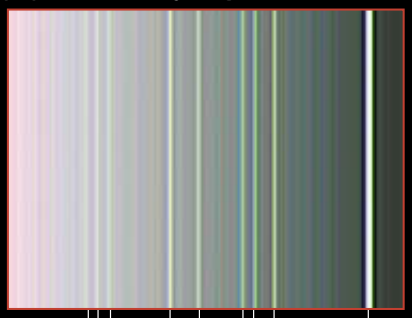


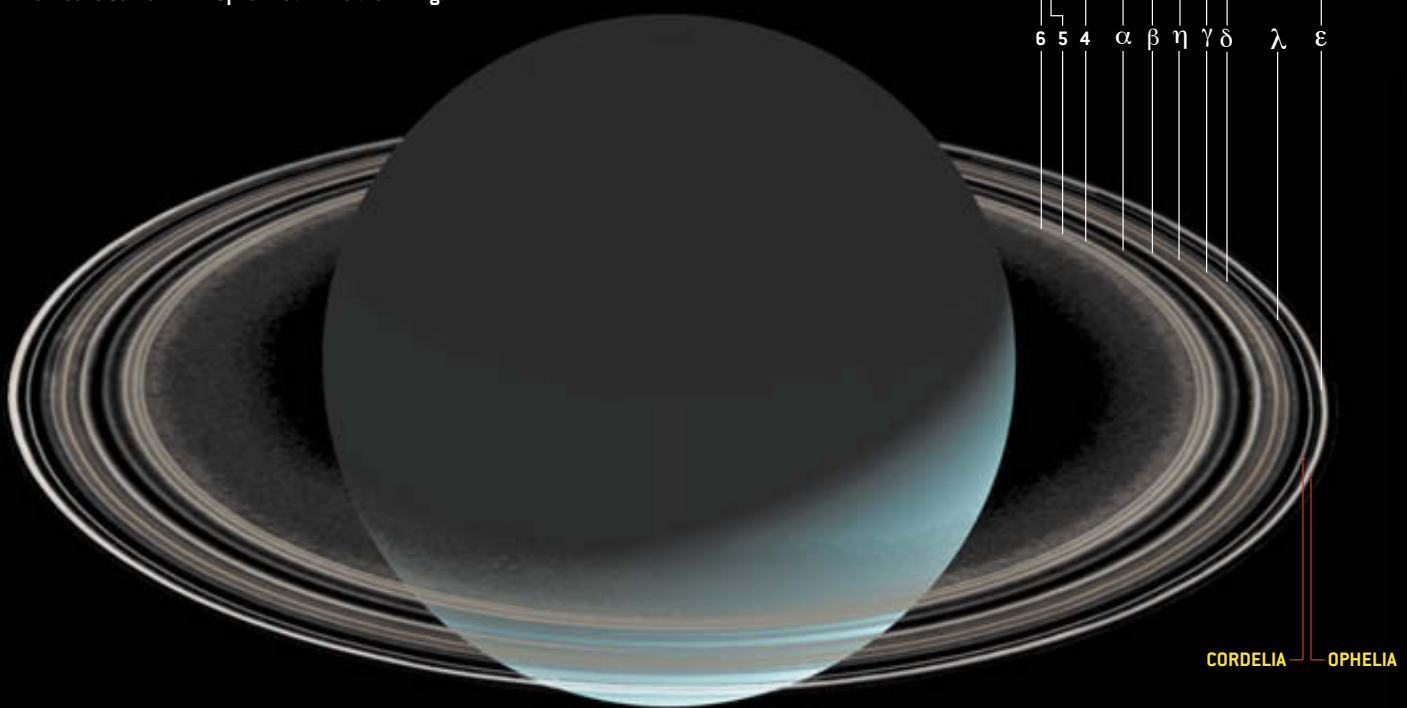
The moons Cordelia and Ophelia straddle the ε ring.



Using a different viewing angle and longer exposure, Voyager saw dust between the main rings.

This false-color image hints at differing particle properties. The dusty λ ring is too faint to see here.





ringlets remain unexplained. Perhaps they are manipulated by moons too small to see with present technology. The Cassini orbiter may be able to spy some of the hidden puppeteers.

Yet another effect of repulsive gravity is to scallop ring edges. These undulations are easiest to understand from the vantage point of the satellite. In rings, a continuous stream of particles flows past the satellite. When these particles overtake the moon, gravity modifies their circular orbits into elliptical ones of almost the same size. The particles no longer maintain a constant distance from the planet. Someone riding on the satellite would say that the particles have started to weave back and forth in concert. The apparent motion is sinusoidal with a wavelength proportional to the distance between the orbits of the satellite and the particle.

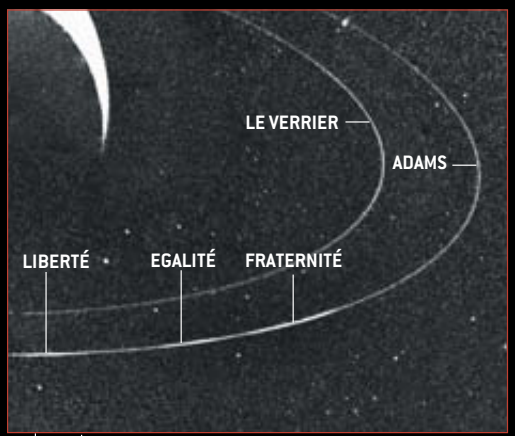
The resulting wave appears behind the satellite if the particle is on the outside and in front of the satellite if the particle is on the inside. It is akin to the wake of a boat in an unusual river where the water on one side of the boat moves faster than the boat itself. One of us (Showalter) analyzed the scalloped edges of Saturn's Encke division to pinpoint a small satellite, Pan, that had eluded observers. Another example is the F ring, whose periodic clumps seem to have been imprinted by Prometheus.

DON DIXON (*drawing*); NASA/JPL (*spacecraft images*)

Neptune

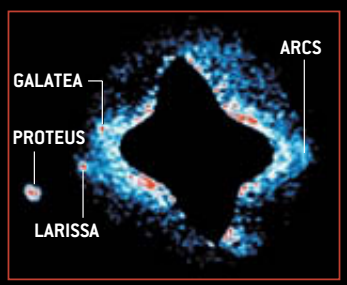
The least known and least understood rings are those of Neptune. The outer ring contains clumps—the so-called arcs. It may take another spacecraft visit to figure them out.

LE VERRIER AND ADAMS RINGS



Voyager images from 1989 reveal clumps in the outermost ring, perhaps the result of a complex satellite resonance.

The ring arcs also appear in this Hubble Space Telescope image from 1998. Not only have the arcs persisted, but they have orbited slightly slower than predicted.



Ground-based observations in 1998 agree with Hubble's conclusions.

Those Dirty Rings

THE THIRD AND FINAL effect of moons on rings is to spew out and soak up material. This role, especially vital for faint, dusty rings such as those around Jupiter, has come into clear view only with the Galileo mission to Jupiter. Earlier the Voyager spacecraft had discovered Jupiter's rings as well as two small moons, Adrastea and Metis, close to the main ring's outer edge. But its camera was not sharp enough to tell us what the satellites actually did. Were they shepherds that prevented the rings' outward spread? Or were they the source of ring material that, once placed into orbit, drifted inward? Neither could Voyager make sense of a faint outer extension—a gossamer ring that accompanied the main one.

Galileo's imaging system found that the gossamer ring vanished abruptly beyond the orbit of the moon Amalthea. It dis-

covered another, fainter gossamer ring that extended as far as the moon Thebe and no farther. On the flight home from the meeting at which these images were first available, one of us (Burns) noticed the smoking gun: the vertical extent of the innermost gossamer ring was equal to the orbital tilt of Amalthea, and the thickness of the outer gossamer ring perfectly matched the inclination of Thebe. Furthermore, both gossamer rings were brightest along their top and bottom edges, indicating a pileup of material—which is exactly what one would expect if particles and satellites shared the same orbital tilt. This tight association is most naturally explained if the particles are debris ejected by meteoroid impacts onto the satellites.

Ironically, small moons should be better sources of material than big ones: though smaller targets, they have weaker gravity, which lets more debris escape. In the Jovian system the most effective supplier is calculated to be 10 or 20 kilometers across—just about the size of Adrastea and Metis, explaining why they generate more formidable rings than do Amalthea and Thebe, which are much larger.

An odd counterexample is Saturn's 500-kilometer-wide moon, Enceladus, which appears to be the source of the E ring. Powerful impacts by ring particles, as opposed to interplanetary projectiles, might explain how Enceladus manages to be so prolific. Each grain that hits Enceladus generates multiple replacement particles, so the E ring could be self-sustaining. Elsewhere such collisions usually result in a net absorption of material from the ring.

Ring Out the Old

THE EVIDENT IMPORTANCE of sources and sinks reopens the classic question of whether rings are old and permanent or young and fleeting. The former possibility implies that rings could date to the formation of the solar system. Just as the protosun was surrounded by a flattened cloud of gas and dust out of which the planets are thought to have emerged, each of the giant planets was surrounded by its own cloud, out of which satellites emerged. Close to each planet, within the Roche limit, tidal forces prevented material from agglomerating into satellites. That material became a ring instead.

Alternatively, the rings we see today may have arisen much later. A body that strayed too close to a planet may have been torn asunder, or a satellite may have been shattered by a high-speed comet. Once a satellite is blasted apart, the fragments will reagglomerate only if they lie beyond the Roche limit. Even then, they will be unconsolidated, weak rubble piles susceptible to later disruption.

Several lines of evidence now suggest that most rings are young. First, tiny grains must lead short lives. Even if they survive interplanetary micrometeoroids and fierce magnetospheric plasma, the subtle force exerted by radiation causes their orbits to spiral inward. Unless replenished, faint rings should disappear within just a few thousand years. Second, some ring moons lie very close to the rings, even though the back reaction from spiral density waves should quickly drive them off.

Third, icy ring particles should be darkened by cometary debris, yet they are generally bright. Fourth, satellites just beyond Saturn's rings have remarkably low densities, as though they are rubble piles. Finally, some moons are embedded within rings. If rings are simply primordial material that failed to agglomerate, how did those moons get there? The moons make most sense if they are merely the largest remaining pieces of a shattered progenitor.

So it seems that rings are not quite the timeless fixtures they appear to be. Luke Dones of the Southwest Research Institute in Boulder, Colo., has suggested that Saturn's elaborate adornments are the debris of a shattered moon roughly 300 to 400 kilometers across. Whether all rings have such a violent provenance, we now know they were not simply formed and left for us to admire. They continually reinvent themselves. Joshua E. Colwell and Larry W. Esposito of the University of Colorado envision recycling of material between rings and ring moons. Satellites gradually sweep up the particles and subsequently slough them off during energetic collisions. Such an equilibrium could determine the extent of many rings. Variations in the composition, history and size of the planets and satellites would naturally account for the remarkable diversity of rings.

Indeed, the emerging synthesis explains why most of the inner planets are ringless: they lack large retinues of satellites to provide ring material. Earth's moon is too big, and any micron-size dust that does escape its surface is usually stripped away by solar gravitational and radiation forces. Mars, with its two tiny satellites, probably does have rings. But two of us (Hamilton and Showalter) were unable to find any rings or smaller satellites in Hubble observations last year. If a Martian ring does exist, it must be exceedingly tenuous, with an optical depth of less than 10^{-8}.

As often happens in science, the same basic principles apply to phenomena that at first seem utterly unrelated. The solar system and other planetary systems can be viewed as giant, star-encircling rings. Astronomers have seen hints of gaps and resonances in the dusty disks around other stars, as well as signs that source bodies orbit within. The close elliptical orbits of many large extrasolar planets are best understood as the end result of angular momentum transfer between these bodies and massive disks [see "Migrating Planets," by Renu Malhotra; SCIENTIFIC AMERICAN, September 1999]. Planetary rings are not only striking, exquisite structures; they may be the Rosetta stones to deciphering how planets are born. SA

MORE TO EXPLORE

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OPPOSITE PAGE: DON DIXON (*drawing*); NASA/JPL (*left*); FROM *NATURE*, VOL. 400, NO. 6746, 1999: B. SICARDY ET AL., CANADA-FRANCE-HAWAII TELESCOPE (*center*) AND C. DUMAS ET AL., HUBBLE SPACE TELESCOPE, JPL AND CALIFORNIA INSTITUTE OF TECHNOLOGY (*right*)

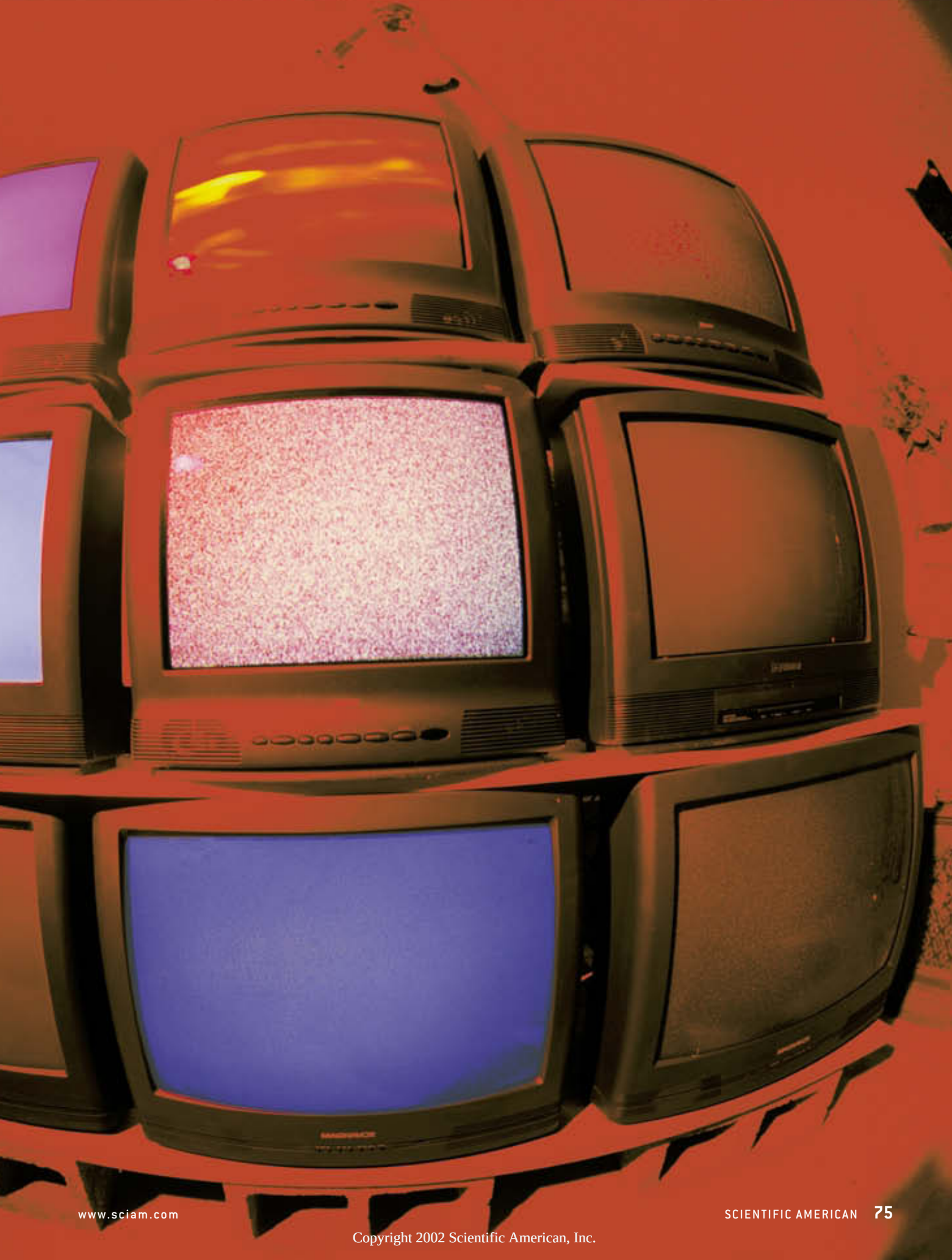
Television Addiction

is no mere metaphor

By Robert Kubey and Mihaly Csikszentmihalyi

Photoillustrations by Chip Simons

Perhaps the most ironic aspect of the struggle for survival is how easily organisms can be harmed by that which they desire. The trout is caught by the fisherman's lure, the mouse by cheese. But at least those creatures have the excuse that bait and cheese look like sustenance. Humans seldom have that consolation. The temptations that can disrupt their lives are often pure indulgences. No one *has* to drink alcohol, for example. Realizing when a diversion has gotten out of control is one of the great challenges of life.



Excessive cravings do not necessarily involve physical substances. Gambling can become compulsive; sex can become obsessive. One activity, however, stands out for its prominence and ubiquity—the world's most popular leisure pastime, television. Most people admit to having a love-hate relationship with it. They complain about the "boob tube" and "couch potatoes," then they settle into their sofas and grab the remote control. Parents commonly fret about their children's viewing (if not their own). Even researchers who study TV for a living marvel at the medium's hold on them personally. Percy Tannenbaum of the University of California at Berkeley has written: "Among life's more embarrassing moments have been countless occasions when I am engaged in conversation in a room while a TV set is on, and I cannot for the life of me stop from periodically glancing over to the screen. This occurs not only during dull conversations but during reasonably interesting ones just as well."

Scientists have been studying the effects of television for decades, generally focusing on whether watching violence on TV correlates with being violent in real life [see "The Effects of Observing Violence," by Leonard Berkowitz; SCIENTIFIC AMERICAN, February 1964; and "Communication and Social Environment," by George Gerbner; September 1972]. Less attention has been paid to the basic allure of the small screen—the medium, as opposed to the message.

The term "TV addiction" is imprecise and laden with value judgments, but it captures the essence of a very real phenomenon. Psychologists and psychiatrists formally define substance dependence as a disorder characterized by criteria that include spending a great deal of time using the substance; using it more often than one intends; thinking about reducing use or making repeated unsuccessful efforts to reduce use; giving up important social, family or occupational activities to use it; and reporting withdrawal symptoms when one stops using it.

All these criteria can apply to people who watch a lot of television. That does not mean that watching television, per se, is problematic. Television can teach and amuse; it can reach aesthetic heights; it can provide much needed distraction and escape. The difficulty arises when people strongly sense that they ought not to watch as much as they do and yet find themselves strangely unable to reduce their viewing. Some knowledge of how the medium exerts its pull may help heavy viewers gain better control over their lives.

Most of the criteria of substance dependence can apply to people who watch a lot of TV.

A Body at Rest Tends to Stay at Rest

THE AMOUNT of time people spend watching television is astonishing. On average, individuals in the industrialized world devote three hours a day to the pursuit—fully half of their leisure time, and more than on any single activity save work and sleep. At this rate, someone who lives to 75 would spend nine years in front of the tube. To some commentators, this devotion means simply that people enjoy TV and make a conscious decision to watch it. But if that is the whole story, why do so many people experience misgivings about how much they view? In Gallup polls in 1992 and 1999, two out of five adult respondents and seven out of 10 teenagers said they spent too much time watching TV. Other surveys have consistently shown that roughly 10 percent of adults call themselves TV addicts.

To study people's reactions to TV, researchers have undertaken laboratory experiments in which they have monitored the brain waves (using an electroencephalograph, or EEG), skin resistance or heart rate of people watching television. To track behavior and emotion in the normal course of life, as opposed to the artificial conditions of the lab, we have used the Experience Sampling Method (ESM). Participants carried a beeper, and we signaled them six to eight times a day, at random, over the period of a week; whenever they heard the beep, they wrote down what they were doing and how they were feeling using a standardized scorecard.

As one might expect, people who were watching TV when we beeped them reported feeling relaxed and passive. The EEG studies similarly show less mental stimulation, as measured by alpha brain-wave production, during viewing than during reading.

What is more surprising is that the sense of relaxation ends when the set is turned off, but the feelings of passivity and lowered alertness continue. Survey participants commonly reflect that television has somehow absorbed or sucked out their energy, leaving them depleted. They say they have more difficulty concentrating after viewing than before. In contrast, they rarely indicate such difficulty after reading. After playing sports or engaging in hobbies, people report improvements in mood. After watching TV, people's moods are about the same or worse than before.

Within moments of sitting or lying down and pushing the "power" button, viewers report feeling more relaxed. Because the relaxation occurs quickly, people are conditioned to associate viewing with rest and lack of tension. The as-

THE AUTHORS

ROBERT KUBEY and *MIHALY CSIKSZENTMIHALYI* met in the mid-1970s at the University of Chicago, where Kubey began his doctoral studies and where Csikszentmihalyi served on the faculty. Kubey is now a professor at Rutgers University and director of the Center for Media Studies (www.mediastudies.rutgers.edu). His work focuses on the development of media education around the world. He has been known to watch television and even to play video games with his sons, Ben and Daniel. Csikszentmihalyi is the C. S. and D. J. Davidson Professor of Psychology at Claremont Graduate University. He is a fellow of the American Academy of Arts and Sciences. He spends summers writing in the Bitterroot Mountains of Montana, without newspapers or TV, hiking with grandchildren and other occasional visitors.

KICKING THE HABIT

Individuals or families that want to achieve better control of their TV viewing can try the following strategies:

RAISING AWARENESS. As with other dependencies, a first critical step is to become aware of how entrenched the viewing habit has become, how much time it absorbs and how limited the rewards of viewing actually are. One way to do this is to keep a diary for a few days of all programs viewed. The diary entries might rate the quality of the experience, denoting how much the viewer enjoyed or learned from various programs.

PROMOTING ALTERNATIVE ACTIVITIES. As soon as they finish dinner, many families rush to the television. To supplant viewing with other activities, it may prove helpful to make a list of alternatives and put it on the fridge. Instead of reflexively plopping down in front of the tube, those interested in reducing their viewing can refer to the list.

EXERCISING WILLPOWER. Viewers often know that a particular program or movie-of-the-week is not very good within the first few minutes, but instead of switching off the set, they stick with it for the full two hours. It is natural to keep watching to find out what happens next. But once the set is off and people have turned their attention to other things, they rarely care anymore.

ENFORCING LIMITS. A kitchen timer can come in handy when setting time limits, especially with video games. When it rings, the kids know to stop. Some parents find that this works much better than announcing the deadline themselves. The kids take the bell more seriously.

BLOCKING CHANNELS/V-CHIP. Television sets now come equipped with microchips that can be used to prevent viewing of violent shows. In addition, electronic add-on devices can count how many hours each family member has viewed and block access beyond a particular quota.

VIEWING SELECTIVELY. Rather than channel-surf, people can use the television listings ahead of time to choose which programs to watch.

USING THE VCR. Instead of watching a program, record it for later viewing. Many people never return to much of the material they have taped.

GOING COLD TURKEY. Many families have succeeded in reducing viewing by limiting the household to one set and placing it in a remote room of the house or in a closet. Others end their cable subscriptions or jettison the set altogether.

SUPPORTING MEDIA EDUCATION. Schools in Canada and Australia, as well as in an increasing number of states in the U.S., now require students to take classes in media education. These sharpen children's ability to analyze what they see and hear and to make more mindful use of TV and other media. *—R.K. and M.C.*

sociation is positively reinforced because viewers remain relaxed throughout viewing, and it is negatively reinforced via the stress and dysphoric rumination that occurs once the screen goes blank again.

Habit-forming drugs work in similar ways. A tranquilizer that leaves the body rapidly is much more likely to cause dependence than one that leaves the body slowly, precisely because the user is more aware that the drug's effects are wearing off. Similarly, viewers' vague learned sense that they will feel less relaxed if they stop viewing may be a significant factor in not turning the set off. Viewing begets more viewing.

Thus, the irony of TV: people watch a great deal longer than they plan to, even though prolonged viewing is less rewarding. In our ESM studies the longer people sat in front of the set, the less satisfaction they said they derived from it. When signaled, heavy viewers (those who consistently watch more than four hours a day) tended to report on their ESM sheets that they enjoy TV less than light viewers did (less than two hours a day). For some, a twinge of unease or guilt that they aren't doing something more productive may also accompany and depreciate the enjoyment of prolonged viewing. Researchers in Japan, the U.K. and the U.S. have found that this guilt occurs much more among middle-class viewers than among less affluent ones.

Grabbing Your Attention

WHAT IS IT about TV that has such a hold on us? In part, the attraction seems to spring from our biological "orienting response." First described by Ivan Pavlov in 1927, the orienting response is our instinctive visual or auditory reaction to any sudden or novel stimulus. It is part of our evolutionary heritage, a built-in sensitivity to movement and potential predatory threats. Typical orienting reactions include dilation of the blood vessels to the brain, slowing of the heart, and constriction of blood vessels to major muscle groups. Alpha waves are blocked for a few seconds before returning to their baseline level, which is determined by the general level of mental arousal. The brain focuses its attention on gathering more information while the rest of the body quiets.

In 1986 Byron Reeves of Stanford University, Esther Thorson of the University of Missouri and their colleagues began to study whether the simple formal features of television—cuts, edits, zooms, pans, sudden noises—activate the orienting response, thereby keeping attention on the screen. By watching how brain waves were affected by formal features, the researchers concluded that these stylistic tricks can indeed trigger involuntary responses and "derive their attentional value through the evolutionary significance of detecting movement.... It is the form, not the

content, of television that is unique."

The orienting response may partly explain common viewer remarks such as: "If a television is on, I just can't keep my eyes off it," "I don't want to watch as much as I do, but I can't help it," and "I feel hypnotized when I watch television." In the years since Reeves and Thorson published their pioneering work, researchers have delved deeper. Annie Lang's research team at Indiana University has shown that heart rate decreases for four to six seconds after an orienting stimulus. In ads, action sequences and music videos, formal features frequently come at a rate of one per second, thus activating the orienting response continuously.

Lang and her colleagues have also investigated whether formal features affect people's memory of what they have seen. In one of their studies, participants watched a program and then filled out a score sheet. Increasing the frequency of edits—defined here as a change from one camera angle to another in the same visual scene—improved memory recognition, presumably because it focused attention on the screen. Increasing the frequency of cuts—changes to a new visual scene—had a similar effect but only up to a point. If the number of cuts exceeded 10 in two minutes, recognition dropped off sharply.

Producers of educational television for children have found that formal features can help learning. But increasing the rate of cuts and edits eventually overloads the brain. Music videos and commercials that use rapid intercutting of unrelated scenes are designed to hold attention more than they are to convey information. People may remember the name of the product or band, but the details of the ad itself float in one ear and out the other. The orienting response is overworked. Viewers still attend to the screen, but they feel tired and worn out, with little compensating psychological reward. Our ESM findings show much the same thing.

Sometimes the memory of the product is very subtle. Many ads today are deliberately oblique: they have an engaging story line, but it is hard to tell

what they are trying to sell. Afterward you may not remember the product consciously. Yet advertisers believe that if they have gotten your attention, when you later go to the store you will feel better or more comfortable with a given product because you have a vague recollection of having heard of it.

The natural attraction to television's sound and light starts very early in life. Dafna Lemish of Tel Aviv University has described babies at six to eight weeks attending to television. We have observed slightly older infants who, when lying on their backs on the floor, crane their necks around 180 degrees to catch what light through yonder window breaks. This inclination suggests how deeply rooted the orienting response is.

Television's stylistic tricks—cuts, edits, zooms—can trigger involuntary responses.

"TV Is Part of Them"

THAT SAID, WE NEED to be careful about overreacting. Little evidence suggests that adults or children should stop watching TV altogether. The problems come from heavy or prolonged viewing.

The Experience Sampling Method permitted us to look closely at most every domain of everyday life: working, eating, reading, talking to friends, playing a sport, and so on. We wondered whether heavy viewers might experience life differently than light viewers do. Do they dislike being with people more? Are they more alienated from work? What we found nearly leaped off the page at us. Heavy viewers report feeling significantly more anxious and less happy than light viewers do in unstructured situations, such as doing nothing, daydreaming or waiting in line. The difference widens when the viewer is alone.

Subsequently, Robert D. McIlwraith of the University of Manitoba extensively studied those who called themselves TV addicts on surveys. On a measure called the Short Imaginal Processes Inventory (SIPI), he found that the self-described addicts are more easily bored and distracted and have poorer attentional control than the nonaddicts. The addicts said they used TV to distract themselves from unpleasant thoughts and to fill time. Other studies over the years have shown that heavy viewers are less likely to participate in community activities and sports and are more likely to be obese than moderate viewers or nonviewers.

The question that naturally arises is: In which direction does the correlation go? Do people turn to TV because of boredom and loneliness, or does TV viewing make people more susceptible to boredom and loneliness? We and most other researchers argue that the former is generally the case, but it is not a simple case of either/or. Jerome L. and Dorothy Singer of Yale University, among others, have suggested that more viewing may contribute to a shorter attention span, diminished self-restraint and less patience with the normal delays of daily life. More than 25 years ago psychologist Tannis M. MacBeth Williams of the University of British Columbia studied a mountain community that had no television until cable finally arrived. Over time, both adults and children in the town became less creative in problem solving, less able to persevere at tasks, and less tolerant of unstructured time.

To some researchers, the most convincing parallel between TV and addictive drugs is that people experience withdrawal symptoms when they cut back on viewing. Nearly 40 years ago Gary A. Steiner of the University of Chicago collected fascinating individual accounts of families whose set had broken—this back in the days when households generally had only one set: "The family walked around like a chicken without a head." "It was terrible. We did nothing—my husband and I talked." "Screamed constantly. Children bothered me, and my nerves were on edge. Tried to interest them in games, but impossible. TV is part of them."

In experiments, families have volunteered or been paid to stop viewing, typically for a week or a month. Many could not complete the period of abstinence. Some fought, verbally and physically. Anecdotal reports from some families that have tried the annual "TV turnoff" week in the U.S. tell a similar story.

If a family has been spending the lion's share of its free time watching television, reconfiguring itself around a new set of activities is no easy task. Of course, that does not mean it cannot be done or that all families implode when deprived of their set. In a review of these cold-turkey studies, Charles Winick of the City University of New York concluded: "The first three or four days for most persons were the worst, even in many homes where viewing was minimal and where there were other ongoing activities. In over half of all the households, during these first few days of loss, the regular routines were disrupted, family members had difficulties in dealing with the newly available time, anxiety and aggressions were expressed.... People living alone tended to be bored and irritated.... By the second week, a move toward adaptation to the situation was common." Unfortunately, researchers have yet to flesh out these anecdotes; no one has systematically gathered statistics on the prevalence of these withdrawal symptoms.

Even though TV does seem to meet the criteria for substance dependence, not all researchers would go so far as to call TV addictive. McIlwraith said in 1998 that "displacement of other activities by television may be socially significant but still fall short of the clinical requirement of significant impairment." He argued that a new category of "TV addiction" may not be necessary if heavy viewing stems from conditions such as depression and social phobia. Nevertheless, whether or not we formally diagnose someone as TV-dependent, millions of people sense that they cannot readily control the amount of television they watch.

Slave to the Computer Screen

ALTHOUGH much less research has been done on video games and computer use, the same principles often apply. The games offer escape and distraction; players quickly learn that they feel better when playing; and so a kind of reinforcement loop develops. The obvious difference from television, however, is the interactivity. Many video and computer games minutely increase in difficulty along with the increasing ability of the player. One can search for months to find another tennis or chess player of comparable ability, but programmed games can immediately provide a near-perfect match of challenge to skill. They offer the psychic pleasure—what one of us (Csikszentmihalyi) has called "flow"—that accompanies increased mastery of most any human endeavor. On the other hand, prolonged activation of the orienting response can wear players out. Kids report feeling tired, dizzy and nauseated after long sessions.

In 1997, in the most extreme medium-effects case on record, 700 Japanese children were rushed to the hospital, many suffering from "optically stimulated epileptic seizures" caused by viewing bright flashing lights in a Pokémon video game broadcast on Japanese TV. Seizures and other untoward effects of video games are significant enough that software companies and platform manufacturers now routinely include warnings in their instruction booklets. Parents have reported to us that rapid movement on the screen has caused motion sickness in their young children after just 15 minutes of play. Many youngsters, lacking self-control and experience (and often supervision), continue to play despite these symptoms.

Heavy viewers report feeling significantly more anxious and less happy than light viewers do.

Lang and Shyam Sundar of Pennsylvania State University have been studying how people respond to Web sites. Sundar has shown people multiple versions of the same Web page, identical except for the number of links. Users reported that more links conferred a greater sense of control and engagement. At some point, however, the number of links reached saturation, and adding more of them simply turned people off. As with video games, the ability of Web sites to hold the user's attention seems to depend less on formal features than on interactivity.

For growing numbers of people, the life they lead online may often seem more important, more immediate and more intense than the life they lead face-to-face. Maintaining control over one's media habits is more of a challenge today than it has ever been. TV sets and computers are everywhere. But the small screen and the Internet need not interfere with the quality of the rest of one's life. In its easy provision of relaxation and escape, television can be beneficial in limited doses. Yet when the habit interferes with the ability to grow, to learn new things, to lead an active life, then it does constitute a kind of dependence and should be taken seriously. SA

MORE TO EXPLORE

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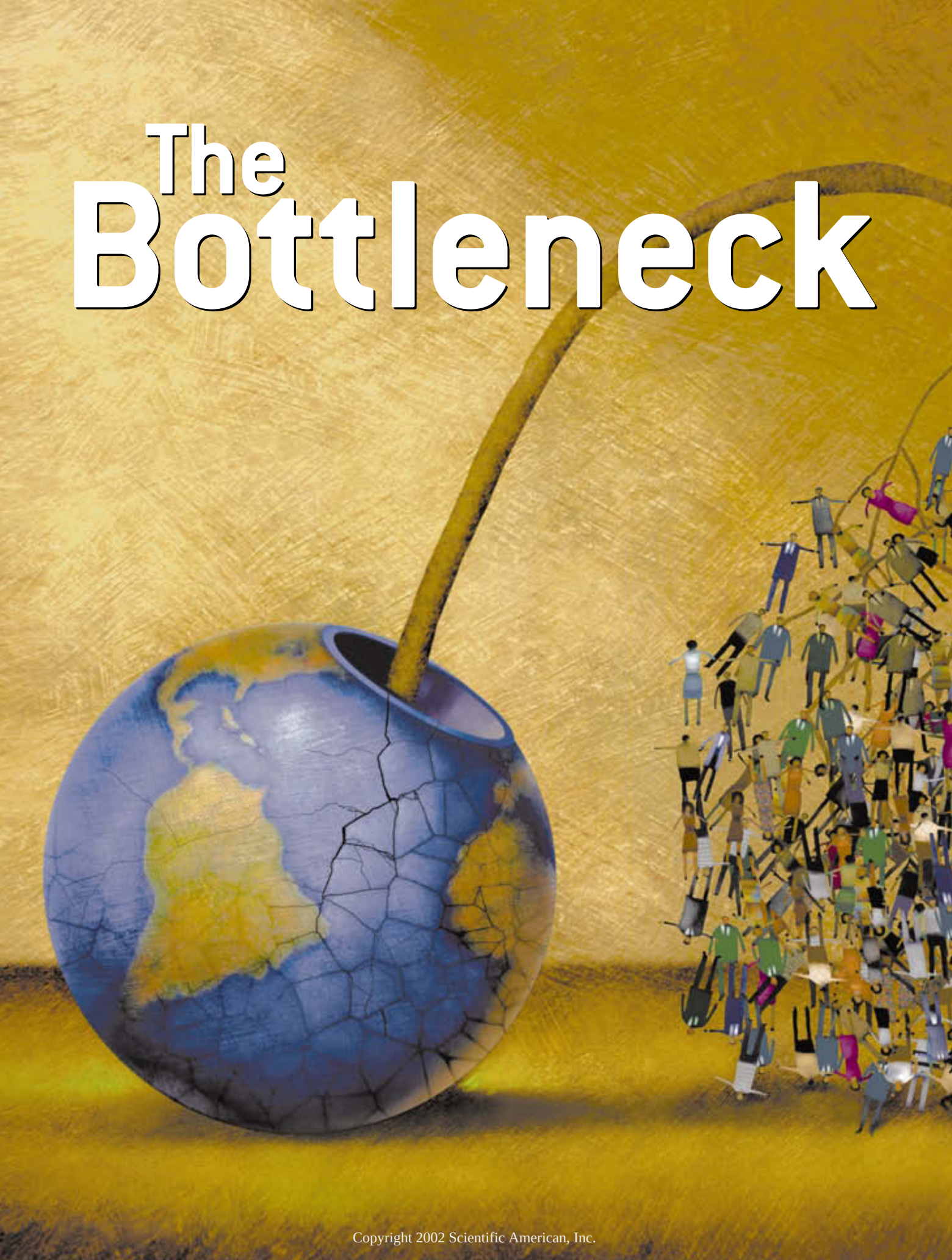
The Bottleneck

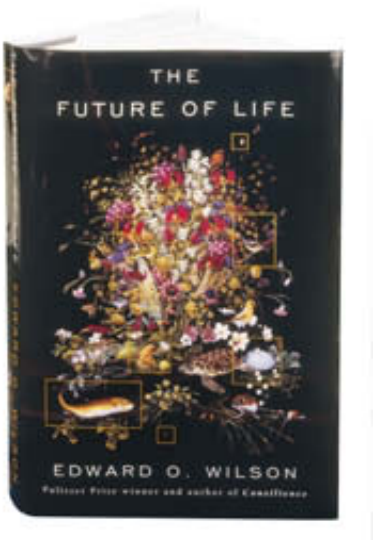


ALL ILLUSTRATIONS BY DAVE CUTLER

Book Excerpt

We have entered the Century of the Environment, in which the immediate future is usefully conceived as a bottleneck: science and technology, combined with foresight and moral courage, must see us through it and out

By Edward O. Wilson



FROM THE BOOK *THE FUTURE OF LIFE*, BY EDWARD O. WILSON. © 2002 BY E. O. WILSON. PUBLISHED BY ARRANGEMENT WITH ALFRED A. KNOPF, A DIVISION OF RANDOM HOUSE, INC., AND WITH LITTLE, BROWN IN THE U.K., WHICH WILL PUBLISH THE BOOK THERE IN APRIL 2002 (£17.99).

The 20th century was a time of exponential scientific and technical advance, the freeing of the arts by an exuberant modernism, and the spread of democracy and human rights throughout the world. It was also a dark and savage age of world wars, genocide, and totalitarian ideologies that came dangerously close to global domination. While preoccupied with all this tumult, humanity managed collaterally to decimate the natural environment and draw down the nonrenewable resources of the planet with cheerful abandon. We thereby accelerated the erasure of entire ecosystems and the extinction of thousands of million-year-old species. If Earth's ability to support our growth is finite—and it is—we were mostly too busy to notice.

As a new century begins, we have begun to awaken from this delirium. Now, increasingly postideological in temper, we may be ready to settle down before we wreck the planet. It is time to sort out Earth and calculate what it will take to provide a satisfying and sustainable life for everyone into the indefinite future. The question of the century is: How best can we shift to a culture of permanence, both for ourselves and for the biosphere that sustains us?

The bottom line is different from that generally assumed by our leading economists and public philosophers. They have mostly ignored the numbers that count. Consider that with the global population past six billion and on its way to eight billion or more by midcentury, per capita freshwater and arable land are descending to levels resource experts agree are risky. The ecological footprint—the average amount of productive land and shallow sea appropriated by each person in bits and pieces from around the world for food, water, housing, energy, transportation, commerce, and waste absorption—is about one hectare (2.5 acres) in developing nations but about 9.6 hectares (24 acres) in the U.S. The footprint for the total human population is 2.1 hectares (5.2 acres). For every person in the world to reach present U.S. levels of consumption with existing technology would require four more planet Earths. The five billion people of the developing countries may never wish to attain this level of profligacy. But in trying to achieve at least a decent standard of living, they have joined the industrial world in erasing the last of the natural environments. At the same time, *Homo sapiens* has become a geophysical force, the first species in the history of the planet to attain that dubious distinction. We have driven atmospheric carbon dioxide to the highest levels in at least 200,000 years, unbalanced the nitrogen cycle, and contributed to a global warming that will ultimately be bad news everywhere.

In short, we have entered the Century of the Environment, in which the immediate future is usefully conceived as a bottleneck. Science and technology, combined with a lack of self-understanding and a Paleolithic obstinacy, brought us to where we are today. Now science and technology, combined with foresight and moral courage, must see us through the bottleneck and out.

"Wait! Hold on there just one minute!"

That is the voice of the cornucopian economist. Let us listen to him carefully. He is focused on production and consumption. These are what the world wants and needs, he says. He is right, of course. Every species lives on production and consumption. The tree finds and consumes nutrients and sunlight; the leopard finds and consumes the deer. And the farmer clears both away to find space and raise corn—for consumption. The economist's thinking is based on precise models of rational choice and near-horizon timelines. His parameters are the gross domestic product, trade balance, and competitive index. He sits on corporate boards, travels to Washington, occasionally appears on television talk shows. The planet, he insists, is perpetually fruitful and still underutilized.

The ecologist has a different worldview. He is focused on unsustainable crop yields, overdrawn aqui-

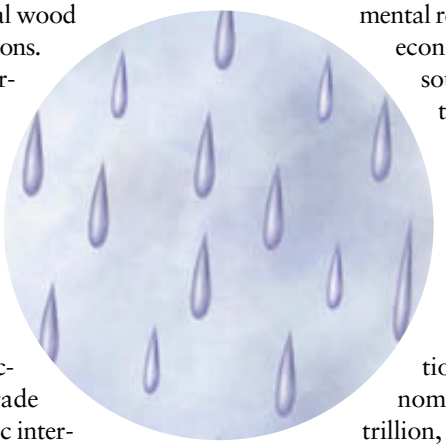
For every person in the world to reach present U.S. levels of consumption with existing technology would require four more planet Earths.

fers, and threatened ecosystems. His voice is also heard, albeit faintly, in high government and corporate circles. He sits on nonprofit foundation boards, writes for *Scientific American,* and is sometimes called to Washington. The planet, he insists, is exhausted and in trouble.

The Economist

"EASE UP. In spite of two centuries of doomsaying, humanity is enjoying unprecedented prosperity. There are environmental problems, certainly, but they can be solved. Think of them as the detritus of progress, to be cleared away. The global economic picture is favorable. The gross national products of the industrial countries continue to rise. Despite their recessions, the Asian tigers are catching up with North America and Europe. Around the world, manufacture and the service economy are growing geometrically. Since 1950 per capita income and meat production have risen continuously. Even though the world population has increased at an explosive 1.8 percent each year during the same period, cereal production, the source of more than half the food calories of the poorer nations and the traditional proxy of worldwide crop yield, has more than kept pace, rising from 275 kilograms per head in the early 1950s to 370 kilograms by the 1980s. The forests of the developed countries are now regenerating as fast as they are being cleared, or nearly so. And while fibers are also declining steeply in most of the rest of the world—a serious problem, I grant—no global scarcities are expected in the foreseeable future. Agriforestry has been summoned to the rescue: more than 20 percent of industrial wood fiber now comes from tree plantations.

"Social progress is running parallel to economic growth. Literacy rates are climbing, and with them the liberation and empowerment of women. Democracy, the gold standard of governance, is spreading country by country. The communication revolution powered by the computer and the Internet has accelerated the globalization of trade and the evolution of a more irenic international culture.

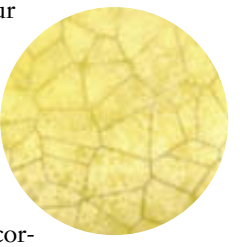


"For two centuries the specter of Malthus troubled the dreams of futurists. By rising exponentially, the doomsayers claimed, population must outstrip the limited resources of the world and bring about famine, chaos, and war. On occasion this scenario did unfold locally. But that has been more the result of political mismanagement than Malthusian mathematics. Human ingenuity has always found a way to accommodate rising populations and allow most to prosper.

"Genius and effort have transformed the environment to the benefit of human life. We have turned a wild and inhospitable world into a garden. Human dominance is Earth's destiny. The harmful perturbations we have caused can be moderated and reversed as we go along."

The Environmentalist

"YES, IT'S TRUE that the human condition has improved dramatically in many ways. But you've painted only half the picture, and with all due respect the logic it uses is just plain dangerous. As your worldview implies, humanity has learned how to create an economy-driven paradise. Yes again—but only on an infinitely large and malleable planet. It should be obvious to you that Earth is finite and its environment increasingly brittle. No one should look to gross national products and corporate annual reports for a competent projection of the world's long-term economic future. To the information there, if we are to understand the real world, must be added the research reports of natural-resource specialists and ecological economists. They are the experts who seek an accurate balance sheet, one that includes a full accounting of the costs to the planet incurred by economic growth.



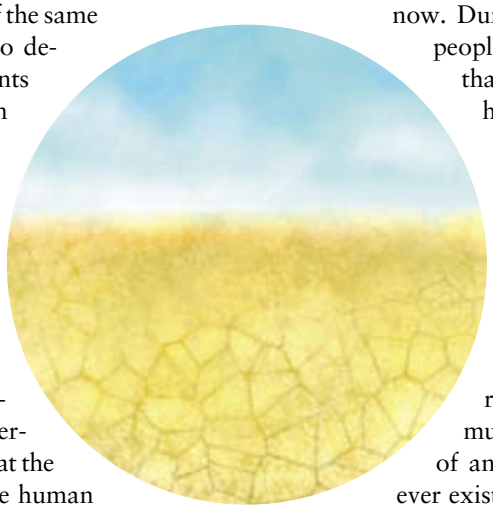
"This new breed of analysts argues that we can no longer afford to ignore the dependency of the economy and social progress on the environmental resource base. It is the *content* of economic growth, with natural resources factored in, that counts in the long term, not just the yield in products and currency. A country that levels its forests, drains its aquifers, and washes its topsoil downriver without measuring the cost is a country traveling blind.

"Suppose that the conventionally measured global economic output, now at about $31 trillion, were to expand at a healthy 3 percent annually. By 2050 it would in theory reach $138 trillion. With only a small leveling adjustment of this income, the entire world population would be prosperous by current standards. Utopia at last, it would seem! What is the flaw in the argument? It is the environment crumbling beneath us. If natural resources, particularly freshwater and arable land, continue to diminish at their present per

capita rate, the economic boom will lose steam, in the course of which—and this worries me even if it doesn't worry you—the effort to enlarge productive land will wipe out a large part of the world's fauna and flora.

"The appropriation of productive land—the ecological footprint—is already too large for the planet to sustain, and it's growing larger. A recent study building on this concept estimated that the human population exceeded Earth's sustainable capacity around the year 1978. By 2000 it had overshot by 1.4 times that capacity. If 12 percent of land were now to be set aside in order to protect the natural environment, as recommended in the 1987 Brundtland Report, Earth's sustainable capacity will have been exceeded still earlier, around 1972. In short, Earth has lost its ability to regenerate—unless global consumption is reduced or global production is increased, or both."

By dramatizing these two polar views of the economic future, I don't wish to imply the existence of two cultures with distinct ethos. All who care about both the economy and environment, and that includes the vast majority, are members of the same culture. The gaze of our two debaters is fixed on different points in the space-time scale in which we all dwell. They differ in the factors they take into account in forecasting the state of the world, how far they look into the future, and how much they care about nonhuman life. Most economists today, and all but the most politically conservative of their public interpreters, recognize very well that the world has limits and that the human population cannot afford to grow much larger. They know that humanity is destroying biodiversity. They just don't like to spend a lot of time thinking about it.



The environmentalist view is fortunately spreading. Perhaps the time has come to cease calling it the "environmentalist" view, as though it were a lobbying effort outside the mainstream of human activity, and to start calling it the real-world view. In a realistically reported and managed economy, balanced accounting will be routine. The conventional gross national product (GNP) will be replaced by the more comprehensive genuine progress indicator (GPI), which includes estimates of environmental costs of economic activity. Already a growing number of economists, scientists, political leaders, and others have endorsed precisely this change.

What, then, are essential facts about population and environment? From existing databases we can answer that question and visualize more clearly the bottleneck through which humanity and the rest of life are now passing.

On or about October 12, 1999, the world population reached six billion. It has continued to climb at an annual rate of 1.4 percent, adding 200,000 people each day or the equivalent of the population of a large city each week. The rate, though beginning to slow, is still basically exponential: the more people, the faster the growth, thence still more people sooner and an even faster growth, and so on upward toward astronomical numbers unless the trend is reversed and growth rate is reduced to zero or less. This exponentiation means that people born in 1950 were the first to see the human population double in their lifetime, from 2.5 billion to over six billion now. During the 20th century more people were added to the world than in all of previous human history. In 1800 there had been about one billion and in 1900, still only 1.6 billion.

The pattern of human population growth in the 20th century was more bacterial than primate. When *Homo sapiens* passed the six-billion mark we had already exceeded by perhaps as much as 100 times the biomass of any large animal species that ever existed on the land. We and the rest of life cannot afford another 100 years like that.

By the end of the century some relief was in sight. In most parts of the world—North and South America, Europe, Australia, and most of Asia—people had begun gingerly to tap the brake pedal. The worldwide average number of children per woman fell from 4.3 in 1960 to 2.6 in 2000. The number required to attain zero population growth—that is, the number that balances the birth and death rates and holds the standing population size constant—is 2.1 (the extra one tenth compensates for infant and child

mortality). When the number of children per woman stays above 2.1 even slightly, the population still expands exponentially. This means that although the population climbs less and less steeply as the number approaches 2.1, humanity will still, in theory, eventually come to weigh as much as Earth and, if given enough time, will exceed the mass of the visible universe. This fantasy is a mathematician's way of saying that anything above zero population growth cannot be sustained. If, on the other hand, the average number of children drops below 2.1, the population enters negative exponential growth and starts to decline. To speak of 2.1 in exact terms as the breakpoint is of course an oversimplification. Advances in medicine and public health can lower the breakpoint toward the minimal, perfect number of 2.0 (no infant or childhood deaths), while famine, epidemics, and war, by boosting mortality, can raise it well above 2.1. But worldwide, over an extended period of time, local differences and statistical fluctuations wash one another out and the iron demographic laws grind on. They transmit to us always the same essential message, that to breed in excess is to overload the planet.

The pattern of human population growth in the 20th century was more bacterial than primate.

By 2000 the replacement rate in all of the countries of western Europe had dropped below 2.1. The lead was taken by Italy, at 1.2 children per woman (so much for the power of natalist religious doctrine). Thailand also passed the magic number, as well as the nonimmigrant population of the U.S.

When a country descends to its zero-population birth rates or even well below, it does not cease absolute population growth immediately, because the positive growth experienced just before the breakpoint has generated a disproportionate number of young people with most of their fertile years and life ahead of them. As this cohort ages, the proportion of child-bearing people diminishes, the age distribution stabilizes at the zero-population level, the slack is taken up, and population growth ceases. Similarly, when a country dips below the breakpoint, a lag period intervenes before the absolute growth rate goes negative and the population actually declines. Italy and Germany, for example, have entered a period of such true, absolute negative population growth.

The decline in global population growth is attributable to three interlocking social forces: the globalization of an economy driven by science and technology, the consequent implosion of rural populations into cities, and, as a result of globalization and urban implosion, the empowerment of women. The freeing of women socially and economically results in fewer children. Reduced reproduction by female choice can be thought a fortunate, indeed almost miraculous, gift of human nature to future generations. It could have gone the other way: women, more prosperous and less shackled, could have chosen the satisfactions of a larger brood. They did the opposite. They opted for a smaller number of quality children, who can be raised with better health and education, over a larger family. They simultaneously chose better, more secure lives for themselves. The tendency appears to be very widespread, if not universal. Its importance cannot be overstated. Social commentators often remark that humanity is endangered by its own instincts, such as tribalism, aggression, and personal greed. Demographers of the future will, I believe, point out that on the other hand humanity was saved by this one quirk in the maternal instinct.

The global trend toward smaller families, if it continues, will eventually halt population growth and afterward reverse it. What will be the peak, and when will it occur? And how will the environment fare as humanity climbs to the peak? The Population Division of the United Nations Department of Economic and Social Affairs released a spread of projections to the year 2050 that ranged from 7.3 billion to 14.4 billion, with the most likely scenario

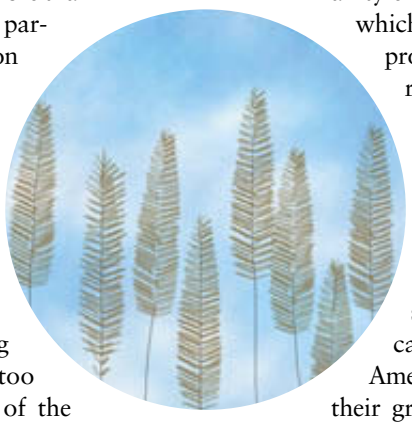
THE AUTHOR

EDWARD O. WILSON has made major contributions to a number of fields, including the behavior and evolution of social insects, chemical communication, and the evolution of social behavior. His interest in living organisms, especially ants, stems back to his childhood and to his undergraduate studies in evolutionary biology at the University of Alabama. He received his Ph.D. in biology from Harvard University, where he is now Pellegrino University Research Professor and Honorary Curator in Entomology at the Museum of Comparative Zoology. Among his many honors are the National Medal of Science, two Pulitzer Prizes (for *On Human Nature,* 1978, and *The Ants,* 1990, with Bert Hölldobler), and the Tyler Prize for environmental achievement. Other groundbreaking books include *Consilience* and *Sociobiology*.

JD SLOAN

falling somewhere between nine billion and 10 billion.

Enough slack still exists in the system to justify guarded optimism. Women given a choice and affordable contraceptive methods generally practice birth control. By 1996 about 130 countries subsidized family-planning services. More than half of all developing countries in particular also had official population policies to accompany their economic and military policies, and more than 90 percent of the rest stated their intention to follow suit. The U.S., where the idea is still virtually taboo, remained a stunning exception.



The encouragement of population control by developing countries comes not a moment too soon. The environmental fate of the world lies ultimately in their hands. They now account for virtually all global population growth, and their drive toward higher per capita consumption will be relentless.

The consequences of their reproductive prowess are multiple and deep. The people of the developing countries are already far younger than those in the industrial countries and destined to become more

The human brain evidently evolved to commit itself emotionally only to a small piece of geography.

so. The streets of Lagos, Manaus, Karachi, and other cities in the developing world are a sea of children. To an observer fresh from Europe or North America, the crowds give the feel of a gigantic school just let out. In at least 68 of the countries, more than 40 percent of the population is under 15 years of age.

A country poor to start with and composed largely of young children and adolescents is strained to provide even minimal health services and education for its people. Its superabundance of cheap, unskilled labor can be turned to some economic advantage but unfortunately also provides cannon fodder for ethnic strife and war. As the populations continue to explode and water and arable land grow scarcer, the industrial countries will feel their pressure in the form of many more desperate immigrants and the risk of spreading international terrorism. I have come to understand the advice given me many years ago when I argued the case for the natural environment to the president's scientific adviser: your patron is foreign policy.

Stretched to the limit of its capacity, how many people can the planet support? A rough answer is possible, but it is a sliding one contingent on three conditions: how far into the future the planetary support is expected to last, how evenly the resources are to be distributed, and the quality of life most of humanity expects to achieve. Consider food, which economists commonly use as a proxy of carrying capacity. The current world production of grains, which provide most of humanity's calories, is about two billion tons annually. That is enough, in theory, to feed 10 billion East Indians, who eat primarily grains and very little meat by Western standards. But the same amount can support only about 2.5 billion Americans, who convert a large part of their grains into livestock and poultry.

There are two ways to stop short of the wall. Either the industrialized populations move down the food chain to a more vegetarian diet, or the agricultural yield of productive land worldwide is increased by more than 50 percent.

The constraints of the biosphere are fixed. The bottleneck through which we are passing is real. It should be obvious to anyone not in a euphoric delirium that whatever humanity does or does not do, Earth's capacity to support our species is approaching the limit. We already appropriate by some means or other 40 percent of the planet's organic matter produced by green plants. If everyone agreed to become vegetarian, leaving little or nothing for livestock, the present 1.4 billion hectares of arable land (3.5 billion acres) would support about 10 billion people. If humans utilized as food all of the energy captured by plant photosynthesis on land and sea, some 40 trillion watts, the planet could support about 16 billion people. But long before that ultimate limit was approached, the planet would surely have become a hellish place to exist. There may, of course, be escape hatches. Petroleum reserves might be converted into food, until they are exhausted. Fusion energy could conceivably be used to create light, whose energy would power photosynthesis, ramp up plant growth beyond that dependent on solar energy, and hence create more food. Humanity might even consider becoming someday what the astrobiologists call a type II civilization and harness all the power of the sun to support human

life on Earth and on colonies on and around the other solar planets. Surely these are not frontiers we will wish to explore in order simply to continue our reproductive folly.

The epicenter of environmental change, the paradigm of population stress, is the People's Republic of China. By 2000 its population was 1.2 billion, one fifth of the world total. It is thought likely by demographers to creep up to 1.6 billion by 2030. During 1950–2000 China's people grew by 700 million, more than existed in the entire world at the start of the industrial revolution. The great bulk of this increase is crammed into the basins of the Yangtze and Yellow rivers, covering an area about equal to that of the eastern U.S. Hemmed in to the west by deserts and mountains, limited to the south by resistance from other civilizations, their agricultural populations simply grew denser on the land their ancestors had farmed for millennia. China became in effect a great overcrowded island, a Jamaica or Haiti writ large.

Highly intelligent and innovative, its people have made the most of it. Today China and the U.S. are the two leading grain producers of the world. But China's huge population is on the verge of consuming more than it can produce. In 1997 a team of scientists, reporting to the U.S. National Intelligence Council (NIC), predicted that China will need to import 175 million tons of grain annually by 2025. Extrapolated to 2030, the annual level is 200 million tons—the entire amount of grain exported annually in the world at the present time. A tick in the parameters of the model could move these figures up or down, but optimism would be a dangerous attitude in planning strategy when the stakes are so high. After 1997 the Chinese in fact instituted a province-level crash program to boost grain level to export capacity. The effort was successful but may be short-lived, a fact the government itself recognizes. It requires cultivation of marginal land, higher per acre environmental damage, and a more rapid depletion of the country's precious groundwater.

According to the NIC report, any slack in China's production may be picked up by the Big Five grain exporters: the U.S., Canada, Argentina, Australia, and the European Union. But the exports of these dominant producers, after climbing steeply in the 1960s and 1970s, tapered off to near their present level in 1980. With existing agricultural capacity and technology, this output does not seem likely to increase to any significant degree. The U.S. and the European Union have already returned to production all of the cropland idled under earlier farm commodity programs. Australia and Canada, largely dependent on dryland farming, are constrained by low rainfall. Argentina has the potential to expand, but due to its small size, the surplus it produces is unlikely to exceed 10 million tons of grain production per year.

China relies heavily on irrigation, with water drawn from its aquifers and great rivers. The greatest impediment is again geographic: two thirds of China's agriculture is in the north, but four fifths of the water supply is in the south—that is, principally in the Yangtze River Basin. Irrigation and withdrawals for domestic and industrial use have depleted the northern basins, from which flow the waters of the Yellow, Hai, Huai, and Liao rivers. Starting in 1972, the Yellow River Channel has gone bone dry almost yearly through part of its course in Shandong Province, as far inland as the capital, Jinan, thence down all the way to the sea. In 1997 the river stopped flowing for 130 days, then restarted and stopped again through the year for a record total of 226 dry days. Because Shandong Province normally produces a fifth of China's wheat and a seventh of its corn, the failure of the Yellow River is of no little consequence. The crop losses in 1997 alone reached $1.7 billion.

Meanwhile the groundwater of the northern plains has dropped precipitously, reaching an average rate of 1.5 meters (five feet) per year by the mid-1990s. Between 1965 and 1995 the water table fell 37 meters (121 feet) beneath Beijing itself.

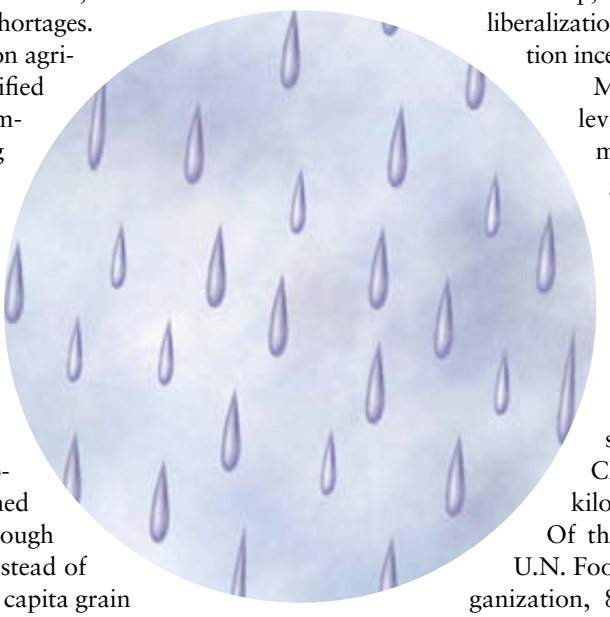
Faced with chronic water shortages in the Yellow River Basin, the Chinese government has undertaken the building of the Xiaolangdi Dam, which will be exceeded in size only by the Three Gorges Dam on the Yangtze River. The Xiaolangdi is expected to solve the problems of both periodic flooding and drought. Plans are being laid in addition for the construction of canals to siphon water from the Yangtze, which never grows dry, to the Yellow River and Beijing, respectively.

These measures may or may not suffice to maintain Chinese agriculture and economic growth. But

they are complicated by formidable side effects. Foremost is silting from the upriver loess plains, which makes the Yellow River the most turbid in the world and threatens to fill the Xiaolangdi Reservoir, according to one study, as soon as 30 years after its completion.

China has maneuvered itself into a position that forces it continually to design and redesign its lowland territories as one gigantic hydraulic system. But this is not the fundamental problem. The fundamental problem is that China has too many people. In addition, its people are admirably industrious and fiercely upwardly mobile. As a result, their water requirements, already oppressively high, are rising steeply. By 2030 residential demands alone are projected to increase more than fourfold, to 134 billion tons, and industrial demands fivefold, to 269 billion tons. The effects will be direct and powerful. Of China's 617 cities, 300 already face water shortages.

The pressure on agriculture is intensified in China by a dilemma shared in varying degrees by every country. As industrialization proceeds, per capita income rises, and the populace consumes more food. They also migrate up the energy pyramid to meat and dairy products. Because fewer calories per kilogram of grain are obtained when first passed through poultry and livestock instead of being eaten directly, per capita grain consumption rises still more. All the while the available water supply remains static or nearly so. In an open market, the agricultural use of water is outcompeted by industrial use. A thousand tons of freshwater yields a ton of wheat, worth $200, but the same amount of water in industry yields $14,000. As China, already short on water and arable land, grows more prosperous through industrialization and trade, water becomes more expensive. The cost of agriculture rises correspondingly, and unless the collection of water is subsidized, the price of food also rises. This is in part the rationale for the great dams at Three Gorges and Xiaolangdi, built at enormous public expense.



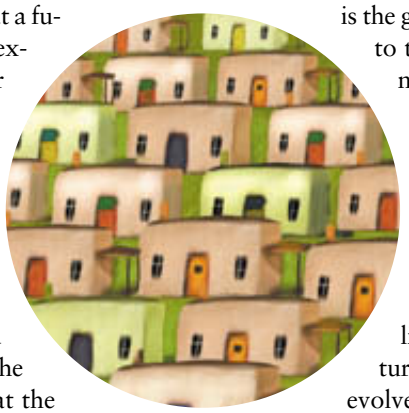
In theory, an affluent industrialized country does not have to be agriculturally independent. In theory, China can make up its grain shortage by purchasing from the Big Five grain-surplus nations. Unfortunately, its population is too large and the world surplus too restrictive for it to solve its problem without altering the world market. All by itself, China seems destined to drive up the price of grain and make it harder for the poorer developing countries to meet their own needs. At the present time, grain prices are falling, but this seems certain to change as the world population soars to nine billion or beyond.

The problem, resource experts agree, cannot be solved entirely by hydrological engineering. It must include shifts from grain to fruit and vegetables, which are more labor-intensive, giving China a competitive edge. To this can be added strict water conservation measures in industrial and domestic use; the use of sprinkler and drip irrigation in cultivation, as opposed to the traditional and more wasteful methods of flood and furrow irrigation; and private land ownership, with subsidies and price liberalization, to increase conservation incentives for farmers.

Meanwhile the surtax levied on the environment to support China's growth, though rarely entered on the national balance sheets, is escalating to a ruinous level. Among the most telling indicators is the pollution of water. Here is a measure worth pondering. China has in all 50,000 kilometers of major rivers. Of these, according to the U.N. Food and Agriculture Organization, 80 percent no longer support fish. The Yellow River is dead along much of its course, so fouled with chromium, cadmium, and other toxins from oil refineries, paper mills, and chemical plants as to be unfit for either human consumption or irrigation. Diseases from bacterial and toxic-waste pollution are epidemic.

China can probably feed itself to at least midcentury, but its own data show that it will be skirting the edge of disaster even as it accelerates its lifesaving shift to industrialization and megahydrological engineering. The extremity of China's condition makes it vulnerable to the wild cards of history. A war, internal political turmoil, extended droughts, or crop disease can kick the economy into a downspin. Its enormous population makes rescue by other countries impracticable.

China deserves close attention, not just as the unsteady giant whose missteps can rock the world, but also because it is so far advanced along the path to which the rest of humanity seems inexorably headed. If China solves its problems, the lessons learned can be applied elsewhere. That includes the U.S., whose citizens are working at a furious pace to overpopulate and exhaust their own land and water from sea to shining sea.



Environmentalism is still widely viewed, especially in the U.S., as a special-interest lobby. Its proponents, in this blinkered view, flutter their hands over pollution and threatened species, exaggerate their case, and press for industrial restraint and the protection of wild places, even at the cost of economic development and jobs.

Environmentalism is something more central and vastly more important. Its essence has been defined by science in the following way. Earth, unlike the other solar planets, is not in physical equilibrium. It depends on its living shell to create the special conditions on which life is sustainable. The soil, water, and atmosphere of its surface have evolved over hundreds of millions of years to their present condition by the activity of the biosphere, a stupendously complex layer of living creatures whose activities are locked together in precise but tenuous global cycles of energy and transformed organic matter. The biosphere creates our special world anew every day, every minute, and holds it in a unique, shimmering physical disequilibrium. On that disequilibrium the human species is in total thrall. When we alter the biosphere in any direction, we move the environment away from the delicate dance of biology. When we destroy ecosystems and extinguish species, we degrade the greatest heritage this planet has to offer and thereby threaten our own existence.

Humanity did not descend as angelic beings into this world. Nor are we aliens who colonized Earth. We evolved here, one among many species, across millions of years, and exist as one organic miracle linked to others. The natural environment we treat with such unnecessary ignorance and recklessness was our cradle and nursery, our school, and remains our one and only home. To its special conditions we are intimately adapted in every one of the bodily fibers and biochemical transactions that gives us life.

That is the essence of environmentalism. It is the guiding principle of those devoted to the health of the planet. But it is not yet a general worldview, evidently not yet compelling enough to distract many people away from the primal diversions of sport, politics, religion, and private wealth.

The relative indifference to the environment springs, I believe, from deep within human nature. The human brain evidently evolved to commit itself emotionally only to a small piece of geography, a limited band of kinsmen, and two or three generations into the future. To look neither far ahead nor far afield is elemental in a Darwinian sense. We are innately inclined to ignore any distant possibility not yet requiring examination. It is, people say, just good common sense. Why do they think in this shortsighted way? The reason is simple: it is a hardwired part of our Paleolithic heritage. For hundreds of millennia, those who worked for short-term gain within a small circle of relatives and friends lived longer and left more offspring—even when their collective striving caused their chiefdoms and empires to crumble around them. The long view that might have saved their distant descendants required a vision and extended altruism instinctively difficult to marshal.

The great dilemma of environmental reasoning stems from this conflict between short-term and long-term values. To select values for the near future of one's own tribe or country is relatively easy. To select values for the distant future of the whole planet also is relatively easy—in theory, at least. To combine the two visions to create a universal environmental ethic is, on the other hand, very difficult. But combine them we must, because a universal environmental ethic is the only guide by which humanity and the rest of life can be safely conducted through the bottleneck into which our species has foolishly blundered. SA

We are innately inclined to ignore any distant possibility not yet requiring examination. It is a hardwired part of our Paleolithic heritage.

AERIAL AND SATELLITE IMAGING

Eye in the Sky

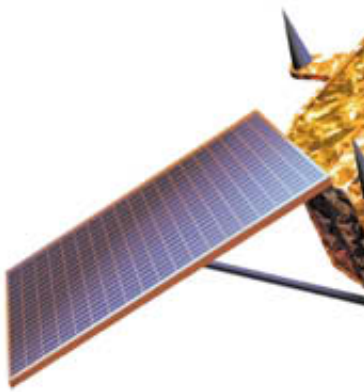
Ever since Icarus melted his waxed wings by flying too close to the sun, humankind has sought a bird's-eye view. Today there are two main ways to image our world from the skies. The first, aerial photography, is used by the University of New Orleans Coastal Research Laboratory (*right*). A computer on a plane flying at 12,000 feet communicates with the Differential Global Positioning System and tells the plane's camera when to take each in a series of overlapping exposures. It marks each frame with the plane's altitude, latitude and longitude. Frames have one-meter resolution.

Back at the lab, technicians assign the frames latitude, longitude and elevation coordinates from U.S. Geological Survey ground references and scan dozens of frames into a computer. Software rectifies and blends the overlaps into a smooth mosaic, filters out water and sun glint, and sometimes assigns color scaled to parameters such as light absorption. An average mission costs $10,000, says Paul Connor, the lab's remote-sensing manager.

The best commercial satellite images also have one-meter resolution. (Some military spy satellites are reputed to achieve five-inch resolution.) Space Imaging's Ikonos satellite (*far right*) orbits from the North Pole to the South Pole at a height of 423 miles and at a slight angle so that in three days it passes over every spot on the earth. A digital telescope made by Kodak records a swath below. The raw, geo-referenced data are downlinked and archived at headquarters near Denver. A technician enters latitude and longitude to retrieve a cropped image corrected for the earth's curvature. Custom images can cost $20,000; preprocessed images are as little as $700.

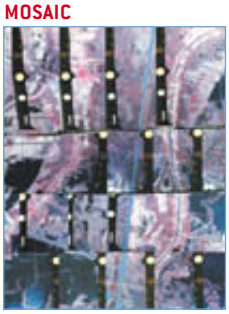
Aerial photography can create images with half-meter resolution if the plane flies at 6,000 feet or so, but more images are required, pushing up expenses. Satellites cost millions of dollars but can produce images continually. They can also capture contentious places such as Afghanistan and Iraq, where planes cannot safely fly. Space Imaging has already received a license to operate a satellite with half-meter resolution. Spokesperson Mark Brender says the company hopes to launch in 2005. —*Mark Fischetti*

AERIAL MOSAIC shows land loss by New Orleans. Sixty overlapping frames were shot by a Wild Heerbrugg Leica camera, which takes nine-by-nine-inch positive-emulsion transparencies. The final image contains about one gigabyte of data.



FRAME COORDINATES

MOSAIC



FINAL IMAGE

1-METER RESOLUTION

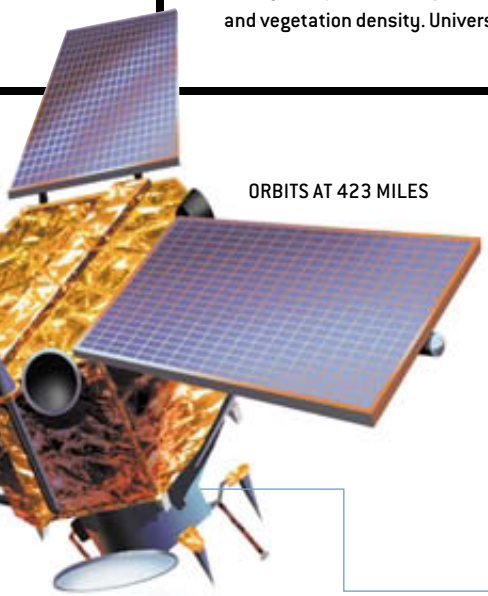
ILLUSTRATION BY GEORGE RETSECK; PHOTOGRAPHS BY UNIVERSITY OF NEW ORLEANS AND SPACE IMAGING, INC.

DID YOU KNOW . . .

➤ CHECKBOOK CONTROL: On September 11, Space Imaging had the only commercial satellite aloft capable of one-meter resolution. The Pentagon soon struck an exclusive license to purchase all its pictures of Afghanistan—some say to prevent enemies and the media from tracking U.S. military operations. In 1996, at Israel's request, Congress added a provision to defense legislation that prohibits American companies from selling one-meter-resolution images of Israel's territory.

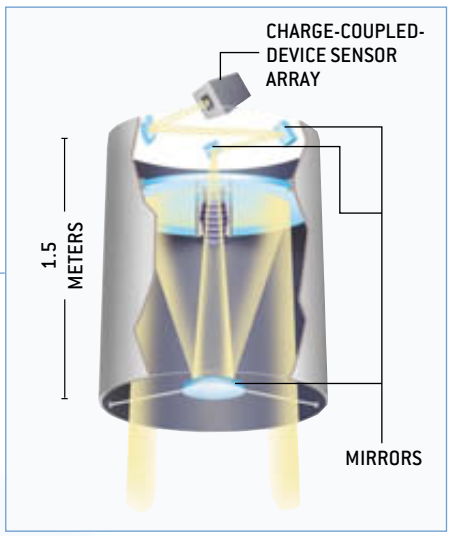
➤ LAYERED LOOK: Landsat 7, NASA's remote-sensing workhorse, has only 15-meter color resolution, but its seven color bands provide handy, inexpensive images of large-scale features such as coastlines and vegetation density. University of New Orleans cartographers sometimes overlay their local one-meter-resolution aerial mosaics onto Landsat photographs to create intriguing reference maps.

➤ SEEING PROFIT: Aerial and satellite images can be used to determine crop health, distinguish tanks from jeeps, chart erosion, site pipelines, find illegal logging and measure snowpack. One executive who wanted to site 219 new stores hired Space Imaging to take satellite photographs of his top 10 outlets to compare their parking-lot sizes and proximity to highway off-ramps, schools or McDonald's restaurants. A Bangkok bank chain manager recently used a similar approach, along with data on property values and office rents, to guide his closing of 29 branches and opening of seven new ones.



ORBITS AT 423 MILES

TELESCOPE



IKONOS SATELLITE

shows repair of the U.S. Pentagon in November. It bounces incoming light between mirrors to focus it onto a dense sensor array. To achieve one-meter resolution, the mirrors are polished so perfectly that if they were 100 miles in diameter, the highest bump would rise less than 0.08 inch. Alignment error among the mirrors is so slight that it is measured in wavelengths of light. Each of the thousands of glass pixels on a sensor is coated with 66 thin-film filters, each film only several angstroms thick.

FINAL IMAGE

1-METER RESOLUTION

ALTITUDE OF 6,000 TO 12,000 FEET

435-MILE LINE OF SIGHT

WASHINGTON, D.C.

TALLAHASSEE

Have a topic for a future column? Send it to workingknowledge@sciam.com

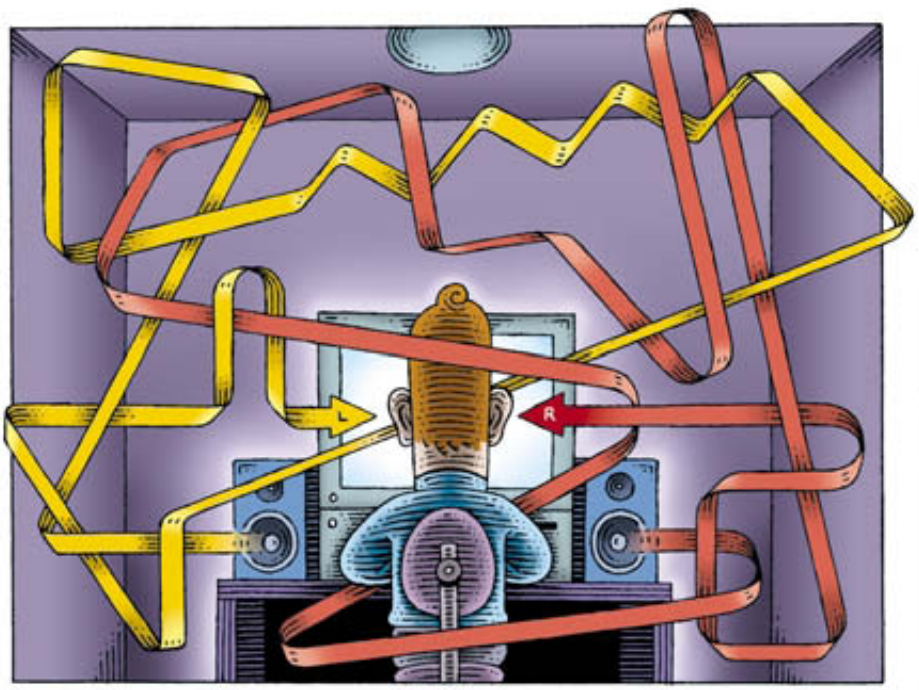
Surrounded by Sound

INGENIOUS SOFTWARE MAKES ORDINARY STEREO SPEAKERS COME ALIVE **BY FIONA HARVEY**

Lying on a beach at Devon on the south coast of England in 1990, Alastair Sibbald had a curious thought. He could hear the seagulls in front of him over the sea and the sheep behind him on the cliffs, each separate and distinct. How was it, he wondered, that he could place these sounds so accurately in space? And could a computer program replicate this three-dimensional aural experience?

Now Sibbald has the answers. As chief scientist at Sensaura, a company based in Middlesex, England, he has spent the past decade developing software that acts like a digital ventriloquist. Sensaura's programs enable ordinary computer speakers, television sets and headphones to create the illusion that sounds are coming from anywhere around a listener's head. The technology has been incorporated into the audio chips used in tens of millions of personal computers. Last November the Royal Academy of Engineering recognized the magnitude of Sensaura's accomplishment by giving the company the MacRobert Award, Britain's most prestigious engineering prize.

To truly appreciate the glories of three-dimensional audio, one must hear it firsthand. On a recent visit to Sibbald's office, I sat in front of a pair of speakers and listened to a series of sounds that had been modified using Sensaura's software. I heard a bumblebee buzz loudly in my ear, then retreat to a point a few feet away. Then I heard the bee fly around the room and return to buzz in my other ear. I could actually point to the exact place where I thought the bee was. The insect seemed to speed up and slow down, its movements controlled by the software. When the bee was replaced by a growling jaguar, the effect was so realistic I nearly jumped out of my seat.



AUDIO SOFTWARE can create the illusion that the sounds from a pair of computer speakers are coming from anywhere around a listener's head. The technology has been incorporated into audio chips and game consoles and may someday enhance cellular-phone conversations.

Human beings typically rely on both ears to get an accurate measurement of where sounds are coming from. My hearing is severely reduced in my left ear, but the software worked despite this problem. Although the sound was best when I was seated in the "sweet spot" between the speakers—equidistant from both—I could turn my head or move from side to side without destroying the illusion.

Generating three-dimensional sounds from a pair of speakers is no easy task. Sibbald started with the basic principles of hearing. The brain relies on several clues to determine where a sound originates. A vital clue is deduced from the effect of the outer ears, which modify sounds before they reach the eardrum. Sibbald likens the effect to blowing across the top of a bottle—if you blow at a certain angle, you produce a distinc-

SAMUEL VELASCO

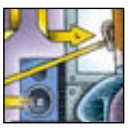
tive tone. The various parts of the outer ear are shaped to produce different resonances, and the brain learns that these resonances are associated with sounds entering the ear at different angles.

Sensaura searched for a way to simulate the sound modifications caused by the outer ears. At first the company's research team used a commercially available "artificial head"—a model of a human head with miniature microphones placed where the eardrums should be. The model, however, was not sufficiently accurate, so Sibbald created artificial ears using materials such as latex to get the right texture. He designed the ear canal by making a mold of his own. "People should never put anything into their ears," he warns. "But I'm a scientist, so it's okay."

Sibbald explored the resonant qualities of his artificial ears by measuring how they modified sounds coming from a variety of points around the head. (Although human ears differ in size, they are remarkably similar in shape, so the sound modifications are also similar.) Sibbald then incorporated his data into software that could synthesize the distinctive acoustic effects.

What lies between the ears is also important. A sound seldom hits both ears simultaneously. The brain gauges the time interval between the sound's reaching one ear and its arrival at the other—the interaural time delay—to make further calculations about the sound's origin. Sensaura's software takes advantage of this phenomenon by releasing the same sound from each of the two speakers at slightly different times. If heard through headphones, this delay convinces the brain that the sounds are coming from different points around the head.

When one tries the same trick with loudspeakers, though, the creation of three-dimensional sound runs into a serious problem called transaural acoustic cross talk. This occurs when the left ear hears some of the sound coming from the right speaker, and vice versa. To give the impression that a sound is coming from a particular spot, the left and right speakers must emit the sound with the interaural time delay that the brain would expect if the sound were actually coming from that spot. For example, if the spot is to the listener's left, the sound from the left speaker should reach the left ear a moment before the sound from the right speaker reaches the right ear. But the sound from the left speaker typically travels around the head and enters the right ear before the sound from the right speaker can arrive.



Generating three-dimensional sounds from a pair of speakers is no easy task.

The problem is compounded by the Haas effect (also known as the precedence effect). After hearing a signal, the brain suppresses any similar signals that occur within about 40 milliseconds. The reasons for the Haas effect are clear: without it, we would constantly be hearing echoes and reverberations in enclosed spaces. "Our ancestors wouldn't have wanted to hear each echo of a saber-toothed tiger in a cave," Sibbald notes. "They'd want to hear just the first sound, so they would know where the animal was."

Because of the Haas effect, the delayed sound released from the right speaker is simply ignored if it arrives too soon after the same sound from the left speaker. To overcome this obstacle, Sensaura's engineers carefully diagrammed the acoustic pathways from each speaker to each ear. The engineers identified the bothersome cross-talk pathways and invented an ingenious system for eliminating them. The cross talk from one speaker would be canceled out by an equal but opposite sound wave from the other speaker. Of course, this method creates its own difficulties: the canceling wave also reaches both ears and interferes with the original sounds as well as the cross talk. Sensaura had to devise a set of overlapping signals that cancels out the cancellations.

The final result of all this effort is very impressive. During my session with Sensaura's three-dimensional sound system, I could easily place the sounds coming from in front of me and from the sides. The illusion was not quite perfect—I got a bit confused when sounds came from behind my head. I blamed my bad ear, but Sibbald said even people with normal hearing can experience similar difficulties. He quoted studies in which sounds were played directly in front of and behind blindfolded people; between 15 and 35 percent of the subjects incorrectly identified the direction of the sound. There appears to be a small region on either side of the body's median plane (which bisects the body vertically) where people have trouble. It is a curious gap in the exceptional fine tuning of our sense of hearing.

So far the most popular application for Sensaura's technology has been in enhancing the sounds of computer games. The company recently announced that its three-dimensional audio software will be incorporated into the new Xbox game console made by Microsoft. But the same software can also enrich the music from CDs and MP3 files, as well as provide a surround-sound effect for home theater systems. Most intriguingly, Sensaura is developing ways to apply the technology to cellular phones. The software could enable a cell-phone user (who uses a device with stereo earphones) to conduct a conference call in which each of the participants' voices would seem to come from a different position. Even the world's best ventriloquist would have some trouble doing that! SA

Fiona Harvey is a journalist based in London who writes about all aspects of technology for the Financial Times.

Treasonous Idealism

NOVA'S INTRIGUING DOCUMENTARY PROBES MISDIRECTED PRINCIPLES—AND THE UNFORESEEN DANGERS OF GOVERNMENT SECRECY **BY CHET RAYMO**

SECRETS, LIES AND ATOMIC SPIES
Written and produced by Tug Yourgrau
Nova, WGBH, Boston
Airdate: February 5, 2002
(www.pbs.org/nova/venona/)

Only in the past half a dozen years have the American people learned the extent to which our World War II ally the Soviet Union was engaged in espionage against the U.S. even as the war proceeded. This knowledge became available to the U.S. government in the late 1940s, when encrypted messages to Moscow were deciphered in a project known as Venona (a meaningless code name), but was withheld from the public long after there was any excuse for secrecy. Apparently, not even Senator Joseph McCarthy knew of the decryptions during his 1950s witchhunt for Communist spies.

The central themes of this *Nova* program—the breaking of the Soviet codes and Los Alamos physicist Theodore (Ted) Hall's betrayal of atomic secrets to the Soviets—have been described in books by John Earl Haynes and Harvey Klehr (*Venona: Decoding Soviet Espionage in America*, 1999) and by Joseph Albright and Marcia Kunstel (*Bombshell: The Secret Story of America's Unknown Atomic Spy Conspiracy*, 1997). Now, with its usual flair, *Nova* has pulled all the pieces together into a fascinating documentary.

The program lucidly explains the theoretically unbreakable Soviet cipher, known as a one-time pad system, and how sloppy encryption gave Venona codebreakers the edge they needed to read some Soviet secrets. Among the shocking revelations was the passing of information to Moscow by hundreds of Americans in every branch of government, including scientists engaged in the building of the atomic bomb.

The Venona files were made public starting in 1995, at the instigation of Senator Daniel Patrick Moynihan. With these revelations, Ted Hall joined his long-exposed Los Alamos colleagues Klaus Fuchs and David Greenglass in a gallery of villains who, for self-proclaimed idealistic motives, betrayed atomic secrets to Soviet intelligence and significantly hastened the Soviet Union's debut as an atomic power.

1951: Ethel and Julius Rosenberg in a marshal's van after being found guilty of espionage.

ARCHIVE PHOTOS/PICTURE QUEST

Hall was a precocious 18-year-old student at Harvard University when he was invited to Los Alamos in 1944 to work on the implosion method of igniting plutonium bombs. He was not recruited by the Soviets; like other wartime scientists with leftist sympathies, he sought out Soviet contacts for the express purpose of passing nuclear secrets. He was evidently unaware of similar treachery by Fuchs and Greenglass.

A decrypted cable flagged Hall as a wartime spy in 1950. The FBI tried to get the young physicist, then at the University of Chicago, to incriminate himself, but he resisted. The government was unwilling to use the decoded transcripts as evidence in court for fear of compromising Venona. Hall's espionage remained a secret until 1995, when the National Security Agency finally released the decrypted wartime cable naming him and his friend Saville Sax as Soviet informants. He was then a respected biophysicist living in England with his wife, Joan, and terminally ill with cancer.

He died in 1999 but not before giving authors Albright and Kunstel what amounted to a signed confession, although with little show of remorse. In an interview on this program, Joan Hall defends her husband's motives. He was afraid the U.S. might become a reactionary power after the war, she says, and wanted to give the Soviet Union a better chance of standing up to Ameri-

cans. His motives, she insists, were "humanitarian." She herself comes across as smugly unrepentant, although she knew of her husband's treasonable activities from the time of their marriage in 1947.

The Manhattan Project to build an atomic bomb brought together some of the smartest scientific minds on the planet, among whom Ted Hall was a minor player. Nevertheless, his sense of his own importance may have led him to think he knew better than his fellow citizens what was best for humankind. Other scientist spies also mistook technical brilliance for political wisdom. A strong odor of intellectual arrogance hangs over the entire Venona affair.

The atomic spies may have been motivated by idealism, but their actions were treasonous. Certainly honor and principle sometimes require civil disobedience, as Henry David Thoreau and Martin Luther King, Jr., taught us, but resistance must be overt and the legal consequences willingly embraced. If there is a lesson to be learned from this compelling *Nova* program, it is that citizens in a democracy must temper their private certainties with a measure of trust in the collective wisdom of the people.

Governments, too, must trust the people. Democracy was subverted by the decision to keep Venona secret long after the Soviets knew the code had been broken (there was a spy *within* the Venona project). Historians can only speculate on what might have been the impact of the Venona revelations on such key episodes of postwar history as the McCarthy hearings and the Rosenbergs' trial. Because of the government's obsession with secrecy, some real traitors, such as Ted Hall, got off scot-free, and others, such as executed spy Ethel Rosenberg, may have suffered fates more serious than they deserved. The present administration should take note. SA

Chet Raymo is emeritus professor at Stonehill College in Massachusetts and a science columnist for the Boston Globe.

BETH PHILLIPS

THE EDITORS **RECOMMEND**

WHAT EVOLUTION IS

by Ernst Mayr. Basic Books, New York, 2001 ($26)

"What I have aimed for," Mayr writes, "is an elementary volume that stresses principles and does not get lost in detail." What the reader gets from this giant in the field of evolutionary biology is a fine basic account of the developing understanding of evolution from ancient times to the present. Mayr presents a spirited defense of Darwinian explanations of biology as well as confronting the reductionist approach that tries to focus all evolutionary phenomena on the gene; he shows instead that evolution must consider two crucial units—the individual and populations.

Mayr, professor emeritus of zoology at Harvard University, asserts that the term "evolutionary theory" should be abandoned. Evolution, he says, "is a fact so overwhelmingly established that it has become irrational to call it a theory."

THE INVISIBLE FUTURE: THE SEAMLESS INTEGRATION OF TECHNOLOGY INTO EVERYDAY LIFE

Edited by Peter J. Denning. McGraw-Hill, New York, 2002 ($24.95)

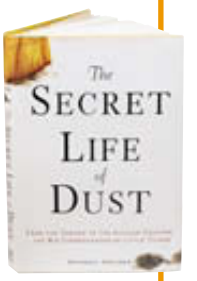
How will technology shape the way humans and machines interact? Eighteen essays posit 18 different answers, some optimistic, some not so. Based on a think tank organized by the Association for Computing Machinery, the book rounds up the usual suspects, among them Rodney Brooks, Vint Cerf, Michael Dertouzos and Ray Kurzweil. Some unexpected suspects have been roped in as well, including oceanographer Marcia McNutt and astrophysicist Neil deGrasse Tyson.

As in any such collection, the individual essays are uneven, but this doesn't prevent the book from being great fun to dip into. Three high points are the musings of John Seely Brown and Paul Duguid, Douglas Hofstadter and Alan Kay. Brown and Duguid, in a particularly well written piece, analyze Bill Joy's famous warning (put forth in the April 2000 issue of *Wired*) that the potential of new technologies for self-replication poses a profound challenge. Hofstadter confesses his "confusion and surprise" at hearing a Chopin-like mazurka written by a music composition system created by Dave Cope of the University of California at Santa Cruz. And in an analogy with the printing press, whose real effects weren't evident until nearly 200 years after its invention, Kay may have said it all in just the title of the collection's shortest contribution: "The Computer Revolution Hasn't Happened Yet."

THE SECRET LIFE OF DUST: FROM THE COSMOS TO THE KITCHEN COUNTER, THE BIG CONSEQUENCES OF LITTLE THINGS

by Hannah Holmes. John Wiley & Sons, Inc., New York, 2001 ($22.95)

Dust, science writer Holmes tells the reader, is so ubiquitous that "by the time you have read this far [11 lines into her first chapter], you may have inhaled 150,000 of these worldly specks." Billions of tons of dust rise from Earth every year, from deserts, volcanoes, oceans, living things and factories. Billions of tons fall to Earth every year, not only from what rose but also from space. This enormous traffic of tiny things has profound effects, good and bad, on Earth and on living organisms. Holmes makes an engaging story of the worldly specks.



All the books reviewed are available for purchase through www.sciam.com

Shifty Witnesses

BY DENNIS E. SHASHA

Skipping the preliminaries, the detective stated his problem: "We have five witnesses whom we don't trust. They have trailed a group of 10 suspected drug dealers. For each suspect, the five witnesses take a vote about whether the suspect has drugs or not.

"Here is a summary of the votes:

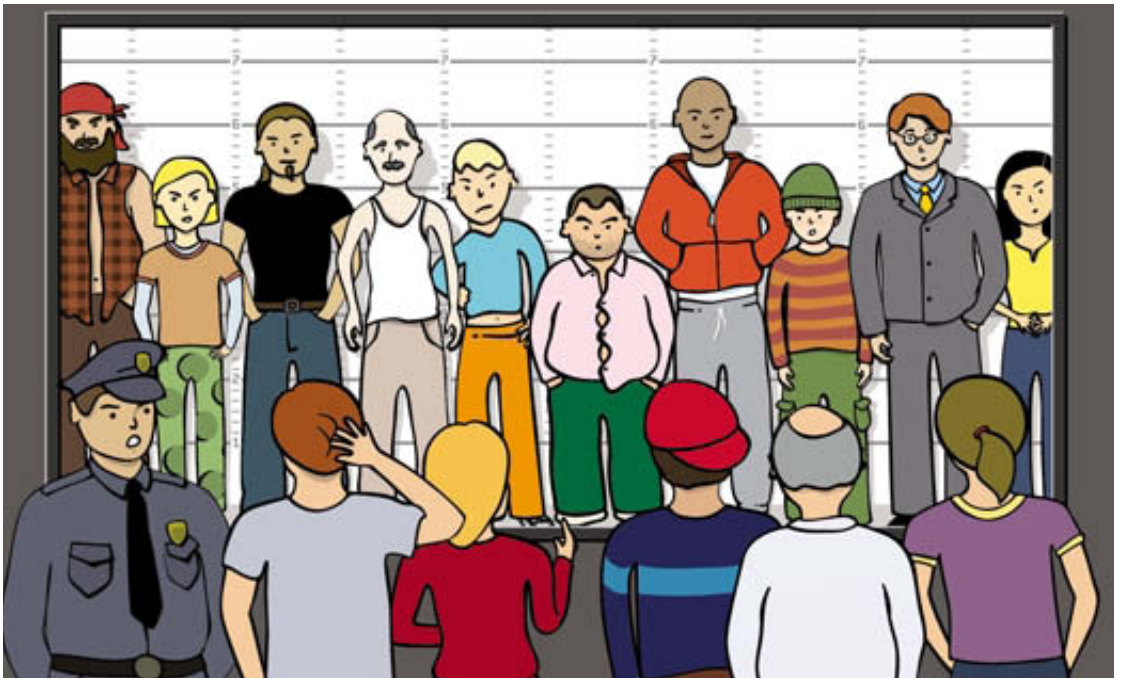
Suspect 1: All five vote that the suspect **has drugs**
Suspect 2: All five vote **has no drugs**
Suspect 3: Three vote **has no drugs,** and two vote **has drugs**
Suspect 4: All five vote **has drugs**
Suspect 5: Four vote **has drugs,** and one votes **has no drugs**
Suspect 6: All five vote **has no drugs**
Suspect 7: Three vote **has drugs,** and two vote **has no drugs**
Suspect 8: All five vote **has drugs**
Suspect 9: All five vote **has no drugs**
Suspect 10: Four vote **has no drugs,** and one votes **has drugs**

"Can you tell us which suspects have drugs given only that the total number of lies among all witnesses is exactly nine, and most of the lies claim 'has no drugs' when the truth is 'has drugs.' They are a corrupt bunch."

As a warm-up, what is the fewest number of lies there could be?

Solution to warm-up: Every nonunanimous vote (disagreement) must correspond to a number of lies at least equal to the minority view and perhaps the majority view. As we can see, there are four occasions of disagreement: three against two occurs twice, and four against one occurs twice. Adding up the minority views gives us six lies. SA

Dennis E. Shasha is professor of computer science at the Courant Institute of New York University.



SARA CHEN

Answer to Last Month's Puzzle

Five gunners are enough to search for a polar bear in the Arctic research center if the seven igloos are arranged in a planar graph. The reason: every such graph has at least one node with four or fewer neighbors (for a detailed explanation, go to www.sciam.com). The answer to the second question, in which 100 igloos are arranged in a rectangular grid, depends on the dimensions of the rectangular grid. The worst case is that the grid is a 10-by-10 square; 11 gunners are needed to search this grid. For any *m*-by-*n* rectangle (where *m* is less than or equal to *n*), $m + 1$ gunners are needed. They start at the *m* positions on the far left, with two gunners occupying the igloo at the bottom left corner. These two gunners advance to the igloo at their right; then one gunner retreats to the second-lowest igloo on the far left, and the process is repeated.

Web Solution

For a peek at the answer to this month's problem, visit www.sciam.com

Kabul Session

A SCIENCE PRIMER FOR ANY READERS WHO RICHLY DESERVE TO GET TAUGHT A LESSON **BY STEVE MIRSKY**

News media revealed last November that notes and textbooks were found in an abandoned house in Kabul that indicated that a member of the Taliban was pursuing various lines of scientific exploration. His level of expertise was judged to be at best that of an undergraduate student in chemistry and physics, which is still good enough to make stuff blow up. (Trust me. I was a chemistry major. I know.) Particularly shocking to the staff here at *Scientific American* was evidence that the Talibaner apparently read this magazine: his discarded notes included references to the so-called plasma jet, a propulsion system designed for lengthy space trips that was described in detail in an article entitled "The VASIMR Rocket," in the November 2000 issue.

If his research goal was indeed to lead the Taliban on a voyage away from Earth, well, more power to him. (With the headline on the December day I write this being "Taliban Flees Last Stronghold in Afghanistan," it would appear that many of them already took the trip, courtesy of the U.S. military.)

We must conclude, however, that he was in fact interested in using the scientific information contained in these pages for nefarious purposes. That people with bad intent read this magazine puts us in an awkward situation. Despite the potential for applications we deplore, we must continue to disseminate the most current and accurate scientific information we can, for the greater good. Therefore, the rest of this space will be devoted to the presentation of various basic facts designed to bring nasty newcomers to the study of science up to speed, which is different from velocity (and from me, because velocity has a direction).

- In Einstein's famous equation $E = mc^2$, the *mc* stands for the introduction of his guests for the evening.
- A watt is often the beginning of an interrogative sentence. Joules are what a nice sword is encrusted with. An erg is a desire.
- A cotyledon was a late Triassic dinosaur with a brain the size of a seed.
- 3.14159 is a large piece of pi.
- In computer language, binary code means that you *owe one.*
- Greenwich mean time refers to four in the morning, when the bars close in New York City's West Village.
- In electromagnetic energy, wavelength is defined as the speed of light divided by the frequency, Kenneth.
- Entomology is the other one; you're thinking of etymology.
- A Fourier transform is a mathematical manipulation by which a chinchilla turns into a coat.
- The Bernoulli principle describes a flow of air that forces Mrs. Bernoulli to sleep in the guest bedroom.
- Prime numbers are whatever Alan Greenspan says they are.
- Continental drift is when your limo wanders into oncoming traffic.
- The Nobel Prize is an award given for the year's best door knocker.
- The sine is the guy who gets a loan. The cosine is the guy who pays off the loan. The tangent is the guy in Rio who actually spends the money.
- Parthenogenesis is the creation of Greek architecture.
- Anthropology is when your uncle has to say he's sorry to his wife. (This actually happens in some places.)
- The hypotenuse is a type of syringe that holds 10 shots.
- A ramjet is anyone who played football for the Rams and the Jets. The most famous ramjet is Joe Namath, who was an expert in field theory.
- The force *F* with which you can pound something is equivalent to *m*, which stands for mallet, times *a*, which stands for the body part into which you should pound it.
- The phalanges is a mighty river. The metatarsals are pouch-bearing mammals. And the humerus is working as hard as he can. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

If nothing sticks to Teflon, how does it stick to pans?

—James Peterson, South Beloit, Ill.

Andrew J. Lovinger, director of the polymers program at the National Science Foundation, offers this explanation:

Teflon is a trademark of Du Pont for a plastic material known as polytetrafluoroethylene. The secret to Teflon's slick surface lies in the fluorine enveloping its molecules. These fluorine atoms repel almost all other materials, preventing them from adhering to Teflon.

We can use two techniques to make Teflon stick to the surfaces of items such as pots and pans. The first is sintering, a process similar to melting, in which Teflon is heated at a very high temperature and pressed firmly onto a surface. When the material cools down to room temperature, however, chances are it will eventually peel away. Chemically modifying the side of Teflon that you want to have "stick" yields better results. By bombarding it with ions in a high vacuum under an electric field, or plasma, we can break away many of the fluorine atoms on the surface that we want to make sticky. We can then substitute other atoms, such as oxygen, that adhere strongly to surfaces.

Though perhaps best known as a cookware coating, Teflon has a wide range of applications, from insulating data communications cables to repelling water and stains from clothing and upholstery.

Why are planets round?

—K. Schumacher, via e-mail

Derek Sears, professor of cosmochemistry at the University of Arkansas and editor of the journal *Meteoritics and Planetary Science*, provides an answer:

Planets are round because their gravitational field acts as though it originates from the center of the body and pulls everything toward it. With its large body and internal heating from radioactive elements, a planet behaves like a fluid, and over long periods it succumbs to the gravitational pull from its center of gravity. The only way to get all the mass as close to a planet's center of gravity as possible is to form a sphere, a process called isostatic adjustment.

With much smaller bodies, such as asteroids, the gravitational pull is too weak to overcome the asteroid's mechanical strength. As a result, these bodies do not form spheres. Rather they maintain irregular, fragmentary shapes. SA

For the complete text of these and many other answers from scientists in diverse fields, visit Ask the Experts online (www.sciam.com/askexpert).

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