THE SCIENTIFIC AMERICAN 50
CELEBRATING THE YEAR'S TOP TECHNOLOGY LEADERS

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On Thin Ice

Antarctica's Ice Is Breaking Up, But Don't Panic Yet

BRIGHT BIRTHS OF
BLACK HOLES

DIETS FOR
EVOLVING BRAINS

POLLOCK'S
GENIUS FOR CHAOS

The Enigma of
HUNTINGTON'S
DISEASE

december 2002

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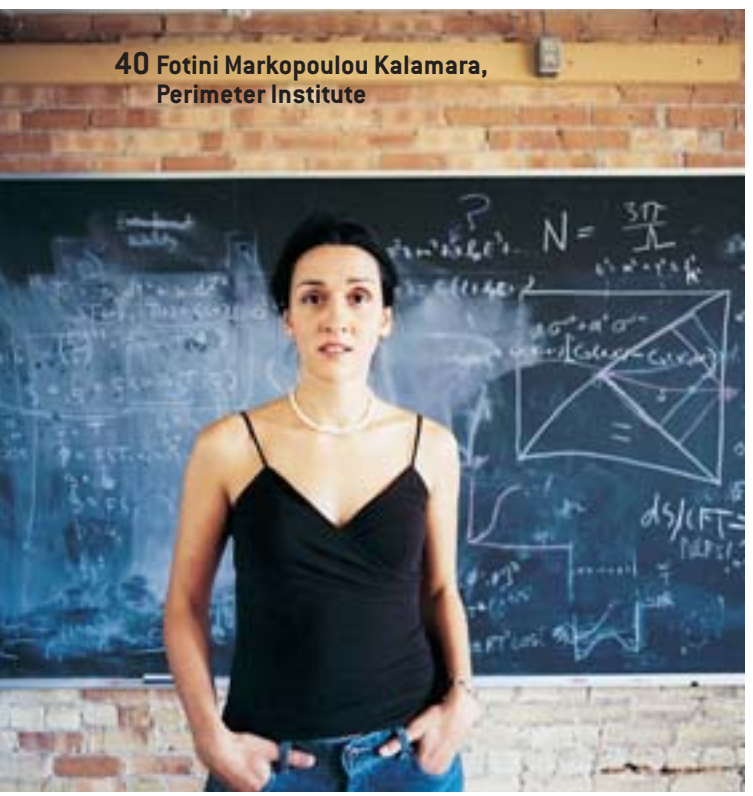

40 Fotini Markopoulou Kalamara, Perimeter Institute

columns

Cover photograph by Gary Buss *GettyImages*

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In Science We Trust

As a year for science, 2002 was marked by many wonderful accomplishments, and our inaugural listing of the Scientific American 50, beginning on page 43, celebrates dozens. But much of the public may also remember the year for blemishes on the scientific record: prominently among them, the fraud of a physicist working on semiconductor technology, the withdrawn discovery of element 118, a reversal on the wisdom of hormone replacement therapy for many postmenopausal women, and conflicting recommendations about dietary fat.

Flip-flops, scandals and overblown headlines can erode confidence in science's authority as a source of truthful information. Society, as much as research, suffers when citizens and policymakers start discounting the good science along with the bad.

Inevitably, scientists will sometimes be just plain wrong—they make mistakes. Interpretation of evidence leaves room for error. Moreover, scientists aren't saints. They can be swayed by careerism, by money, by ego. Biases and prejudices can blind them. As individuals, they are no more or less flawed than those from any other walk of life. Over time, however, science rises above narrow interests and corrects itself more reliably than any other institution through such practices as the open publication of results and methods.

All scientific knowledge is provisional. Everything that science "knows," even the most mundane facts and long-established theories, is subject to reexamination as new information comes in. The latest ideas and data are the most provisional of all. Some recantations will be unavoidable. This is not a weakness of science; this is its glory. No endeavor rivals science in its incremental progress toward a more complete understanding of the observable world.

Announcements of discoveries in professional journals always qualify and quantify their certainty; announcements in the general media often do not, because nonspecialists usually lack the background to interpret them. To the extent that researchers or journalists imply that news represents unchanging truth, we are to blame for the public's confusion over scientific reversals. But *caveat lector,* too: sensible readers must recognize that summaries of science will leave out potentially important details.

Unfortunately, the job of educating the public is made all the harder by those looking to exploit the holes in science. "You see?" they argue. "These scientists don't really know what they're talking about. They're pushing a self-serving agenda. They don't even really agree among themselves, so you are free to believe what you like." Thus, global-warming skeptics write off the consensus of climate research investigators, emphasizing the uncertainties in others' reasoning but not in their own. Anti-evolutionists harrumph about the incompleteness of the fossil record, but the handful of neo-creationist academics they praise have only wisps of evidence and incoherent theories.

How should the public weigh the recommendations of scientists? The greatest mistake is to wait for 100 percent scientific certainty or agreement, because it will never materialize. Conclusions vetted by the professional community might turn out to be wrong, but they generally represent the best-supported views currently available. People are free to disregard those views, but they shouldn't delude themselves that they are being more reasonable by doing so. Perfect certainty belongs only to the gods. The rest of us have to make do with science, imperfections and all.

THE EDITORS editors@sciam.com

LARRY LIMNIDIS *Gettyone*

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Letters

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STORIES ABOUT SPACE seem to exert a gravitational pull on letter writers, and those in the August 2002 issue were no exception. "Does Dark Matter Really Exist?" by Mordehai Milgrom, for one, inspired passionate reactions to his theory of Modified Newtonian Dynamics (MOND). "After reading Milgrom's article on MOND, the most likely alternative to much of the dark matter," one writer enthused, "I vow never to let my subscription to *SA* expire!" Another—perhaps echoing a different Newtonian principle—offered a strong opposing reaction (more on that below). Michael Shermer's look at *L*, the lifetime of communicating extraterrestrial civilizations, in "Why ET Hasn't Called" [Skeptic], drew a meteoric shower of replies. But "Crop Circle Confession," by Matt Ridley [News Scan], seemed to rouse little more heat than an everyday solar flare.

COMBATING TERROR

A year after September 11, the Pentagon is rebuilt. The Ground Zero site is cleared, and plans for a memorial and the redevelopment of Lower Manhattan have begun. But the terror of terrorism has longer-lasting implications than physical destruction alone. "Combating the Terror of Terrorism," by Ezra S. Susser, Daniel B. Herman and Barbara Aaron, illustrates the gravity and diversity of threats to mental health, for which we are not, as yet, prepared.

As the Congress considers measures necessary to prevent and prepare for future attacks, it is important that we develop a public health infrastructure capable of treating the psychological consequences of terrorism. Last year I introduced the Extended Disaster Mental Health Services Act, which will strengthen our communities' ability to respond to the psychological impact of terrorist attacks and other disasters. This bill will dedicate funding for disaster mental health services, help states develop disaster mental health plans, establish a National Mental Health Crisis Response Technical Assistance Center and provide training for mental health professionals.

As we struggle to cope with the less visible, yet still devastating, consequences of terrorism, I am grateful to *Scientific American* for drawing critical attention to this important issue.

Patrick J. Kennedy
U.S. Representative of Rhode Island
Washington, D.C.

PLANKTON AND CLIMATE

Paul G. Falkowski's article "The Ocean's Invisible Forest" and its description of phytoplankton's potential to remove significant amounts of atmospheric carbon raised an unanswered question. A limiting factor cited is the amount of dead cells that can be expected to settle out of the short-period carbon cycle. Could a coagulating agent be used?

Nathan Webb
Mississauga, Ontario

FALKOWSKI REPLIES: Such an approach would seriously alter the ecological structure of the upper ocean and, moreover, would be ineffective. If phytoplankton sank faster because of a coagulating agent, the upper ocean would become nutrient-depleted; organic matter sinks at a rate roughly equal to that of nutrients being supplied to the upper ocean. Last, fundamentally, carbon sequestration by oceanic phytoplankton is limited by nutrients such as iron.

PERPETUAL MOTION AND MOND

Mordehai Milgrom's theory of Modified Newtonian Dynamics, MOND ["Does Dark Matter Really Exist?"], holds an ideal promise of solving the energy crisis: the replacement for Newton's second law can be used to violate the conservation of energy. In an apparatus in which a mass oscillates, it would be possible to extract energy on each cycle by ensuring that the mass accelerates slowly, requiring less than the Newtonian force, but decelerates quickly, returning all its kinetic en-

ergy (somewhat the same way my father drives his car). Running in reverse, the apparatus could be used as an energy sink. Just think of the applications!

Christopher P. Hamkins
Worms, Germany

MILGROM REPLIES: I was very proud to see the first attempt to design a perpetual-motion machine based on MOND, after so many failed attempts with Newtonian dynamics. I am afraid, however, that neither of us will get rich from this. As you say, one of the first things to check with a new theory of dynamics is conservation of energy, and I can assure you that it has been done. The detailed theory—which was beyond the scope of the article—is fully energy conserving (as well as momentum and angular-momentum conserving). In fact, technically one can ensure this from the start by constructing the theory on the basis of a principle of least action, which has been done in this case.

NOT DEAD YET

"Saving Dying Languages," by W. Wayt Gibbs, has the defeatist tone of so much journalism about this topic, which suggests that the "dying" is inevitable and, by inference, not worth the time, energy or resources to reverse. Of course, there are projects to document and promote languages of indigenous peoples; the author mentions a few. He ignores, however, one of the most significant recent efforts: Ontario's Aboriginal Language Standardization Project. Between 1993 and 1998 the government of Ontario funded language planning conferences and language development programs, as well as dictionaries and grammars in Ontario's 12 Aboriginal languages. The fruits of this initiative have already started to appear: language conference proceedings for Mohawk, Omushkego Cree and Nishnaabemwin; bilingual dictionaries in Delaware, Oneida and Tuscarora; a reference grammar in Nishnaabemwin.

More are on the way. Language preservation is doable. It's time to focus on what can be—and is being—done, rather than reinforcing negative perceptions.

John Stanley
Toronto

Different languages are a menace to a friendly world.

Mary C. Thomas
Garden Grove, Calif.

PATIENTS AND PAIN

Your recommendation in "A Real Pain" [SA Perspectives]—that weighing the risks and benefits of pain control should ultimately be the province of the patient—sounds simple, but the implications are massive. Is the physician absolved of responsibility for the results of the patient's choice? Not in this society. As long as the physician is held responsible, ultimate province will be solely his.

Edward Joganic
Phoenix, Ariz.

You mentioned the "silver bullet" of anesthesia for simple but painful procedures: nitrous oxide. Nitrous oxide is quick-acting, and its effects disappear almost instantaneously when it's turned off. Yet emergency rooms don't use it. The reason: there is a universal fear of staff abuse.

Richard C. Mallyon
Lancaster, Calif.

NUMBER, PLEASE?

In "Why ET Hasn't Called" [Skeptic], Michael Shermer finds it "perplexing" that there is a controversy about the term "lifetime of communicating civilizations" in the Drake equation. He calculates an average lifetime of 420.6 years from a database of 60 Earth civilizations.

Unfortunately, he calculates the wrong number. In the Drake equation, L must account for the total lifetime of all such civilizations at a given star. If a civilization falls and a new civilization follows, the combined durations of both civilizations, not just one, is the relevant lifetime L. (For completeness, I should note that for Earth this will include not only the sum of human civilizations but also any radio-communicating nonhuman societies that may emerge on the planet following the extinction of human civilizations.)

Geoffrey A. Landis
NASA John Glenn Research Center
Cleveland, Ohio

SHERMER REPLIES: It is not "civilization" that becomes space-faring (and communicating), it is "a civilization"—a political entity—that must convince its citizenry to pay for such a program, which is not cheap. It is entirely conceivable that civilization as a whole may succeed on a planet for tens, if not hundreds, of thousands of years without a particular political unit ever lasting long enough to succeed in making contact with a species on another planet. And the shorter the lifetime of any particular communicating civilization, the lower the probability of its ever making contact. Given the history of civilizations on Earth—the only data we have to calculate L*—that probability appears to be rather low.*

LIVING LONGER—TOO MUCH LONGER

With all the enthusiasm shown by Mark A. Lane, Donald K. Ingram and George S. Roth for attempting to prolong human life artificially in "The Serious Search for an Anti-Aging Pill," I look forward to their next article, in which they explain how to provide for these years with an improved Social Security system and other (now decaying) retirement plans. How will these octogenarians-plus be assimilated into an overcrowded world? As a 77-year-old, I would rather let nature take its course.

Eugene Kosso
Gualala, Calif.

ERRATUM The diatom in the opening photograph of "The Ocean's Invisible Forest," by Paul G. Falkowski, is misidentified as *Actinocyclus sp.*; it should be *Arachnoidiscus sp.*

IRAIDA ICAZA

50, 100 & 150 Years Ago

FROM *SCIENTIFIC AMERICAN*

Fishy Sex ▪ Expensive Scenery ▪ TB Plague

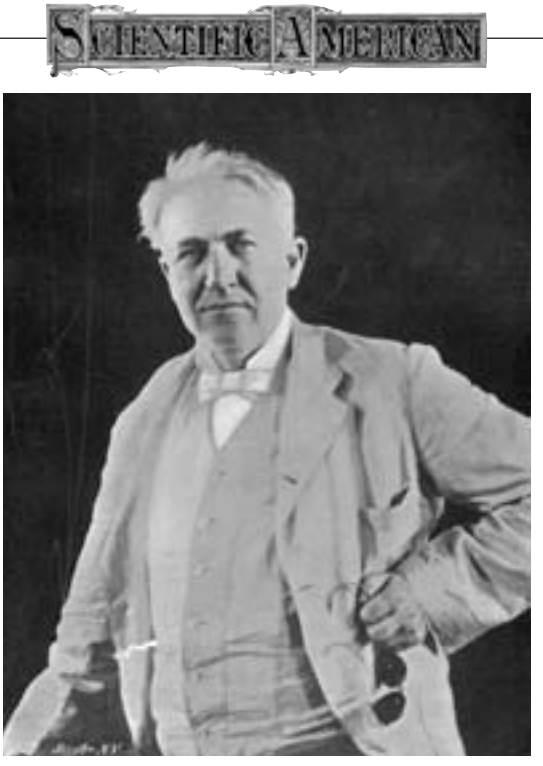
DECEMBER 1952

CURIOUS BEHAVIOR OF STICKLEBACKS—"The sex life of the three-spined stickleback (*Gasterosteus aculeatus*) is a complicated pattern, purely instinctive and automatic, which can be observed and manipulated almost at will. One result that is now beginning to emerge from the stickleback experiments is the realization that mammals are in many ways a rather exceptional group, specializing in 'plastic' behavior. The simple and more rigid behavior found in our fish seems to be the rule in most of the animal kingdom. One therefore expects to find an innate base beneath the plastic behavior of mammals. Thus the study of conflicting drives in so low an animal as the stickleback may throw light on human conflicts and the nature of neuroses. —N. Tinbergen" [*Editors' note: Nikolaas Tinbergen won the 1973 Nobel Prize in Physiology or Medicine for research in social behavior.*]

POTATO HISTORY—"It is in Ireland, the classic land of the potato, that one finds the clearest evidence of the influence which a cheap, nutritious foodstuff can exercise on a society. The potato reached Ireland around 1588. Through the next centuries, how often we hear the potato spoken of as the lifeline of the people, the trusted bulwark against ever-recurring failures of the cereal crop! In the early 19th century, failures of the potato crop led many to warn the government and the people against undue reliance on the potato. It was too late: in 1845 and 1846 came the total destruction of the potato crop by the previously unknown fungus *Phytophthora infestans,* and the Great Famine followed. —Redcliffe N. Salaman, author of 'The History and Social Influence of the Potato' "

DECEMBER 1902

THOMAS ALVA EDISON—"With the commercial introduction of a radically new type of storage battery, public attention is again drawn to the man who has done more than any other in our time to apply electricity to the needs of every-day life. There is not an electrical instrument, or an electrical process now in use, but bears the mark of some great change wrought by the most ingenious of Americans [*see illustration*]. 'Genius is two per cent inspiration and ninety-eight per cent perspiration' is the incisive, epigrammatic answer Edison once gave."



THOMAS ALVA EDISON: Inventive genius, 1902

THE VALUE OF SCENERY—"The value of waterfalls has greatly increased since the electrical era, says the Mining and Scientific Press. Time was when a cataract was valuable only for scenic purposes, but now it is useful as well as ornamental. Niagara is worth one thousand million dollars more as a source of electrical power than merely as a sight."

JAPAN ON AMERICAN PATENTS—"Some three years ago the Japanese government sent to this country a certain Mr. Takahashi to study our patent system. Mr. Takahashi pays a glowing and picturesque tribute to the American system. 'We saw the United States not much more than one hundred years old,' he said, 'and we asked, 'What is it that makes the United States such a great nation?' We investigated, and found it was patents, and so we will have patents [in Japan].' "

DECEMBER 1852

WIDESPREAD TUBERCULOSIS—"Consumption is the most prevalent disease in Britain, the New England States of America and nearly the whole of New York State; the young and the lovely are its victims. It spares no rank, yea, rather those who are blessed above others, and more exempt from common troubles on account of their wealth, are more often the victims than the children of the poor. Dr. Burnett, of Boston, attributes the prevalence of consumption in the New England States to the intemperate changeable climate, the tendency of which is to produce disease in the pulmonary organs."

VOLCANOES—"The almost universal opinion expressed by writers on the subject is that water in some way is an active agent in all volcanic eruptions. Water, however, in all likelihood exerts no agency whatever; and a strong argument in proof of this, is, that in the moon there is neither atmosphere nor water, and yet the volcanoes of the earth are mere dwarfs compared with those on our satellite."

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POLICY

Under the Microscope

WILL "SOUND SCIENCE" WEAKEN THE ENDANGERED SPECIES ACT? BY DANIEL G. DUPONT

RIVER OF DEATH: A decision based on a National Research Council report may have killed tens of thousands of salmon in the Klamath River in September.

RON WINN/THE HERALD AND NEWS *AP Photo*

The Endangered Species Act (ESA), now nearly 20 years old, remains one of the more controversial pieces of legislation ever enacted by Congress. To many, it is the most important and noblest environmental law on the books; to others, it is among the most onerous. Nearly 1,300 plant and animal species are listed under the act as either endangered or threatened in the U.S., and powerful legal tools are at the disposal of government agencies in charge of protecting them and their habitat. But the use of a number of those tools depends on scientific evidence—the proof in the pudding of the ESA and, lately, the subject of much debate.

Critics of the ESA have long maintained that the act's language makes it too easy for a species to get onto the list; they point to its requirement that such decisions be made "solely on the basis of the best scientific and commercial data available." No elaboration on the meaning of this crucial phrase is included in the law or in relevant agency regulations, leaving tremendous room for argument.

In June the debate over science and the ESA took voice before the U.S. House of Representatives's Resources Committee, which met to discuss a bill called the Sound Science for the Endangered Species Act Planning Act of 2002. Supported by Representative James V. Hansen of Utah, the committee chairman, the legislation was crafted to give greater weight to "empirical" or "field-tested" data in making listing decisions. That revision would result in more stringent standards for listing and, when it comes to habitat protection, give landowners more leeway. Hansen called the bill the "first step in fixing" the ESA by ensuring the use of "sound science through peer review."

But what, exactly, constitutes sound science? The Council of State Governments defines it as "research conducted by qualified individuals using documented methodologies that lead to verifiable results and conclusions." But such research may be hard to come by, as two Congressional Research Service analysts point out in a July report: that the species in question are likely to be rare means "there may be little or no information" to be had about them. Moreover, funds for their study could be scarce. Arguing against the bill's attempt to give greater weight to field-tested data is William T. Hogarth. The National Oceanic and Atmospheric Administration's assistant administrator for fisheries says other sources, such as computer models and statistical analyses, are just as important and go "hand in hand" with empirical data.

Hansen's belief that peer review leads to sound science is shared by many legislators, who in recent years have proposed bills that would basically poll scientists for their opinion. But this practice raises questions, too. As the Congressional Research Service report notes, "There may be few (or no) people in the world knowledgeable about some species," and those who are may not be able or willing to participate in peer reviews.

The Pacific Northwest has become the heart of the debate regarding sound science. In 2001, an acute drought year in the region, nearly all the water in the Klamath River Basin was allocated to the river to protect endangered Coho salmon and to Upper Klamath Lake to preserve two species of endangered suckerfish—at the expense of irrigation-dependent Oregon farmers. But in February 2002 a National Research Council report concluded that there was no sound scientific evidence that the increased lake and river levels benefited the fish. So this summer the farmers got their water.

Advocates of stricter scientific requirements point to the initial decision to divert water for the salmon and suckerfish as one of the more glaring examples of an ESA move based on faulty science. Making it harder to prove a species is endangered, they argue, will protect the interests of those who stand to lose if those species are listed and must be protected. Then, in the fall, upward of 30,000 (mostly chinook) salmon died in the lower stretches of the river in one of the worst fish kills ever in the Northwest. Although no one agrees on a definitive cause, some have attributed the deaths to the drop in water caused by diverting the flow to farms.

The sound science act was approved by the Resources Committee in July, but it went no further, as homeland security and the upcoming elections steered congressional debate elsewhere. Those elections, however, may dictate a stronger challenge to the ESA in the next Congress. Robert Irvin, the director of U.S. programs at the World Wildlife Fund, says, "It's a perennial effort for critics of endangered species protection to argue that the implementation of the act is not based on sound science." And such moves, he contends, are often used as "smoke screens for efforts to weaken the ESA."

Daniel G. Dupont is a frequent contributor based in Washington, D.C.

SOURCES FOR SOUND SCIENCE

The U.S. Fish and Wildlife Service and the National Marine Fisheries Service say that a wide variety of information sources, including peer-reviewed studies and oral or anecdotal data from individuals, should be consulted in making decisions related to the Endangered Species Act. An FWS handbook states that when a biological opinion must be rendered promptly, it should be based on the best available information, "giving the benefit of the doubt to the species."

BONE HOIST: A U.S. Army Chinook helicopter lifts out dinosaur fossils from what may be one of the densest beds ever discovered.

SONYA SENKOWSKY

PALEONTOLOGY

Cretaceous Park

CACHE OF DINO FOSSILS TURNS UP IN AN ARCTIC RESERVE **BY SONYA SENKOWSKY**

From a bluff-side vantage point 500 feet above the braids and twists of Alaska's Colville River, we notice that a line of brush along a distant gravel bed is, in fact, moving. "Caribou," someone says—hundreds of them, in fact, surging along the river in an improbably large, swirling mass. For expedition leader Anthony R. Fiorillo, it's enough to prompt a paleontological daydream: What if, 70 million years ago, a similar grouping of dinosaurs had passed this way? And what if those dinosaurs had met with a sudden, mass death, as caribou sometimes do? That might explain the bonanza of horned dinosaur fossils in the tundra underneath our feet—possibly the densest concentration of saurian fossils in the world.

Fiorillo—curator of earth sciences at the Dallas Museum of Natural History—first brought his team to this remote, roadless spot on the edge of the National Petroleum Reserve above the Arctic Circle to recover the skull of a type of horned dinosaur known as a pachyrhinosaurus, or "thick-nosed dinosaur," a member of the family Ceratopsidae. It didn't take much digging to realize that fossilized dinosaur bones were nearly as ubiquitous here as the Arctic's summer sun. By expedition's end, the team members, also from the University of Alaska–Fairbanks and South-

ern Methodist University, had turned up evidence of eight pachyrhinosaurs from a quarry not 50 feet square.

Paleontologists were aware of the dinosaur bone area, named the Kikak-Tegoseak bed, but not its remarkable density. Previously Alaska's horned dinosaurs have been discovered one at a time. "Finding that many skulls [of] ceratopsians stacked one on top of another is a pretty unusual situation," says Roland Gangloff, expedition organizer and curator of earth sciences at the University of Alaska Museum, a sponsor of the expedition. Gangloff and his colleague David W. Norton, operator of Arctic Rim Research in Fairbanks, first found the site in 1994, after following a trail of bone fragments from the river's edge up a sheer, eroding bluff.

This year's discovery of eight individuals makes the site the largest collection of ceratopsians ever found above the Arctic Circle. "It's probably a huge bone bed," Fiorillo says, "and we're looking at a little, tiny part of it." Gangloff goes further, adding that the entire Colville region "will someday be recognized worldwide as one of the greatest dinosaur fossil accumulations in the world." The full size of the find remains to be seen.

This summer's excavation was limited by time, manpower and the rigors of working on isolated tundra. Reaching the bed required daily climbs up a mud-slicked bluff. Work was also slowed once by a midnight visit from a bear. Such rugged conditions meant in the past that many fossils went uncollected. But this year heavy-lifting Chinook helicopters and the cooperation of the U.S. Army made the extrications possible.

Fiorillo's team retrieved parts of at least three skulls and other skeletal material, including leg bones, ribs and vertebrae, much of it so jam-packed that researchers were finally forced to set aside delicate tools for pickaxes and to sacrifice surrounding bone to retrieve a reasonable sample.

Among the assortment were eight bones that looked like boccie balls. These occipital condyles—distinctive, spherical bones characteristic of ceratopsians—were part of the ball joint that supported the horned dinosaur's weighty head. Each condyle discovery represents another skull—and, most likely, skeleton—lying below the earth, Fiorillo concludes. His preliminary examination suggests that the Arctic pachyrhinosaurs were close in age and probably died together in a catastrophe, such as a flood. It provides the first evidence that horned dinosaurs north of Alberta, Canada, behaved gregariously.

"We've been waiting for this for some time," says ceratopsian expert Peter Dodson of the University of Pennsylvania, referring to Fiorillo's find, which has yet to be published in a scientific journal. Although horned dinosaur remains have previously been found in the Arctic, Dodson notes, "we had not really learned very much other than that they were present." Now, he remarks, "we're going to learn something definitive."

Sonya Senkowsky, a writer based in Anchorage, was also a volunteer on the expedition.

HEADING NORTH FOR DINOSAURS

The Kikak-Tegoseak site, between 69 and 70 degrees north latitude, lies about 20 miles from where Shell Oil geologist Robert Liscomb found the region's first dinosaur bones in 1961. Liscomb died in a rock slide the next year, and his discovery went unnoted for decades. Paleontologists finally confirmed in the mid-1980s that dinosaurs were in the Arctic.

The unprecedented opportunity to examine a group of Arctic horned dinosaurs could also answer questions about how high-latitude dinosaurs adapted to the Cretaceous Arctic. (The climate was more temperate then, similar to weather today in southern Alberta, Canada.) It will also add to a picture of how all dinosaurs responded to climate change.

IMMUNOLOGY

Subduing Suppressors

SILENCING CERTAIN IMMUNE CELLS COULD DEFEAT DISEASE **BY LISA MELTON**

For decades, scientists have tried to manipulate the immune system to fight disease, but finding the right tools to crank up or slow down immune cells hasn't been easy. Now immunologists may have finally struck gold, in the form of a white blood cell known as a regulatory, or suppressor, T cell. Such cells are the levers that quiet the immune system. Keep them subdued, some scientists predict, and it soon will be possible to wipe out intractable pathogens that cause hepatitis C, HIV/AIDS and tuberculosis and even annihilate cancer cells.

Numerous laboratory studies in the 1970s

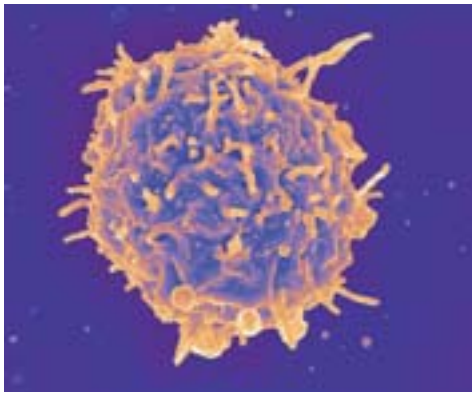
proved that suppression existed; unfortunately, there was nothing to distinguish these cells from other, similar T cells in the body. And because the experiments were hard to reproduce, immunologists eventually gave up on the idea.

Until 1996, that is, when Shimon Sakaguchi of Kyoto University in Japan showed that regulatory cells are normally present in the body as a type of CD4 T lymphocyte (also known as a helper T cell). Crucially, Sakaguchi also found a common identification tag: the CD25 molecule. Nobody yet understands exactly how suppressor cells work, but they protect us from autoimmune diseases by stifling harmful, self-reactive cells.

When it comes to fighting off tumors or chronic infections, however, the influence of suppressor cells is detrimental. "In immunology it's always a question of balance," observes Ethan Shevach of the National Institutes of Health. "In certain situations, it might be better to get rid of them." In chronic infections, for example, "microorganisms may be using T suppressor cells as a window of escape," says Kim J. Hasenkrug of the NIH Rocky Mountain Laboratories in Hamilton, Mont. Indeed, in many viral and bacterial infections, the number of suppressor T cells skyrockets—evidently they take the bite out of killer T cells designed to destroy invaders. The trick is to silence regulatory cells and thereby tip the balance to killer cells.

To test different tactics, Hasenkrug infected mice with the Friend leukemia virus, which leads to high numbers of suppressor cells. Using antibodies that block TGF-beta and IL-10 receptors—molecules that regulatory cells need to do their job—proved a winning strategy. The number of CD25 cells plummeted, and mice regained their ability to reject tumors. In skin infections with the parasite *Leishmania major*, Shevach has had similar results using an antibody that depletes CD25 cells.

In the clinic, however, the ideal is to restrain suppressor cells, not eliminate them. Sakaguchi has developed a monoclonal antibody that can manage just that. Rather than deplete the cells, the antibody blocks their function by locking onto a molecule on their surface called glucocorticoid-induced TNF receptor (GITR). This past July at a Novartis Foundation meeting in London, Sakaguchi reported that when mice bearing tumors were injected with anti-GITR, the invigorated immune response shrunk the tumors. "The animal data are very promising, and pharmaceutical companies are pursuing this molecule intensively," he noted.



REGULATORY T CELL—this one retrieved from a mouse—controls the initiation of immune responses.

Some researchers are trying to find out if cancer patients might benefit from silencing suppressor cells. "It is an attractive hypothesis, but we don't know yet," says Jacques Banchereau of the Baylor Institute for Immunology Research in Dallas. In a small clinical trial involving advanced melanoma, Banchereau found that vaccines made from patients' own dendritic cells loaded with bits of tumor protein triggered an immune response to the tumors. The results are dramatic: of the 10 patients injected, nine remained free of disease for 10 weeks, and four are still alive nearly four years after treatment. In other experiments, "we have seen skin, liver, brain and lung tumors disappear," Banchereau claims. "It's something amazing to do with regulatory cells," he thinks, though for the moment, he is unwilling to give away the details.

It may take a while before such intensive research pays off. "In immunology, we understand a great deal, but unfortunately the number of drugs that have emerged from that understanding is rather small," Shevach acknowledges. But if the 30 years of ignominy are taken into account, then the time may be ripe for regulatory T cells to take center stage.

Lisa Melton, based in London, did her postdoctoral work in immunology during the "dark ages" for suppressor cells.

VACCINES THAT FIT TO A "T"

Vaccines would also benefit from having fewer regulatory T cells kicking about. "When you have a suboptimal vaccine, it would be great to get rid of CD25 cells, at least temporarily," points out Ethan Shevach of the National Institutes of Health. Many experimental vaccines, especially for HIV, malaria and mycobacterium tuberculosis, have not made it to the clinic, because they are not protective enough. Keeping the CD25 cells out of the picture would allow the immune system to mount a vigorous response.

DAVID W. DORWARD AND RONALD J. MESSER *NIH Rocky Mountain Laboratories*

ANTHROPOLOGY

Parched Turf Battle

DID CLIMATE CHANGES CAUSE CIVILIZATIONS TO COLLAPSE? BY DANIEL GROSSMAN

The largest drought in the past 12,000 years occurred about 2200 B.C., according to an October 18 *Science* report by Ohio State University geologist Lonnie G. Thompson. The result, part of a study of ice cores drilled in a glacier on Mount Kilimanjaro, made Harvey Weiss ecstatic: the archaeologist from Yale University has been saying for years that a scorching drought around that time was so extreme that it toppled civilizations from Egypt to India. But he couldn't convince fellow ancient historians of his theory. The Kilimanjaro work, along with several other recent studies, supports Weiss's ideas and heats up the debate on climate's role in shaping civilizations.

DRIED OUT: Did drought drive Mayans from their homes and structures, such as this one in Edzna, Yucatán?

For decades, the dominant view has been that cultural factors—war, religion, trade, palace intrigue—explain civilizations' ups and downs. According to this view, if the climate changes, humans adapt. "People cope with remarkable tenacity," explains Karl W. Butzer, an archaeologist and geographer at the University of Texas at Austin.

Now the pendulum is swinging back to an earlier view that emphasizes geophysical factors. The shift is fueled in part by discoveries about the climate since the end of the last ice age, a period known as the Holocene. In 1988 the U.S. began drilling in Greenland to retrieve what would be one of the deepest ice cores ever. The ice and gases trapped in it preserved clues about the climatic conditions dating back thousands of years. The Greenland core proved definitively what earlier ice and sediment cores had intimated—that the Holocene's climate was wracked by abrupt changes in temperature and aridity. The discovery encouraged researchers to seek detailed regional climate information by drilling sea and lake sediment and glacier cores around the world. Archaeologists began matching up important transitions in civilizations with these climate records.

University of Chicago anthropologist Alan L. Kolata discovered one such match. In the early 1990s he realized that an ice core from a South American glacier substantiated his theory that the Tiwanaku civilization on the shores of Lake Titicaca was destroyed by drought. The core, drilled in the Quelccaya ice cap, Peru's largest glacier, showed a 300-year stretch of low precipitation beginning around A.D. 1100, right when Tiwanaku cities were abandoned. In his recent book, *The Great Maya Droughts: Water, Life, and Death,* Richardson B. Gill proposes that the inhabitants of the Classic Maya civilization either died of starvation or migrated elsewhere during a series of brutal droughts between A.D. 800 and 1000. His claim was bolstered by University of Florida geologists who have found evidence in Yucatán lake sediments that during this period the region had less rain than at any time in the previous 7,000 years.

But many researchers are unwilling to cast climate in a starring role again. "It's a terribly simplified way of looking at what's going on," Butzer insists. To him, the "complex web of social interactions," like the trading of goods, explains the evolution of civilizations. David Webster, a Maya expert at Pennsylvania State University, calls climate theories like Gill's and Kolata's "a fad." He instead traces changes in Mayan culture to the incompetence and extravagance of kings and nobles in an empire stressed by explosive population growth and destructive wars. "Humans crave simple answers," Webster says of climate proponents. But "the facts of history are so complicated you can't come up with a nice, satisfying, simple explanation."

Gill, an unaffiliated Ph.D. archaeologist, responds that in the case of the Maya, a simple explanation is all you need. People must have water to grow food. And where surface water supplies are unreliable, extended droughts can be catastrophic. "I have seen with my own two eyes the devastating effects of drought as a 12-year-old," remarks Gill, who grew up in central Texas in the 1950s during the state's worst drought in generations.

Researchers who stick to cultural explanations also criticize climate researchers who

BRAVING THE ELEMENTS

The idea that physical factors such as climate dictate human history dates back a century. In 1909 geographer Ellsworth Huntington led a Yale University expedition to Palestine to study past societies, and during the next several decades he wrote many influential books. In *World-Power and Evolution* he concluded that "the evolution of man's ancestors ... was largely guided by climatic environment." Although the sentiment influenced a generation of social scientists, Huntington's theories were for the most part in error. Formulating his theories before carbon dating and ice or sediment core analyses, Huntington could only guess at the dates of key events and had no reliable way to estimate past precipitation or temperature. By mid-century Huntington's environmental conjectures fell out of favor, replaced by the idea that cultural factors molded the course of ancient civilizations.

SEF/ART RESOURCE, NEW YORK

provide the fodder for proponents and who sometimes co-author anthropology papers. Butzer questions whether they understand the complexity of cultural change. "They're like a fish out of water," he says. "They should keep their mouths shut."

Michael E. Moseley, an archaeologist at the University of Florida, is certain that climate will continue to figure prominently in research on human history. "It will probably take another 10 to 15 years for younger people who are not so indentured to old ideas for this to shake out," he says. Yale's Weiss is less diplomatic: "Science changes one funeral at a time."

Daniel Grossman is a writer and radio producer based in Watertown, Mass.

HISTORY OF SCIENCE

Mendelmania Takes Off

THE OSTRACIZED FATHER OF GENETICS FINALLY GETS HIS DAY **BY LUBA VIKHANSKI**

Every high school biology student learns of Gregor Mendel and his classic studies of inheritance. As the importance of genetics soared in the 20th century, so did Mendel's fame—except in his homeland. He was blacklisted in the former Soviet Union and its satellites as the founder of a "reactionary" discipline, and Mendelian genetics was declared a pseudoscience. Only now are efforts under way to pay him fitting tribute in the city in which he lived and worked all his adult life.

An Augustinian monk and later abbot at the Abbey of St. Thomas in Brno—once in Austria-Hungary, today part of the Czech Republic—Mendel revealed the laws of inheritance by experimenting with pea hybrids in the walled monastic garden. His 1866 paper, rediscovered around 1900, well after his death, laid the foundations for contemporary genetics. The notion that traits are inherited, however, ran afoul of Stalin and other Communist leaders; they advocated Lysenkoism, which claimed that acquired traits, rather than genetic ones, were passed on. Even after Lysenkoism was condemned as a fraud in 1965, Mendel remained an outcast because his religious background offended the Communist Czech goverment, which would last until 1989.

"Starting in 1990, I tried to put forward the idea of commemorating him, but people were hesitant," says Emil Palecek, a professor at the Czech Academy of Sciences's Institute of Biophysics in Brno. "Though it's not true for scientists, many other people here still have a feeling that something was wrong with Mendel."

An international initiative launched this year aims to bring the science of genetics back to its spurned cradle. Its champions include St. Thomas's current abbot, along with local and foreign scientists, backed by such notables as Czech president Vaclav Havel and Nobel laureates Paul M. Nurse, James D. Watson and Eric F. Wieschaus.

One move has been to hold scientific conferences at the abbey. The first was a workshop called "Genetics after the Genome," held there by the European Molecular Biology Organization this past May. In September the opening sessions of a chemometrics conference took place in the newly renovated refectory, and in August 2003 the abbey is to host an international symposium on the genetic aspects of heart disease. Furthermore, an exhibition, "The Genius of Genetics," combining science with art, has opened at the abbey; it will run until May 2003 (see www.mendelmuseum.org). Plans are already being drawn up for a follow-up exhibition, a restoration of Mendel's experimental garden, a permanent museum and a life sciences center.

Much of the cash for the initiative has come from the VFG, a Viennese charity. Two Gregor Mendel trusts, in the U.K. and the U.S., have been established for larger-scale projects. The abbey's exhibition shop covers some of the costs in ways the modest Augustinian friar could never have imagined: Mendel pencils,

STEPAN BARTOS

MICROSCOPE SLIDES and other tools that Gregor Mendel may have used are displayed at the Abbey of St. Thomas.

MENDEL OFF ABBEY ROAD

The Abbey of St. Thomas isn't the only place in Brno to pay homage to Mendel. The first major Mendel museum is actually the Mendelianum. It was founded by a small group of Czech geneticists in 1965 in the white baroque compound of the abbey but has moved off those premises to a government building. The Mendelianum has two new exhibits: one, on the genetic refutation of racism, is to open in the fall of 2003; the other, called "The Scientific Milieu of Mendel's Discovery," can be viewed at a branch of the Moravian Museum in Brno's central square.

notepads, cups and even a brand of Mendel beer. And there's talk of restoring Mendel's beehive (he bred bees in an attempt to confirm his pea data) and selling Mendel honey.

A major Mendel revival would be a boon to Czech science, long isolated during the Communist era. The revival is further supported by the city of Brno as a means of boosting tourism. And last but not least, it makes up for the long, obliterating neglect in his own land of one of history's greatest scientific visionaries.

Luba Vikhanski, based in Tel Aviv, did not see any Mendel frozen peas at the gift shop.

TAXONOMY

Making Do

THIRD WORLD NATURALISTS COPE WITH SCARCE RESOURCES **BY GARY STIX**

The National Museum of Namibia is a tiny institution. On paper, it reserves places for 12 natural scientists, but its staff is currently a third of that level. Its size, though, has not prevented it from making a major contribution to the natural sciences.

The museum helped to turn up living exemplars of an unknown insect order, Mantophasmatodea, dubbed more familiarly "gladiators" [see "Gladiators: A New Insect Order," by Joachim Adis, Oliver Zompro, Esther Moombolah-Goagoses and Eugène Marais; SCIENTIFIC AMERICAN, November]. Eugène Marais, the museum's senior curator for natural history, observes that the Namibian institution might not have played the role it did but for a decision by the museum staff in 1999 that allowed it to make the best use of its limited resources. It was then that Marais and four colleagues met to commiserate about how difficult it had become to do the type of research carried out at better-endowed institutions. No one wanted to lend books and specimens to investigators in a Third World country—and it was hard to come up with the funds to travel abroad. "We started looking at it from a sociological perspective," Marais remarks. "We said, 'We can do research, but we can't be very effective.'"

From that informal meeting, a new strategy emerged. The staff decided that it would try, for the most part, to forgo independent, publishable research; rather its members would function as "facilitators" for other institutions. The naturalists would provide scientists worldwide with collected samples of insects, snakes, spiders, scorpions and the retinue of diverse fauna, some of which can be found only in Namibia. As facilitators, they would not have to conduct laborious taxonomic classifications of the specimens they found on their travels.

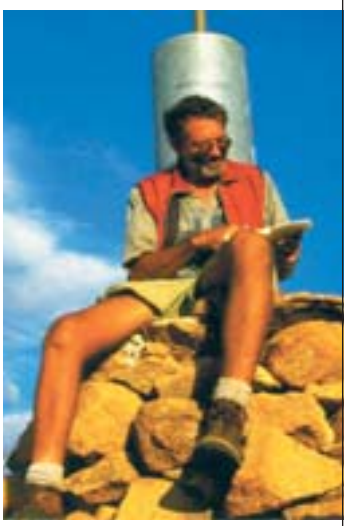
If the museum had not changed its practices, Marais says, he might have been slow in responding when the Max Planck Institute for Limnology in Plön, Germany, sought out living specimens of gladiators. As it was, the museum was the sole African institution that promptly recognized the insect.

The new approach has been fruitful; overall productivity of the scientists has gone up. From the collection, Marais and his colleagues have been able to assist in the cataloguing of about 30 new species every year—had the museum been doing the work on its own, it would have logged just half that number. These discoveries have come from the 8,000 specimens sent around the world annually to 30 to 40 institutions, which then proceed to classify the shipments.

Acting as research scouts gives scientists more latitude to conduct cross-disciplinary studies. Marais has also pursued an interest in documenting the insect classification systems developed by the San Bushmen and other tribal groups. Although the Bushmen categorizations lack scientific rigor, they can provide hints about where a researcher should look for a specimen. Marais noted that the Bushmen in northeastern Namibia have names for eight species of bees, whereas only two have been recorded by entomologists, a disparity that suggests that naturalists still have much work left to do.

FREE TO ROAM

Scientists at the National Museum of Namibia can go outside their various fields more easily than investigators at European and North American institutions can. Eugène Marais, whose main area of research is entomology, is collaborating with colleagues from U.S. universities on a study to measure the aridity of conditions in Namibia during the past 130,000 years. And he has written a paper with Australian colleagues that reports on which microclimates within caves are chosen by Namibian bats for roosting.



ENTOMOLOGY often brings Eugène Marais to the Brandberg, Namibia's highest peak.

COURTESY OF EUGÈNE MARAIS

TISSUE REGENERATION

Dentures Begone

Don't cast pearls before swine—get pearly whites from them instead. A research team led by molecular biologist Pamela C. Yelick of the Forsyth Institute in Boston removed unerupted molars from six-month-old pigs and dissolved them with enzymes. Cells from the resulting soup were placed in a biodegradable polymer scaffolding and implanted in the abdomens of immunosuppressed rats, close to blood-rich tissues. Thirty weeks later two-millimeter-wide molar crowns emerged, complete with pulp chambers, root tips and bonelike layers of dentin and, in a first, enamel. The scientists, who described their findings in the October 1 *Journal of Dental Research*, say it may be possible a decade from now to grow living substitutes for lost human teeth, perhaps in tailored shapes and sizes.

—Charles Choi

COMPUTER SECURITY

Keyboard Cops

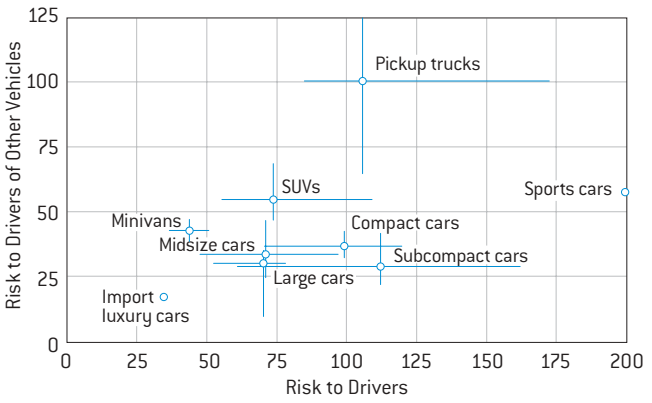
Software designed to guard the nation's high-security networks from hackers detects suspicious anomalies in system traffic based purely on statistics and is usually correct only 60 to 80 percent of the time. Computer scientist Shambhu Upadhyaya of the University of Buffalo explained that his team has a more reliable and efficient way. Their prototype software simply monitors commands that users enter, comparing their behavior with the well-defined habits of legitimate users. The new program can double-check suspicious behavior against every user's unique profile of activity to sort out masquerading intruders from genuine users. The "user-level anomaly detection system" was presented in October at the military communications conference MILCOM 2002 in Anaheim, Calif. Upadhyaya says that the software is successful 94 percent of the time but thinks near 100 percent reliability is years away. *—Charles Choi*

SECURITY CLUES in the typing.

HANS NELEMAN *Photonica (top)*; LISA BARBER *Photonica (middle)*; JOHNNY JOHNSON *(bottom)*

DATA POINTS: CRASH COURSE

Sport utility vehicles are a consumer favorite in part because of their perceived safety. A recent study shows, however, that SUVs are no better than midsize to large cars—in fact, compact cars such as the Honda Civic and the Volkswagen Jetta are just as safe. When one factors in the risk to drivers of other vehicles (*chart below*), SUVs become even more dangerous. The risk numbers refer to driver deaths per year per million vehicles. The blue lines denote the range of risk discovered for each class of vehicle.



SOURCE: "An Analysis of Traffic Deaths by Vehicle Type and Model," by Marc Ross and Tom Wenzel. American Council for an Energy-Efficient Economy, March 2002. http://enews.lbl.gov/Science-Articles/Archive/EETD-SUV-Safety.html

CHEMISTRY

Nucleotide Nanotubes

Instead of pure carbon, nanotubes can now be made from the stuff of DNA. Researchers at Purdue University used synthetic forms of guanine and cytosine. Unlike their carbon counterparts, the organic nanotubes are easier to make and have a wider range of properties that can be controlled by dressing up the nanotubes with certain molecules. Attaching nylon molecules to a nanotube surface, for example, could make long, flexible nylon fibers to reinforce clothing as well as aircraft surfaces, body armor and parachutes. Because the tubes are hollow, they could also be tailored to mimic some antibiotics that kill bacteria by puncturing them and draining the insides. The research appears in the September 18 *Journal of the American Chemical Society*. *—Tariq Malik*

The Nobel Prizes for 2002

The Royal Swedish Academy announced 11 researchers who will shake hands with the king of Sweden this month. More details can be found at www.nobel.se

PHYSIOLOGY OR MEDICINE

The worm *Caenorhabditis elegans* has just 959 cells, but insights gained by studying its life cycle earned three scientists this year's award. The laureates' understanding of the processes that govern organ development and cell death may point to new treatments for a variety of diseases. In the 1960s **Sydney Brenner** of the Molecular Sciences Institute in Berkeley, Calif., began noting the potential of the tiny, transparent worm as a model organism. In the 1970s, building on Brenner's early work, **John E. Sulston** of the Wellcome Trust Sanger Institute in Cambridge, England, mapped the lineage of every one of *C. elegans*'s cells and determined that specific ones always die during its development. In 1986 **H. Robert Horvitz** of the Massachusetts Institute of Technology identified two genes, *ced-3* and *ced-4*, that are required for cell suicide to occur. Subsequent investigations showed that humans have corresponding genes.

—Sarah Graham

AP/WIDE WORLD PHOTO

CHEMISTRY

Thanks to this year's Nobelists, chemists have many methods to study the shape and structure of proteins, DNA and other macromolecules. In 1988 **John B. Fenn** of Virginia Commonwealth University and **Koichi Tanaka** of Shimadzu Corporation in Kyoto invented the now standard ways to determine protein structure. Fenn soaked proteins in water exposed to an electric field to separate macromolecules into their component parts through evaporation. Tanaka developed a technique using a laser to blast the molecules into smaller pieces. In the 1980s **Kurt Würtrich** of the Scripps Research Institute in La Jolla, Calif., and the Swiss Federal Institute of Technology determined the cornerstone for the structural studies of proteins. He was able to assign a protein fixed points separated by a known distance and then reconstruct its shape, similar to the way a carpenter could rebuild a house if the dimensions were already known. *—Tariq Malik*

PHYSICS

In 1969 **Raymond Davis, Jr.**, working for Brookhaven National Laboratory, proved the existence of solar neutrinos, elusive particles created during the sun's fusion process. Detecting them took an underground tank filled with 615 tons of cleaning fluid set in a South Dakota gold mine. The neutrinos reacted with chlorine atoms in the tank to produce argon, which Davis could then measure. In 1987 **Masatoshi Koshiba** of the University of Tokyo used Kamiokande, an enormous subterranean detector, to support Davis's findings and catch the first neutrinos seen coming from a supernova. **Riccardo Giacconi** of Associated Universities, Inc., in Washington, D.C., laid the foundations of x-ray astronomy in 1959 by developing instruments to study x-ray sources from space. His research has led to the detection of the background x-ray radiation in space and to knowledge about black holes and other stellar phenomena. *—Tariq Malik*

ECONOMICS

This year's prize went to psychologist **Daniel Kahneman** of Princeton University and economist **Vernon L. Smith** of George Mason University. Kahneman (together with the late Amos Tversky) showed that decision making in uncertain times often departs from what is expected under standard economic theory because people rely on shortcuts when analyzing complex circumstances. The pair also developed "prospect theory" to try to explain behavioral patterns such as why people view saving $5 on a $15 purchase as worthwhile but not when the same dollar-amount discount is applied to more expensive goods. Smith's contributions, meanwhile, provided a framework for reliable laboratory experiments in economics. In particular, he instituted "wind-tunnel" experiments, in which new market arrangements for products such as deregulated electricity can be tested before being put into practice. *—Sarah Graham*

BRIEF POINTS

- **Scientists have sequenced the DNA of the parasite that causes malaria and the primary mosquito species that carries it. Knowing the genomes should lead to better treatment and control of the killer disease.**

  Nature, October 3, 2002; *Science*, October 4, 2002

- **Quaoar: No, that's not a *Lord of the Rings* character but a 1,300-kilometer-wide Kuiper Belt object beyond Pluto discovered by the Palomar Oschin Schmidt telescope. It's pronounced "kwa-whar," or possibly "kwah-o-ar," or just call it KBO 2002 LM60.**

  http://science.nasa.gov/headlines (October 7, 2002)

- **Can you be allergic to your own DNA? In a study of fruit flies, improperly digested DNA fragments created by the natural breakdown of cells provoked an immune response.**

  Genes & Development, October 15, 2002

- **Scavenging a magnetron tube from a microwave oven, researchers created a microwave drill. A coaxial cable channels the energy to a spot that heats up and melts enough to be scooped out.**

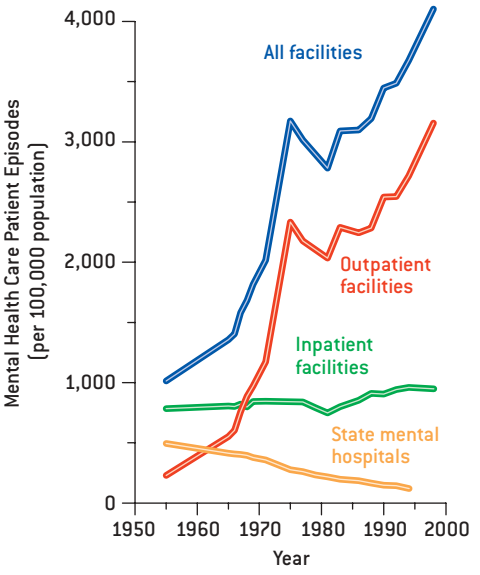
  Science, October 18, 2002

BY THE NUMBERS

Deinstitutionalization

WHY A MUCH MALIGNED PROGRAM STILL HAS LIFE **BY RODGER DOYLE**

Fifty years ago the mentally ill generally had two choices: for the affluent, there was psychotherapy, and for all others, there were the state mental hospitals, which had a reputation for treating patients badly. Today's mental health system offers a far wider range of services for the seriously ill, including outpatient care, help with living arrangements, job placement and social support. In addition, it provides options for those with less severe psychiatric problems. The once dominant state mental hospitals now play a minor role.



Deinstitutionalization gained favor in the 1950s as psychiatrists came to believe that the mentally ill would do better as outpatients living close to relatives and jobs. This view gained momentum in the mid-1950s with the emergence of antipsychotic drugs, which improved patients' ability to function outside the asylum. With federal funding of community health centers and the start of Medicaid, states saw in the mid-1960s an opportunity to shift the cost of mental health care to the federal government. So they began transferring patients out of the mental hospitals to community health centers, nursing homes and other institutions. The number served by private psychiatric hospitals and inpatient units of general hospitals grew, but the most spectacular growth, as the chart illustrates, was in outpatient facilities.

In retrospect, it is not surprising that deinstitutionalization was a troubled process, for it was largely based on untested theories about rehabilitation, and not enough was done to anticipate the needs of the seriously mentally ill in the community. One consequence has been the high number of homeless adults with a major mental disorder, estimated at between one third and one half of all homeless adults. In addition, there are about 280,000 people with severe mental illness in jail or prison, where psychiatric help is often unavailable. Another concern is the quality of care given to the 400,000 mentally ill in nursing homes, because treatment in these facilities is sometimes poor or nonexistent. Finally, a substantial number of mentally ill fall outside the system, because they have limited knowledge of treatment options and inadequate health insurance or because they do not want the stigma of being labeled mentally ill.

Despite this catalogue of blunders, most people with mental illness lead better lives now than in the time before deinstitutionalization. Several studies have shown that about two thirds of those with severe mental illness who are provided with a comprehensive range of services, including social support, can live outside the asylum. But the most telling evidence in support of the modern system comes from patients themselves, who overwhelmingly prefer living in the community to being in a mental hospital. The problem, says sociologist David Mechanic of the Institute for Health, Health Care Policy and Aging Research at Rutgers University, is that treatment is often administered on a hit-or-miss basis. The future of mental health care in the U.S., Mechanic feels, lies in developments outside the mental health sector. For instance, if the country moves to a universal health care system, then resources are more likely to become available to incorporate those features that have proved effective in community care.

Rodger Doyle can be reached at rdoyle2@adelphia.net

FAST FACTS: PREVAILING ILLS

Among adults ages 18 to 54 years:

21% have a mental disorder

5.4% have serious mental illness, defined as one disorder (other than substance abuse) lasting a year or more, plus serious impairment

2.6% have severe and persistent mental illness, a subset of serious mental illness

RECOMMENDED READING

- ***Mental Health: A Report of the Surgeon General.*** **U.S. Public Health Service, 1999 (www.nimh.nih.gov/).**
- ***Mental Health, United States, 2000*** **(www.mentalhealth.org/publications/allpubs/SMA01-3537/default.asp). See the articles by Gerald N. Grob, by David Mechanic, and by Ronald W. Manderscheid et al.**

SOURCE FOR CHART: National Mental Health Information Center, U.S. Department of Health and Human Services. Patient care episodes provide an estimate of the number of persons under care throughout the year. State mental hospital episodes are included in inpatient facilities episodes. Comparable data on psychiatric patients in nursing homes are not included.

RODGER DOYLE

The Captain Kirk Principle

Intuition is the key to knowing without knowing how you know By MICHAEL SHERMER

Stardate: 1672.1. Earthdate: October 6, 1966. *Star Trek,* Episode 5, "The Enemy Within."

Captain James T. Kirk has just beamed up from planet Alpha 177, where magnetic anomalies have caused the transporter to malfunction, splitting Kirk into two beings. One is cool and rational. The other is impulsive and irrational. Rational Kirk must make a command decision to save the crew, but he is paralyzed with indecision, bemoaning to Dr. McCoy: "I can't survive without him. I don't want to take him back. He's like an animal—a thoughtless, brutal animal. And yet it's me!"

This psychological battle between intellect and intuition was played out in almost every episode of *Star Trek* in the characters of the ultrarational Mr. Spock and the hyperemotional Dr. McCoy, with Captain Kirk as the near perfect synthesis of both. Thus, I call this balance the Captain Kirk Principle: intellect is driven by intuition, intuition is directed by intellect.

The Captain Kirk Principle: intellect is driven by intuition, intuition is directed by intellect.

For most scientists, intuition is the bête noire of a rational life, the enemy within to beam away faster than a phaser on overload. Yet the Captain Kirk Principle is now finding support from a rich emerging field of scientific inquiry brilliantly summarized by Hope College psychologist David G. Myers in his book *Intuition: Its Powers and Perils* (Yale University Press, 2002). I confess to having been skeptical when I first picked up the book, but as Myers demonstrates through numerous well-replicated experiments, intuition—"our capacity for direct knowledge, for immediate insight without observation or reason"—is as much a component of our thinking as analytical logic.

Nalini Ambady and Robert Rosenthal of Harvard University, for example, discovered that evaluations of teachers by students who saw a mere 30-second video of the teacher were remarkably akin to those of students who had taken the course. Even three two-second video clips of the instructor yielded a striking 0.72 correlation with the course students' evaluations.

Research consistently shows how so-called unattended stimuli can subtly affect us. At the University of Southern California, Moshe Bar and Irving Biederman flashed emotionally positive images (kitten, romantic couple) or negative scenes (werewolf, corpse) for 47 milliseconds immediately before subjects viewed slides of people. Although subjects reported seeing only a flash of light for the initial emotionally charged pictures, they gave more positive ratings to people whose photographs had been associated with the positive ones—so something registered.

Intuition is not subliminal perception; it is subtle perception and learning—knowing without knowing that you know. Chess masters often "know" the right move to make even if they cannot articulate how they know it. People who are highly skilled in identifying "micromomentary" facial expressions are also more accurate in judging lying. In testing college students, psychiatrists, polygraphists, court judges, police officers and Secret Service agents on their ability to detect lies, only the agents, trained to look for subtle cues, scored above chance.

Most of us are not good at lie detection, because we rely too heavily on what people say rather than on what they do. Subjects with damage to the brain that renders them less attentive to speech are more accurate at detecting lies, such as aphasic stroke victims, who were able to identify liars 73 percent of the time when focusing on facial expressions. (Nonaphasic subjects did no better than chance.) We may even be hardwired for intuitive thinking: damage to parts of the frontal lobe and amygdala (the fear center) will prevent someone from understanding relationships or detecting cheating, particularly in social contracts, even if he or she is otherwise cognitively normal.

Although in science we eschew intuition because of its many perils (also noted by Myers), we'd do well to remember the Captain Kirk Principle, that intellect and intuition are complementary, not competitive. Without intellect, our intuition may drive us unchecked into emotional chaos. Without intuition, we risk failing to resolve complex social dynamics and moral dilemmas. As Dr. McCoy explained to Kirk: "We all have our darker side—we need it! It's half of what we are. It's not really ugly, it's human. Your strength of command lies mostly in him." SA

Michael Shermer is publisher of Skeptic *magazine (www.skeptic.com) and author of* In Darwin's Shadow.

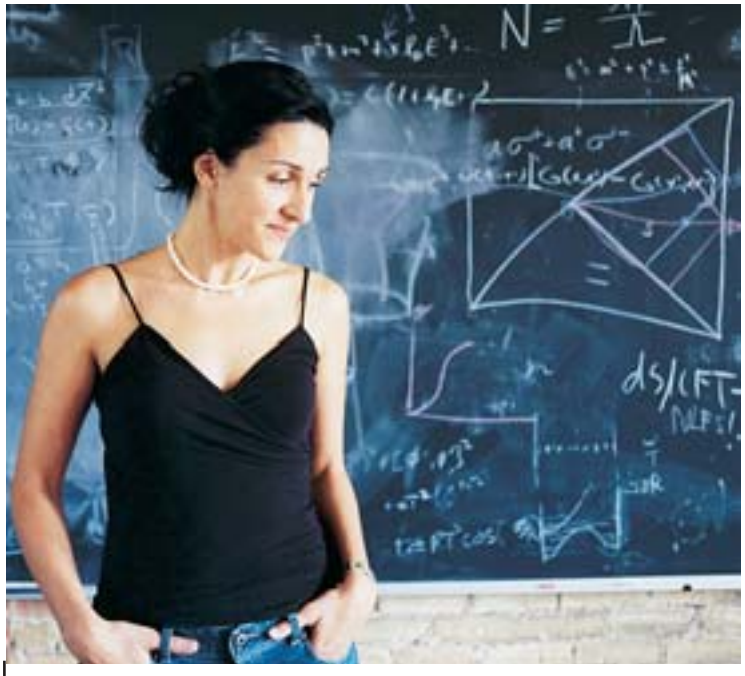
BRAD HINES

Throwing Einstein for a Loop

Physicist Fotini Markopoulou Kalamara has developed a way to connect relativity with quantum theory—while making sure that cause still precedes effect By AMANDA GEFTER

She talks about physics like it's cooking. "My strength is to put things together out of nothing," she says, "to take this ingredient and another one there and stick something together." The art is figuring out which ones to use and how to combine them so that when the oven bell dings, the universe comes out just right.

At 31 years old, Fotini Markopoulou Kalamara is hailed as one of the world's most promising young physicists. She recently accepted a position at the Perimeter Institute for Theoretical Physics in Waterloo, Ontario (Canada's answer to the Institute for Advanced Study in Princeton, N.J.). There she works alongside such prominent physicists as Robert Myers and Lee Smolin, hoping to blend Einstein's general relativity with quantum theory to explain the nature of space and time.



DEREK SHAPTON

FOTINI MARKOPOULOU KALAMARA: QUANTIZING GRAVITY

- **Recently accepted a five-year renewable post at the Perimeter Institute in Waterloo, Ontario, where "it's very open-minded."**
- **If correct, the causal spin networks theory that she's helped to develop would mean that the universe functions like a giant quantum computer.**
- **On her career: "Having fun is essential, because otherwise you get stressed out. You think, I have to show the universe is made out of atoms, and aaaaahhh, you flip out! So you want to keep loose."**

This unification is probably the single greatest challenge of modern physics. String theory has been the predominant contender. It proposes that the building blocks of matter are tiny, one-dimensional strings and that various vibrations of strings play the familiar medley of particles as if they were musical notes.

Although string theory finds a way to incorporate gravity into a quantum description of matter, some physicists believe that it has shortcomings that prevent it from being the ultimate theory of everything. For one, the theory presupposes up to 26 spatial dimensions, many more than have yet to be experimentally discovered. More fundamental still, whereas strings are fine for describing matter, they do not explain the space in which they wiggle. Newer versions of string theory may fix this problem. But a small band of physicists, including Smolin, Abhay Ashtekar of Pennsylvania State University and Carlo Rovelli of the Theoretical Physics Center in Marseilles, France, place greater stock in a different approach: loop quantum gravity, or LQG.

In LQG, reality is built of loops that interact and combine to form so-called spin networks—first envisioned by English mathematician Roger Penrose in the 1960s as abstract graphs. Smolin and Rovelli used standard techniques to quantize the equations of general relativity and in doing so discovered Penrose's networks buried in the math. The nodes and edges of these graphs carry discrete units of area and volume, giving rise to three-dimensional quantum space. But because the theorists started with relativity, they were still left with some semblance of a space outside the quantum networks.

That was the state of LQG in the late 1990s, when Markopoulou Kalamara began tackling it. Serendipity actually led her to the subject. "I only decided on physics when I was 16 or 17," says the theorist, who is from Athens, Greece. "Before that, I wanted to be all sorts of things: an archaeologist, an astronaut, a painter." While she was an undergraduate at the University of London, a friend taking theoretical physics recommended lectures being given by quantum-gravity theorist Chris Isham of Imperial College London. "It was on my way home, so I went once a week, and I loved it." She convinced Isham to be her adviser and wound up with a Ph.D. in quantum gravity. She then joined Smolin at Penn State as a postdoctoral fellow.

Markopoulou Kalamara approached LQG's extraneous space problem by asking, Why not *start* with Penrose's spin networks (which are not embedded in any preexisting space), mix in some of the results of LQG, and see what comes out? The result was networks that do not live in space and are not made of matter. Rather their very architecture gives rise to space and matter. In this picture, there are no things, only geometric relationships. Space ceases to be a place where objects such as particles bump and jitter and instead becomes a kaleidoscope of ever changing patterns and processes.

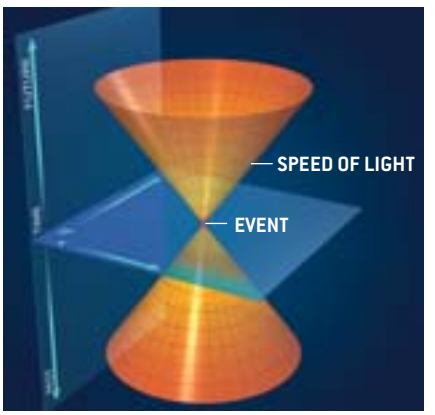
Each spin network resembles a snapshot, a frozen moment in the universe. Off paper, the spin networks evolve and change based on simple mathematical rules and become bigger and more complex, eventually developing into the large-scale space we inhabit.

By tracing this evolution, Markopoulou Kalamara can explain the structure of spacetime. In particular, she argues that the abstract loops can produce one of the most distinctive features of Einstein's theory—light cones, regions of spacetime within which light, or anything else, can reach a particular event. Light cones ensure that cause precedes effect. We can understand this concept by gazing upward and knowing that there are countless stars we cannot see because not enough time has passed since the birth of the universe for their light to shine our way; they are beyond our light cone.

It is not so obvious, though, where light cones fit into the spin networks. Those networks are subject to quantum mechanics. In that wonderland of uncertainty, any network has the potential to evolve into infinite new ones, leaving no trace of a causal history. "We didn't know how, in the language we were working in, to put in the notion of causality" in LQG, Smolin says. Markopoulou Kalamara found that by attaching light cones to the nodes of the networks, their evolution becomes finite and causal structure is preserved.

But a spin network represents the entire universe, and that creates a big problem. According to the standard interpretation of quantum mechanics, things remain in a limbo of probability until an observer perceives them. But no lonely observer can find himself beyond the bounds of the universe staring back. How, then, can the universe exist? "That's a whole sticky thing," Markopoulou Kalamara says. "Who looks at the universe?" For her, the answer is: we do. The universe contains its own observers on the inside, represented as nodes in the network. Her idea is that to paint the big picture, you don't need one painter; many will do. Specifically, she realized that the same light cones she had used to bring causal structure into quantum spacetime could concretely define each observer's perspective.

Because the speed of light is finite, you can see only a limited slice of the universe. Your position in spacetime is unique, so your slice is slightly different from everyone else's. Although there is no external observer who has access to all the information out there, we can still construct a meaningful portrait of the universe based on the partial information we each receive. It's a beautiful thought: we each have our own universe. But there's a lot of overlap. "We mostly see the same thing," Markopoulou Kalamara explains, and that is why we see a smooth universe despite a quantized spacetime. "I actually think theoretical physics is very much like art," concludes Markopoulou Kalamara, the daughter of two sculptors. "Putting these things together is like taking clay and making something out of nothing, and it should work from every side. I like the creative part, but I also like that you can check."



LIGHT CONES, generated by plotting the speed of light against time and three dimensions of space (*x*, with *y* and *z* together), define all past and future connections to an event.

The time to check is fast approaching. There are details to work out, such as how to derive the usual one-dimensional time from the quantum causality, but she figures that if observations can confirm the basics of spin networks, she'll smooth out the kinks. One experiment could be to track gamma-ray photons from billions of light-years away. If spacetime is in fact discrete, then individual photons should travel at slightly different speeds, depending on their wavelength. Markopoulou Kalamara is trying to decipher the form of that dispersion.

If true, her predictions could forever change the way we think about the structure of space. Several tests of quantum gravity could take place within the next few years. "I always told myself that if it doesn't turn into real physics, if it doesn't get in touch with experiment, I'm getting a really well paying job in New York. For all I know, it may work easily. There's always that possibility," Markopoulou Kalamara says. In the meantime, she's hard at work, and waiting for the oven bell.

Amanda Gefter is based in New York City.

SLIM FILMS

SCIENTIFIC AMERICAN 50

THE ADVANCE OF TECHNOLOGY depends on many heroic efforts, not all in the laboratory. Scientists and engineers extend our understanding and control of the physical world, while industrialists and corporations mobilize their own forces to make innovations available and commentators and legislators shape the policies guiding how society uses technology. This new annual roundup, the SCIENTIFIC AMERICAN 50, honors four dozen individuals, teams and companies—selected by the editors for their recent contributions to 12 broad categories of technological endeavor—as well as a Research Leader and a Business Leader of the Year. Join us in celebrating their bright visions of the future.

AGRICULTURE

CHEMICALS & MATERIALS

COMMUNICATIONS

COMPUTING

DEFENSE

ENERGY

ENVIRONMENT

MANUFACTURING

MEDICAL DIAGNOSTICS

MEDICAL TREATMENTS

TRANSPORTATION

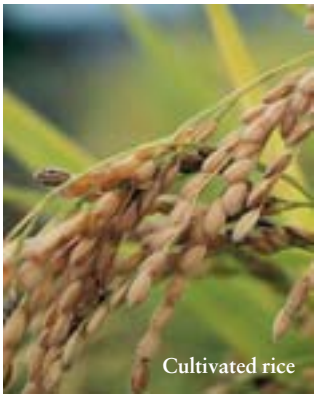
GENERAL TECHNOLOGY

TOM DRAPER DESIGN

STEPHEN GOFF, HUANMING YANG and JUN YU

Goff, Syngenta's Torrey Mesa Research Institute; Yang, Beijing Genomics Institute; and Yu, University of Washington Genome Center

Vision: Deciphering the genome of rice paves the way for breakthroughs in farming humankind's most important food staples.



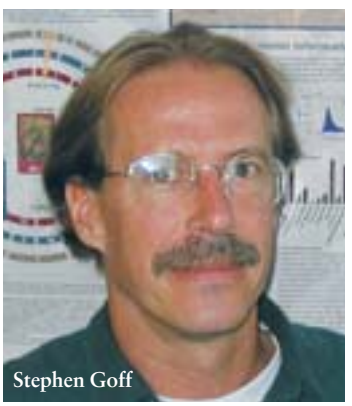
Cultivated rice

THE APRIL 5, 2002, ISSUE OF *SCIENCE* published two papers from independent laboratories that simultaneously reached a long-awaited goal: a map of the rice genome. The studies provided gene sequences—lists of genetic building blocks, called nucleotide bases, that make up an organism's chromosomes—for two types of rice, a crop that feeds more than half the world's population. One study, led by Huanming Yang and Jun Yu, unveiled a draft sequence for *indica,* a subspecies that is common in most of Asia. Another team, directed by Stephen Goff, published a similar report on *japonica,* usually grown in Japan. Together the investigations should lead to better strains of rice and benefits for other crops.

Both groups achieved their goals by leveraging a powerful combination of molecular biology and computer science called the whole-genome shotgun method. In most sequencing, scientists examine the DNA piece by piece, but the shotgun technique looks at the entire genome at once. Scientists break up the genome, sequence the overlapping pieces simultaneously, then use advanced computing to arrange the segments as they exist on the chromosomes. The technique's virtue is speed: genome-sequencing projects by other means can take years, but Yang and his colleagues, working around the clock, completed the sequencing in just 74 days.

Each of the rice studies predicts that its subspecies contains tens of thousands of genes, but no one knows exactly how many. Although the shotgun technique gives an approximate number, it can leave holes in the overall sequence. Goff estimated that *japonica* contains between 32,000 and 50,000 genes. Nevertheless, the shotgun method reveals important information. Yang and Yu's team, for instance, concluded that a rice gene creates only one protein, whereas a single human gene usually spawns several. This understanding is expected to make it easier to determine exactly what proteins these genomes make.

Knowing the sequences of rice species should also give scientists a good start on defining all grasses, which is the family of many grain crops, including wheat, corn, oats, sorghum and barley. Of all the world's agricultural land, 70 percent of the acres are planted in rice, wheat and corn. Because the rice sequence probably contains most of the same genes found in those other grasses, researchers anticipate that the rice knowledge will help advance the efforts on the more complex crops. Meanwhile, armed with the genome maps of Goff, Yang and Yu, scientists will be able to breed or engineer rice that resists disease, drought and pests.



Stephen Goff

Huanming Yang

Jun Yu

RIC ERGENBRIGHT *Corbis (top)*; LISA MATTLE *(bottom left)*; COURTESY OF HUANMING YANG *(bottom center)*; COURTESY OF JUN YU *(bottom right)*; MARK GILBERT *(opposite page)*

GEOFFREY BALLARD
Chairman, General Hydrogen

Vision: Hydrogen can replace gasoline as the automotive fuel of choice.

Geoffrey Ballard

GEOFFREY BALLARD, A.K.A. MR. HYDROGEN, has done more than anyone to advance fuel cells. Like batteries, fuel cells cleanly convert chemical energy into electrical power. But they wring more power from their weight, in part because they don't have to store a key ingredient: oxygen from the air. Last year, having concluded that the greatest remaining impediment to fuel cells' widespread adoption was the lack of a system for distributing hydrogen fuel, Ballard co-founded General Hydrogen in Vancouver to solve the problem. The company has backing from the Canadian government and alliances with British Energy, General Motors and other corporations.

Ballard, 70, is a dual citizen of Canada and the U.S. He trained as a geophysicist and worked for the oil industry, the U.S. military and the then newly founded Department of Energy, where he studied energy conservation. He soon judged that conservation alone could not free up sufficient energy for developing countries and in 1975 went into business for himself.

Ballard turned a former motel in Arizona into a laboratory to work on his first project, lithium batteries. That enterprise never paid off. Nevertheless, Ballard Power Systems, which he founded in 1979, went on to make inexpensive hydrogen-consuming fuel cells that replaced liquid and heated ceramic electrolytes with a thin plastic barrier, called a proton exchange membrane (PEM). The concept had been worked on in the mid-1960s by General Electric for NASA's Gemini program, only to be supplanted later. Ballard revived the approach in the 1980s, after the patents had expired, and rendered it cost-effective through discoveries made by him and others.

In 1993 Ballard demonstrated PEM by using it to power a 30-foot city bus in Vancouver, dubbed the "Ballard Bus." Four years later Daimler-Benz (now DaimlerChrysler) and Ford Motor Company, themselves developers of fuel cells, bought equity stakes in the company. Ballard, finding he had less interest in running companies than in starting them, left in 1998. He subsequently co-founded General Hydrogen.

General Hydrogen is developing ways to sidestep the chicken-and-egg problem of a hydrogen-based automotive economy: no one wants to make cars without readily available fuel, and no one wants to distribute fuel without a large population of cars. The company has not unveiled its entire strategy; so far its main product is a high-pressure gas canister to store fuel in the vehicle, a critical link in the chain of supply.

When Ballard first plunged into fuel-cell research, he hoped to save cities from smog. Tightening auto-emissions standards soon lent support to Ballard's efforts. Now another issue he could not have foreseen—the fight against global warming—has further strengthened the case for his hydrogen economy. The question is, Where will all the energy come from to manufacture that hydrogen? "Within the scope of today's technology, nuclear fission is the only viable, clean source of large quantities of energy," Ballard said recently in Montreal. Improvements in fission safety have been achieved, he argues, and the risks that remain compare favorably with those inherent in fossil-fuel sources.

AGRICULTURE

RESEARCH LEADER

ALLISON A. SNOW
Professor of evolution, ecology and organismal biology, Ohio State University

Vision: The potential of genetically engineered crops to pass traits to weeds must be understood.

SCIENTISTS CAN ENHANCE MODERN CROPS by using advanced molecular biology to add genes that confer beneficial traits, such as drought tolerance and pest resistance. Unfortunately, as Allison Snow has shown, these transgenic crops can also sometimes crossbreed with related weeds—those sharing the same genus—that may surround a field crop, giving the hybrid weeds the robust traits, too. This transference might create a powerful weed that is harder to control.


Allison A. Snow

In 2001 Snow and her colleagues presented their findings from a series of experiments at the University of Michigan Biological Station. They worked with two kinds of radish: an edible one and its wild, weedy relative. Under ordinary circumstances, the weedy relative is the growth champion among the two species and easily wins any battle between them to capture acreage. Snow and her team crossed the two strains, developing a hybrid similar to what might be created in the field between a crop and a related weed; they then tested the productivity of the original weed and the weedy hybrid in large field tests.

The results dispel some folklore surrounding the safety of genetic engineering for crops. Supposedly, hybrid plants reproduce less and eventually die out, so if a trait were to pass from a genetically engineered crop to a nearby relative, the resulting hybrid weed would not survive very long. Yet Snow watched her hybrid wild radishes grow and reproduce through six generations. Even more dangerous, the reproductive capabilities of the hybrids improved in the second generation over the first. Moreover, after a couple of generations, traits from the edible radish, including the color of its flowers, started showing up in the hybrid, as the genes for color began to express themselves more strongly. If the crop radish can pass flower color to its weedy relative, it could also pass other traits, such as ones added to the crop through genetic engineering.

Hybrid superweeds could create real trouble for farmers. The weedy relative of the radish, which is superior in reproduction, might become even more aggressive if it acquired potent new traits from a crop with modified chromosomes. Many crops could face similar challenges: carrots, oilseed rape, rice, sorghum, squash, sunflowers and others already compete with natural weedy relatives. Weedy hybrids could grow too strong to be held back by the herbicides that currently minimize their invasion of agricultural fields. And it could happen fast. As Snow's diligent research shows, the hybrids can appear in a single season and evolve quickly into more aggressive invaders.

OHIO STATE UNIVERSITY

BUSINESS LEADER

G. STEVEN BURRILL
Chief executive officer, Burrill & Company

Vision: Ag-biotech is promising and deserves prudent investment.

STEVEN BURRILL MANAGES more than $100 million in two agricultural biotechnology investment funds, AgBio Capital Funds I and II. But his reputation as a spokesperson for life sciences and technology industries is what makes him a highly regarded voice in the investment community. The funds invest in a handful of companies—such as Aventis CropScience and Bayer—that steer clear of controversial genetically modified organisms. Burrill also forges deals among companies that are creating hardier animal breeds for agriculture. In May, Burrill guided Pyxis Genomics to a $17.5-million collaboration with Genome Canada to explore the genetics of infectious diseases in cattle and poultry. Pyxis uses DNA microarrays to identify genetically superior animals that can be bred for resistance to food-borne illnesses or for other desirable traits. To keep investors and managers up-to-date, he has convened many meetings, including the Life Sciences Partnering Meeting. In addition, he writes an annual report—the most recent is "Bio 2002"—that some call the bible of biotechnology.


G. Steven Burrill

COMPANY


Altered corn

PRODIGENE

Vision: Transgenic corn can be used as a chemical factory to produce proteins for an edible AIDS vaccine and other pharmaceuticals.

THIS YEAR PRODIGENE in College Station, Tex., showed that its genetically modified corn can produce compounds for a vaccine that might fight AIDS. The corn makes a protein called gp120, which is situated on the surface of HIV. Investigators hope that ingesting small amounts of the protein could trigger the production of antibodies against HIV, helping to defeat the virus and beat any future HIV infection. ProdiGene is now conducting tests to see whether the protein triggers a useful immune response when ingested by animals. The transgenic corn could also make large quantities of gp120 for HIV research. This and other proteins from ProdiGene will be some of the first industrial-scale products from a transgenic plant, and they could be developed into pharmaceuticals or industrial proteins. For example, ProdiGene recently used its corn to produce trypsin, an enzyme used in pharmaceutical manufacturing and other industrial processing; it should be available in 2003.

POLICY LEADER

SANDRA L. POSTEL
Director, Global Water Policy Project

Vision: Sweeping changes in farming and consumer habits could preserve the world's dwindling supplies of freshwater.

SANDRA POSTEL SEES the decreasing supply of freshwater as the planet's greatest environmental and social challenge. Her private research group, headquartered in Amherst, Mass., helps people around the world get as much benefit as possible from every drop of water. Because agricultural irrigation uses two thirds of all the water taken from rivers, lakes and aquifers, it draws the lion's share of Postel's attention. She advocates a host of improvements for farming, including more efficient irrigation systems and the recycling of wastewater for irrigation. She encourages homeowners to landscape using native plants, which consume less water than the standard, carpetlike grass lawn. Postel also promotes a vegetarian diet, because sustaining high-meat diets such as those in the U.S. requires extensive agricultural water use. Postel's ideas are capturing worldwide attention. For example, the Sopris Foundation invited her to speak as a leading authority on global freshwater issues at its 2002 State of the World Conference.


Sandra L. Postel

BURRILL & COMPANY (*top*); PRODIGENE, INC. (*middle*); WORLDWATCH INSTITUTE (*bottom*)

50 CHEMICALS AND MATERIALS

RESEARCH LEADER

ANTHOULA LAZARIS and COSTAS KARATZAS
Lazaris, senior scientist, and Karatzas, senior vice president for R&D, Nexia Biotechnologies

Vision: Natural, superstrong materials and other products can be manufactured through the genetic engineering of milk proteins.

HIGH ON THE WISH LIST of everyone involved in biomimetics, the field that mimics the materials made by living things, has been a means of mass-producing spider silk. In the past year this milestone was reached by Anthoula Lazaris and Costas Karatzas, a husband-and-wife team, and their colleagues at Nexia Biotechnologies in Montreal. The achievement was striking for a company employing only 100 people, given that it beat mighty DuPont, which had spent 10 years chasing the same goal.

Spider dragline silk is lighter, much tougher and more flexible than an equivalent volume of DuPont's Kevlar aramid fiber—the strongest synthetic fiber on the market. The silk should make possible lightweight body armor that can stop a bullet without weighing down a soldier. Small wonder, then, that after scientists in 1990 identified the two spider genes that make the dragline silk protein, it was military researchers who first spliced them into bacteria to try to manufacture the stuff. Bacteria, however, turned out truncated proteins that lacked toughness. Nexia decided to tackle the problem because of the company's expertise in just the right areas: mammalian genetic engineering and large-molecule biosynthesis.

Anthoula Lazaris and Costas Karatzas

Lazaris and Karatzas were at the technical heart of the effort, as they are for everything Nexia does, says founder and chairman Jeffrey D. Turner. The two employees have been with Turner since he met them when he was a biology professor at McGill University and they were finishing doctorates in molecular biology there. "Anthoula has a firm grasp of gene expression," Turner notes, "and Costas has a strong background in using that to make things, especially large proteins."

Lazaris and Karatzas began by proving that they could get silk from mammalian cells, splicing the spider genes into cow and hamster cells and culturing them until they could draw off enough protein to work with. Then collaborators at the U.S. Army Soldier and Biological Chemical Command in Natick, Mass., used syringes to squeeze out fiber a bit finer than a human hair. The fiber turned out more elastic than, but wider and not quite as strong as, natural dragline silk. The next step was to splice the genes into mammary cells in Nexia's patented breed of fast-growing, early-lactating goats. Goat mammary glands, standing in for a spider's spinnerets, can manufacture the silk along with the milk and secrete tiny silk strands from the animal's body by the bucketful. The polymer strands would have to be extracted from the milk and woven into thread. A few silk-secreting goats have already been born, and the company is now breeding them with hundreds of standard animals on two farms in Canada and the U.S. Beyond flak jackets for the military, Lazaris and Karatzas hope to see their fibers developed as microsutures, artificial ligaments, tennis racket strings and other products demanding advanced materials.

NEXIA BIOTECHNOLOGIES


Randy Howard

BUSINESS LEADER

RANDY HOWARD
President and CEO, Cargill Dow

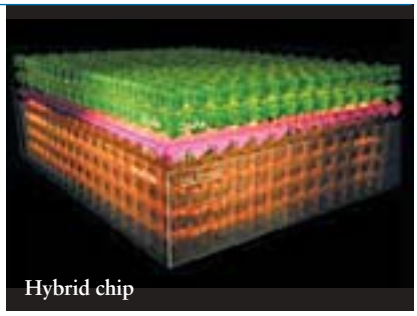
Vision: "Green" plastics can compete economically with more polluting alternatives.

LAST YEAR Randy Howard's company began making plastic not from petroleum but from corn, marking the industry's first foray into renewable products. Howard emphasizes that his firm, a joint venture in Minnetonka, Minn., of Dow Chemical and private grain trader Cargill, sells its biologically based, compostable plastic on performance alone. That is quite a feat in a commodity market that otherwise has not provided the profit margins that biomaterials have enjoyed in pharmaceuticals and other health-related industries. The plastic, called polylactide, has so far found its way into retail food containers, soft-drink cups and bedding. More products will emerge as manufacturing ramps up at a new factory in Blair, Neb., in the heart of corn country. At capacity it will consume 40,000 bushels of corn a day, but eventually some of the fermentation feedstock will come from an even more ecofriendly source: cornstalks and other crop stubble.

COMPANY

MOTOROLA

Vision: Varieties of semiconductors could be combined affordably on a single, superior integrated-circuit chip.


Hybrid chip

IN THE PAST TWO YEARS Motorola has aggressively developed a novel process for layering gallium arsenide onto silicon microchips. That goal had eluded a generation of engineers in the 1980s, most of whom had given up by the time Motorola's Jamal Ramdani achieved it in 1999, by inserting a buffer layer of strontium titanate between the clashing crystals. The forced marriage promises to integrate heretofore incompatible materials, leading to chips that can handle optical signals and electronics that are much faster as well as far cheaper than silicon circuits. Other compound semiconducting materials should also yield to this strategy. Among the tempting applications are the use of one chip to do the work of many, particularly in wireless products. Motorola has launched a crash program to develop the chips in a wholly owned subsidiary, Thoughtbeam, in Austin, Tex. It has already generated hundreds of patents and produced prototype chips for cell phones.

POLICY LEADER

JON S. CORZINE
U.S. Senator of New Jersey

Vision: Better federal and public oversight can fortify chemical plants against terrorists and accidents.


Jon S. Corzine

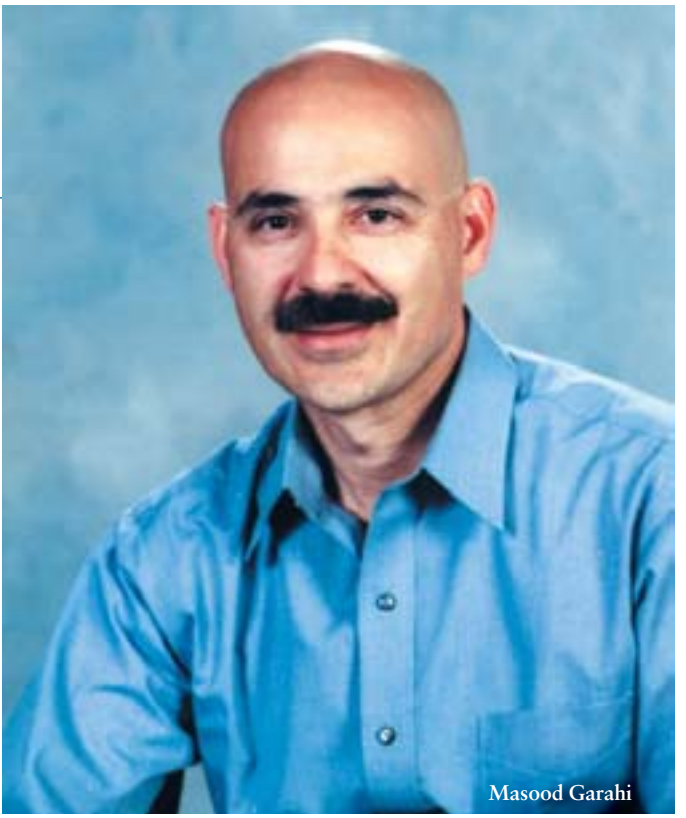
AFTER THE SEPTEMBER 11 ATTACKS, Senator Jon Corzine submitted a bill to improve protection against terrorist acts and industrial accidents at chemical plants. According to an Environmental Protection Agency study, about one in 10 chemical plants handles toxic materials in quantities sufficient to endanger the surrounding population in the event of an uncontrolled release. The study cites two facilities in heavily populated areas in Corzine's state—a factory in East Rutherford that handles chlorine and another in South Kearney that works with sulfur dioxide. Corzine's bill would require the Justice Department and the EPA to identify such plants and ensure that they cut their use of dangerous materials while improving their security measures. Corzine, a freshman senator and former investment banker, has also opposed the Bush administration's efforts to keep secret reports such as the EPA's that identify potential disaster scenarios, arguing that terrorists who want a list of inviting targets can simply consult a telephone book.

CARGILL DOW (*top*); MOTOROLA (*middle*); CHARLES REX ARBOGAST *AP Photo* (*bottom*)

BUSINESS LEADER

MASOOD GARAHI
Chairman and CEO, MeshNetworks

Vision: Broadband wireless networks can arise and thrive without massive investment in infrastructure.


Masood Garahi

WHEN YOUR CELLULAR PHONE cuts out at a crucial point in a conversation, blame it on the shortage of base stations, the relay transceivers on hilltops and buildings that track phones in their vicinity and hand them off to neighboring stations as you move about. Base stations cost a lot of money, which is why engineers look for ways to make the most of those already erected. Masood Garahi's company may have a solution. In June, MeshNetworks in Maitland, Fla., released for field testing the first transceiver chips designed to establish so-called ad hoc wireless networks. The chips incorporate proprietary software and protocols that enable handheld devices to route calls to one another, turning them into a temporary "mesh" network. Garahi maintains that the technology could be cheaper and more quickly put into practice than the long-proposed solution, a standard known as 3G, whose reliance on plentiful base stations has slowed its implementation.

In a mesh network—itself an emerging technology—signals from mobile devices hop along a string of small antennas on, say, telephone poles to a base station, which communicates with the Internet and wired telephone systems. In Garahi's basic scheme, the handheld devices themselves do the job of those antennas. In his advanced scheme, they calculate the best route for a signal, acting as full-fledged routers. In both cases, the cell phone needs a new chip, and Garahi's is it.

Garahi sent his first transceivers into field tests in June, in Delphi Corporation's Japanese networks. There they fit into mobile phones, PDAs and laptops that seek out similarly equipped neighbors, start up two-way communication and then link with other such pairs to form an ad hoc network. If one of the devices can reach a base station, then the entire network has access. Yet even if no base station lies within range, the devices can at least talk to one another, eliminating dropped calls.

Application of this kind of peer-to-peer networking is perhaps best known from Napster's music-swapping service on the Internet. Garahi has argued recently that music swapping will eventually return, most likely among wireless networks. Any group of drivers idling in a traffic jam, for example, could share music files among themselves.

Mesh networks hark back to work at the Defense Advanced Research Projects Agency, which wanted to let soldiers quickly set up communications systems that would function even if parts were destroyed by enemy action. MeshNetworks, which Garahi helped to found in January 2000, licensed a related patent and did substantial development work. Previously, as chief technology officer at Skytel, Garahi led the development of the first two-way paging system.

MESHNETWORKS

COMPANY


Launch of XM satellite

XM SATELLITE RADIO

Vision: Satellite-based radio can provide CD-quality audio entertainment coast to coast without the homogeneous framework of commercial formats.

LAST YEAR XM SATELLITE RADIO in Washington, D.C., launched the first satellite service to provide radio airplay to the entire contiguous U.S. XM's two satellites, dubbed Rock and Roll, hover in geosynchronous orbit and beam down 100 channels of crystal-clear music, news and talk—far more variety than is available in a typical local market. Some 140,000 subscribers have paid $200 for a radio set—primarily designed for automobiles—and a $10 monthly subscription. More patrons are expected this fall when General Motors, which owns 22 percent of XM, begins selling 25 models that carry the radio as standard or optional equipment. Honda is also an investor. XM says it will turn profitable when it reaches four million subscribers, a daunting number given the competition recently offered by the even younger Sirius Satellite Radio, which has deals with Ford, Daimler-Chrysler and BMW. Still, independent estimates put the eventual market in the tens of millions.

RESEARCH LEADER


Marc Goldburg

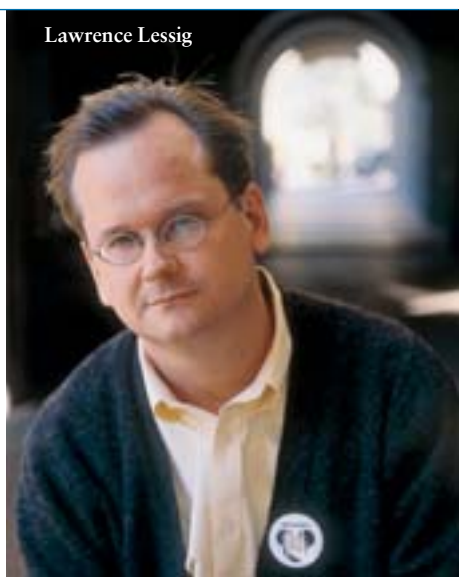
MARC GOLDBURG

Chief technical officer, ArrayComm

Vision: Base stations can beam focused signals directly at mobile devices to improve and expand wireless services.

TO ENSURE A QUALITY CONNECTION to all mobile users in its area, a broadcasting antenna may need such a strong signal that it interferes with neighboring antennas. Why not therefore trade the blunderbuss for a rifle, called an adaptive antenna, that would train a separate beam on each user, providing an even better connection and minimizing interference? The idea has many fathers, but Marc Goldburg, an electrical engineer and a founder of ArrayComm in San Jose, Calif., is one of the most successful at realizing it. Goldburg's algorithm measures all arriving signals, including late-arriving echoes, to infer a wireless device's position and then electronically manipulates the transmitted beam to converge there. Recent trials in Asian countries show that a base station with such "spatial channels" can serve 10 times as many customers as it could by simply broadcasting. In combination with mesh networks, smart antennas could postpone a bandwidth shortage that experts say will soon confront mobile communications.

POLICY LEADER


Lawrence Lessig

LAWRENCE LESSIG

Professor of law, Stanford University Law School, and founder of its Center for Internet and Society

Vision: Intellectual-property rights should not be used to stifle innovation.

LAWRENCE LESSIG SAYS that intellectual-property rights on the Internet have been defined in ways that favor corporate interests at the expense of the common good. He says certain Internet regulations are excessive and discourage innovation, an argument he made persuasively in his 2001 book, *The Future of Ideas* (Random House). Lessig, a former clerk to Supreme Court Justice Antonin Scalia, has no objection to intellectual-property rights or copyrights in general, but he insists that these laws were never intended, and should not be used, to reward innovators but rather to create incentives for people to innovate. He maintains that the recent 20-year extension of the Disney Corporation's copyright on Mickey Mouse fails that test because the cartoon's creators are dead and thus beyond all incentives. He has argued the point on the highest level, when the U.S. Supreme Court recently heard *Eldred v. Ashcroft,* which challenged the extension. The case has proved to be the most newsworthy copyright hearing in many years.

SEA LAUNCH/AP PHOTO (*top*); ARRAYCOMM, INC. (*middle*); ELENA DORFMAN (*bottom*)


Paul Horn

BUSINESS LEADER

PAUL HORN
Director, IBM Research

Vision: Computer systems should function like the human autonomic nervous system, taking care of themselves without coddling or supervision.

AT THE AGENDA 2002 CONFERENCE in October 2001, Paul Horn presented a self-described manifesto that challenged the computer industry to move toward "autonomic computing." As systems become ever larger and more complex, Horn observed, the cost of their construction is increasingly dwarfed by the cost of keeping them running. Indeed, a study of computer installations at various institutions published in March by the University of California at Berkeley found that labor costs typically outstrip equipment costs by a factor of three to 18, depending on the type of system. And one third to one half of the total budget for such installations is spent preventing or recovering from crashes.

Developed under Horn's direction, the IBM manifesto describes a vision in which major computer systems function less like confusing, maintenance-intensive agglomerations and more like the human autonomic nervous system. Horn notes that autonomic systems have eight defining characteristics that computer systems should exhibit. They should be aware of their own boundaries and be able to negotiate with other systems for access to resources. They should communicate using open standards, so the computing world isn't divided into proprietary and incompatible fiefdoms. They ought to adapt to environmental changes, such as updated software or new equipment added to networks. They should monitor their own health, noting when performance falls and seeking ways to restore it. They should use active defense mechanisms to prevent malicious or accidental damage and be capable of repairing most malfunctions. Finally, and most ambitiously, to be more responsive and comprehensible, systems should anticipate users' actions—rebooking a canceled flight, for example, or stopping an unbalanced assembly line.

IBM has since reorganized much of its research agenda around Horn's vision. Horn saw to it that 75,000 copies of his manifesto were delivered to opinion leaders in academia and industry. He has also organized workshops and spoken at other conferences to encourage a more open and collaborative approach to long-term research. As a result, even though not everyone in the field agrees with its details, the manifesto has helped redirect the goals of the computer science community. At Hewlett-Packard, engineers are now focusing on "planetary" computing; at Microsoft, "trustworthy" computing; at Stanford University, "recovery-oriented" computing. No longer is higher performance the only goal.

Already one early IBM Research effort, Project eLiza, has been incorporated into all the company's server products, making them easier to manage. Blue Gene, a supercomputer under construction, uses a "self-healing" cellular architecture that can detect failed processors and work around them. Truly autonomic systems are still years away. But at least now the software industry giants have taken a hard look at their products, confessed their flaws and vowed to do better.

IBM

POLICY LEADER

ANN BEESON
Staff counsel, American Civil Liberties Union

Vision: People should be free to communicate, online and in all media, without fear of censorship.


Ann Beeson

ANN BEESON HAS LED the ACLU's Technology and Liberty program to several signal court victories in the past year. Beeson and other ACLU attorneys challenged the Children's Internet Protection Act (CIPA), a law passed in 2000 that would force libraries to install "content filtering" software on all public Internet terminals. Studies have shown that existing censorship software cannot accurately distinguish pornographic sites from those that are useful and appropriate for children and other library visitors. Beeson also argued against the Child Online Protection Act (COPA), an older but similar law, before the U.S. Supreme Court last November. In May a federal appeals court ruled in favor of the ACLU and repealed the sections of the CIPA law that applied to libraries. The same month the Supreme Court blocked the enforcement of the COPA law.

COMPANY

MATRIX SEMICONDUCTOR

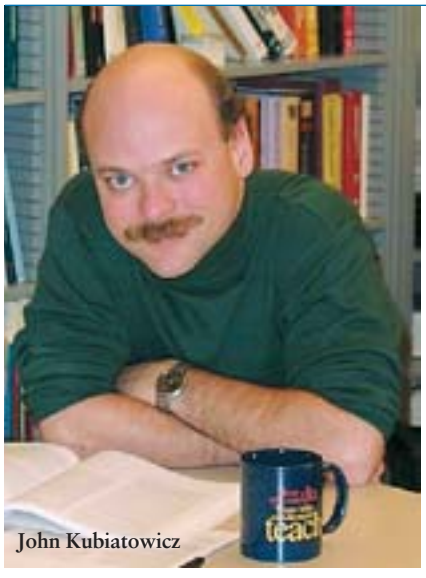
Vision: Integrating circuits vertically as well as horizontally will extend the semiconductor industry's fantastic rate of progress.

MOORE'S LAW—the steady growth in silicon-based microchip complexity on which the information technology industry depends—is approaching fundamental physical limits set by quantum mechanics. In late 2001 and early 2002 engineers at Matrix in Santa Clara, Calif., solved many long-standing technical problems that had prevented the semiconductor industry from taking the next logical step forward: laying out and connecting circuit elements not just within a silicon substrate but also vertically in multiple silicon layers. The company's innovations promise in the short term to make solid-state digital recording media cheaper than photographic film and magnetic tape. In the long term, the expansion of silicon photolithography in the vertical dimension could accelerate Moore's Law and add years to its reign. Thomson Multimedia is incorporating Matrix's 3-D chips into digital audio and video storage cards for release next year.

RESEARCH LEADER

JOHN KUBIATOWICZ
Assistant professor of computer science, University of California, Berkeley

Vision: An Internet-scale "grid computing" system could knit together the processing and storage capabilities of millions of independent computers.


John Kubiatowicz

COMPUTER SCIENTIST John Kubiatowicz is chief architect of the innovative OceanStore system. OceanStore would provide a secure storage space in which millions or even billions of users could share countless gigabytes of digital data. Kubiatowicz's team released prototype software for one part of the system in April and is now testing other components. Data deposited in OceanStore would be split into fragments, and multiple copies of each fragment would be placed on myriad computer servers and desktop machines around the world. The "grid computing" system can reconstruct files from just a fraction of the fragments and regenerate fragments as needed. Data would thus be protected against tampering and accidental damage for generations. Unlike the finicky servers available today, OceanStore would be largely self-maintaining, a crucial feature in an Internet-scale operating system. Kubiatowicz sees OceanStore as part of a greater long-term agenda to build a global-scale operating system that combines the processing power and data storage capacities of millions of separate machines.

DECLAN McCULLAGH (*top*); ANTHONY JOSEPH (*bottom*)

RESEARCH LEADER

JOAQUIN H. CASTRO
Manager of hypersonic programs, Pratt & Whitney Space Propulsion

Vision: Scramjets can propel aircraft and spacecraft at hypersonic speeds, cutting transit times significantly.

Joaquin H. Castro

THE DEVELOPMENT OF HYPERSONIC FLIGHT rocketed past a key milestone last year when engineers from Pratt & Whitney in West Palm Beach, Fla., and the U.S. Air Force successfully operated a powerful propulsion technology called a supersonic-combustion ramjet—"scramjet"—in a high-speed wind tunnel. Scramjet-engine technology has been investigated for nearly half a century because it could enable new generations of ultrahigh-performance aerospace vehicles. These include high-velocity missiles, strike or reconnaissance aircraft, and even space planes that could provide routine, affordable access to low-earth orbit.

A crack research team assembled and led by Joaquin Castro designed and built the functional scramjet prototype. The pioneering work was conducted under contract to the Air Force Research Laboratory as part of its $80-million Propulsion Directorate's Hypersonic Technology (HyTech) program to demonstrate hydrocarbon-fueled scramjet engines. The open-ended HyTech project began in 1995 and should conclude in several years.

A variation of ramjet propulsion technology, a scramjet engine can start up only when the vehicle is already traveling at high speed. As forward progress rams intake air into the engine chamber, the air is compressed while fuel is injected into it. The resulting mixture ignites and expands out the exhaust nozzle at supersonic velocities. In terms of engineering difficulty, this accomplishment is equivalent to lighting a match in a hurricane.

After meticulous preparation, Castro's copper bench model produced positive net thrust while burning conventional fossil-based fuel in Mach 4.5 and 6.5 conditions. During previous attempts, researchers could not determine whether the power plants actually generated thrust. In addition, earlier scramjets ran on volatile, difficult-to-handle hydrogen rather than on traditional hydrocarbon fuels, for which a supply infrastructure already exists. Castro's project helps to prove that scramjets can be viable systems.

Although a scramjet is mechanically simple, the supersonic airflows inside it are extraordinarily complex; simulation requires sophisticated computer models. To improve the mixing of fuel and air and the system's overall performance, Castro's HyTech engineers minimized physical intrusions that could impede smooth passage through the flow path. The team also developed fuel-cooled engine structures in which standard JP-7 fuel removed heat from the combustion chamber while simultaneously being warmed and partially broken down before being set alight.

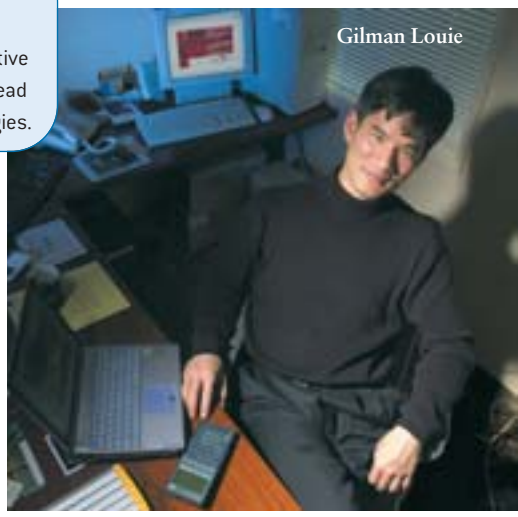
Castro and his development group are now finalizing the design of a forthcoming flight-weight test engine for ground demonstrations. Using this full-size device, the Pratt & Whitney researchers will evaluate performance, operability and structural integrity in a supersonic wind tunnel. Developers must meet strict size and weight requirements to create a flight-worthy scramjet prototype. Following successful ground trials, industry and government scientists and engineers will begin extending the advanced scramjet-engine cycle to future hypersonic vehicle designs, such as the NASA-USAF X-43C space plane.

PRATT & WHITNEY

BUSINESS LEADER

GILMAN LOUIE
President and CEO, In-Q-Tel

Vision: The CIA can harness the innovative power of free enterprise to stay ahead in intelligence-gathering technologies.


Gilman Louie

FOR NEARLY 60 YEARS, the U.S. Central Intelligence Agency developed advanced technologies to support its critical missions by establishing classified "skunkworks" operations in which a group of researchers or a quasi-company was set up to build specific products. Unfortunately, the blistering pace of innovation today has made it difficult for America's spy organization to access and absorb the latest information technologies. In late 1999 the CIA decided to address this problem by chartering Arlington, Va.–based In-Q-Tel as a private not-for-profit venture-capital fund dedicated to identifying and delivering next-generation tools for such tasks as knowledge management and remote sensing. Led by Gilman Louie, an interactive-games business pioneer, the "venture catalyst" firm is investing about $30 million a year in new technical approaches to problems facing an agency inundated daily with massive amounts of data. "Our mission is to go after technologies that are going to get to market anyway," Louie says. "We want to get there ahead of time."

COMPANY

NORTHROP GRUMMAN CORPORATION

Vision: Unmanned spy planes can perform valuable reconnaissance in wartime, reducing the risks to pilots.

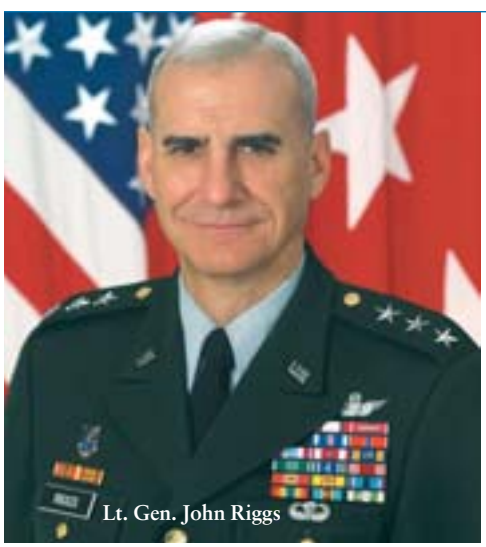

Global Hawk drone

DIFFERENT WARS tend to highlight different military technologies. In the recent Afghan conflict, unmanned aerial vehicles have provided sustained, near-real-time intelligence, surveillance and reconnaissance information that has proved to be invaluable to allied commanders. One of the standout performers over the battlefield has been the American RQ-4A Global Hawk, a new aircraft that had not yet entered operational service when the hostilities began. Only through the efforts of Northrop Grumman and U.S. Air Force personnel did the remotely controlled spy plane make it to the combat zone in time. Despite difficult operational and logistical obstacles, the people and equipment needed to deploy the advanced drones on a wartime footing were put in place in short order. Global Hawk program manager Carl O. Johnson oversaw the team effort by Northrop Grumman Integrated Systems, which is headquartered in El Segundo, Calif. Soon the pilotless aircraft was winging its way high above the mountainous Afghan terrain for as long as 36 hours at a time, delivering high-resolution imagery of the battle zone day and night.

POLICY LEADER

LT. GEN. JOHN RIGGS
Director, U.S. Army Objective Force Task Force

Vision: The 21st-century army needs technologically advanced combat forces to defeat new types of foes.


Lt. Gen. John Riggs

SINCE THE END of the cold war, the U.S. Army has faced major changes to its global war-fighting doctrine. With large-scale hostilities becoming less likely and the prospect of smaller, far-flung "unconventional" conflicts more the norm, the army's force structure—what it has to fight with—is under fundamental reconsideration. John Riggs has been influential in leading the often contentious, even acrimonious debate among military planners about how to transform today's ground divisions into high-tech fighting units of the future. One great controversy is the configuration of its heavy battlefield maneuvering forces, which are currently based on the 70-ton Abrams battle tank. The policy deliberations center on whether next-generation combat vehicles should be so massive, given the difficulty of transporting them by air. If Riggs's untiring arguments are successful, future combat systems could comprise a highly flexible array of manned and robotic land cruisers, directed-energy weapons and unmanned aerial vehicles, all linked by advanced intelligence sensors and data networks.

JULIE JACOBSON *AP Photo (top)*; DEPARTMENT OF DEFENSE *AP Photo (middle)*; U.S. ARMY OBJECTIVE FORCE TASK FORCE *(bottom)*

ENERGY

BUSINESS LEADER

MANFRED STEFENER
Founder and CEO, Smart Fuel Cell Company

Vision: Fuel cells can be made small enough to power even mobile consumer products, from flashlights to laptops.

EVERYONE WITH A LAPTOP has at some point wished for a better battery, but Manfred Stefener believes that miniature fuel cells would be the cleanest, most efficient answer to those dreams. His optimism showed in his business plan, which won a 1999 competition in Munich, where his company is now headquartered. Starting Smart Fuel Cell in 2000, Stefener built a 20-member team and set about creating a prototype. The resulting fuel cells, he maintains, could be used as external power supplies or integrated into portable devices. They would then be applicable to the huge disposable-battery market, which is $4 billion annually in the U.S. alone.


Manfred Stefener

The cells consume methanol and water and give off unnoticeable amounts of air, carbon dioxide and water. Many other fuel cells use hydrogen for fuel, but it is more expensive and potentially more combustible than methanol. When a conventional battery runs down, we throw it away, tossing caustic chemicals into landfills. When one of Stefener's fuel cells runs out of methanol, he removes a methanol cartridge and puts in another. It takes just a few seconds, and fuel already in the cell keeps it running until the new cartridge is in place—meaning you can change the cartridge while the fuel cell continues to power whatever device it is running. The replacement cartridges' potentially low cost—$3 to $5, according to Stefener—would make them attractive because they would last three to five times as long as conventional batteries with the same power rating.

One of the major hurdles for fuel cells has been shrinking them to a practical size. A conventional fuel-cell stack is rarely smaller than a mini refrigerator. But Stefener's first product, the Remote Power System SFC 25.2500 R, is as small as a shoe box and can provide 25 watts of power for 100 hours on one fuel cartridge. So far it is available to Smart Fuel Cell's industrial partners. In January the company began producing the fuel cells; it expects to manufacture more than 1,000 of them by the end of the year. Because the power packs are still too big for a laptop or a handheld gadget, Stefener is aiming current models at camping gear and remote sensors. His team has also built a prototype called the Mobile Office System, which has the proportions of a midsize paperback and can run a laptop for eight hours. By 2004 Stefener plans to produce 100,000 fuel cells annually. He also hopes that his products will be ready to compete in the market with lithium-ion batteries in just a few years.

SMART FUEL CELL COMPANY

RESEARCH LEADER

KEN DEERING
Co-founder and vice president of engineering, Wind Turbine Company

Vision: Windmills built "backward" can provide the greatest power output.

FOR DECADES, ENGINEERS have tried to construct less expensive turbines that capture wind power efficiently. Most have placed the blades on the upwind side of the tower, primarily out of convention, which requires that in strong winds the blades be rigid enough not to deform and hit the tower. Ken Deering put the blades on the downwind side, as a few other rebels before him had. But he bested his predecessors by developing a hinge that lets the blades flex with the wind, thereby reducing the stress on the entire structure. Consequently, he can build taller towers to lift the blades to the strongest winds. He also can use less material in the structure, cutting construction costs. In March, Deering and his colleagues installed a 500-kilowatt turbine in Los Angeles and connected it to the local utility grid. The Wind Turbine Company, based in Bellevue, Wash., has also secured the rights to build a 30-turbine wind farm in Washington State. If erected, it will be the first real testament to his towering design.


Deering's wind turbine

POLICY LEADER

EDDIE O'CONNOR
Chief executive, Airtricity

Vision: Wind power can lead Ireland toward a future of green energy.

EDDIE O'CONNOR is showing policymakers in Ireland that a shift toward environmentally friendly electricity is justified. In recent years, Ireland's legislators have expressed some desire to reduce air pollution but have moved cautiously. By deregulating the country's electric industry, however, they opened the door for renewable energy, and O'Connor jumped in with wind power. Airtricity in Dublin has already built and operates two wind farms and has begun importing electricity from hydropower plants in Scotland. The power flows down the Moyle Interconnector, a new electric cable that joins Northern Ireland to the Great Britain power grid. Airtricity now serves 14,000 business customers and was valued at $65 million in January. O'Connor is planning a 200-turbine wind farm four miles from Ireland's southeastern coast that would generate 520 megawatts. The facility would be the world's biggest offshore wind farm, providing 10 percent of Ireland's electricity demand. The company has also secured permits for six more onshore wind farms, each rated at 400 megawatts. This would give Ireland about 3,000 megawatts of wind power—substantial, considering that the entire generating capacity of Ireland in 2000 was 4,054 megawatts.

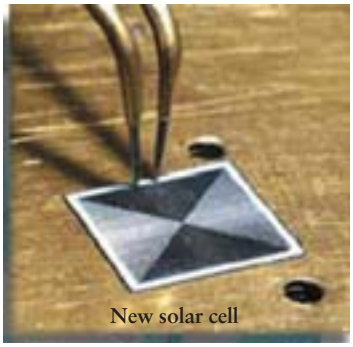

Eddie O'Connor

COMPANY

SPECTROLAB and THE NATIONAL RENEWABLE ENERGY LABORATORY

Vision: Highly efficient photovoltaics can be produced at low cost.

IN JUNE the National Energy Resources Organization honored Spectrolab in Sylmar, Calif., and the National Renewable Energy Laboratory (NREL) in Golden, Colo., for constructing the most efficient land-based solar cell. Spectrolab grew the so-called triple-junction cells, which consist of three layers of different crystals: gallium indium phosphide, gallium arsenide, and germanium. Researchers at NREL then added antireflection coatings and metal contacts to make the cells functional. In laboratory tests, the cells converted 34 percent of the energy in sunlight to electricity, beating the previous world record by about 2 percent. Equally important, Spectrolab used standard production equipment to manufacture the cells and built them on a low-cost base of germanium; they are more than 40 percent more efficient than other mass-produced cells. Spectrolab plans to put these cells in large-scale systems, including ones for utility companies. The cells improve the odds of making photovoltaics commercially successful, and NREL officials predict that their design could lead to ever higher efficiencies.


New solar cell

WIND TURBINE COMPANY (*top*); JASON CLARKE (*middle*); SPECTROLAB (*bottom*)

BUSINESS LEADER

JOAN BAVARIA
CEO, Trillium Asset Management, and founding chair, CERES

Vision: Wall Street should judge companies not merely on their financial returns but on the kind of world they support.


Joan Bavaria

JOAN BAVARIA HAS BEEN AT THE FOREFRONT of the movement to guide investment by social and environmental criteria since its inception more than 20 years ago. She continues to cajole, praise and savage firms according to their behavior. Last year alone, one organization she founded, the Coalition for Environmentally Responsible Economies (CERES), urged shareholders at ExxonMobil's annual meeting to demand the establishment of corporate environmental goals. CERES also threatened to end its cooperation with General Motors because of the company's opposition to stricter fuel-economy standards for SUVs.

In 1981, after several years of working in conventional banking, Bavaria co-founded the Social Investment Forum, an association of lending firms dedicated to investing in corporations chosen on social and environmental merit. She was the forum's president for four years and a member of its board for eight. In 1982 she founded Trillium, then called Franklin Research and Development Corporation, to establish a portfolio of such investments, organizing it as an employee-owned firm that does pro bono work and donates 5 percent of before-tax profits to charity. In 1989 Bavaria founded CERES to promote her standards of corporate behavior.

Potential investors had considered criteria other than the purely financial long before Bavaria came on the scene, but typically they did so for reasons of personal propriety. Muslims, for instance, would invest only in noninterest-bearing instruments, and nonprofit institutions would eschew holdings in firms involved in gambling, alcohol, birth control—whatever they considered unseemly at the time. It was Bavaria and the movement she inspired that first grasped the possibility of influencing corporate behavior by coordinated investing and, no less important, the publicity that accompanies it.

Boston-based Trillium—named for a three-petaled flower, representing the three investment goals of ecology, economy and equity—has 35 employees and manages only $650 million. Yet the respect that the fund commands in the worldwide community of social investors—which, according to the Social Investment Forum, controls more than $2 trillion—gives it substantial clout. "Sell" recommendations and other advice issued by Trillium have affected the disposition of such companies as the Body Shop and Ben & Jerry's. Both companies had won support among socially conscious investors and were thus particularly sensitive to Trillium's censure.

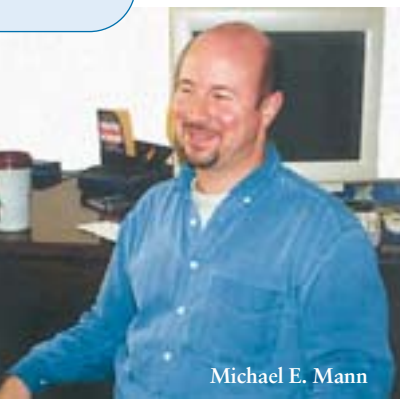
The social-investing community that Bavaria helped to mold can make life difficult even for those companies that have no particular following among environmentalists. In 1989, when the breakup of the *Exxon Valdez* drenched Alaska's Prince William Sound in crude oil, Bavaria titled a list of 10 corporate guidelines she was in the process of drafting the "Valdez Principles." The name caught the eye of many CEOs, who, not wanting to be tarred as Exxon had been, acceded to the objectives; today they are known as the CERES Principles. To gain and retain CERES's imprimatur, these companies—which include BankAmerica, Sun Microsystems and Ford Motor Company—must submit periodic reports to CERES regarding their environmental goals.

TRILLIUM ASSET MANAGEMENT

RESEARCH LEADER

MICHAEL E. MANN
Assistant professor of environmental sciences, University of Virginia

Vision: More scientific evidence will resolve the debate over global warming.


Michael E. Mann

WHILE JUST A POSTDOC at the University of Massachusetts at Amherst in the late 1990s, Michael Mann made a splash with his studies of climate variability over the past 1,000 years. Using tree-ring and ice-core measurements to estimate global temperatures, he and his colleagues Raymond Bradley and Malcolm Hughes devised a graph that was dubbed "the hockey stick" because it showed a sharp upward swing in temperatures after 1850. The research helped to prompt a shift in the position of the United Nations International Panel on Climate Change, which reported last year that humans were responsible for most of the global warming over the past century. Mann was also the lead author of the panel's chapter on climate variability. He has subsequently buttressed his findings with more studies. Mann's work figured prominently in the Environmental Protection Agency's statement earlier this year that humans are gradually heating the planet, and although the Bush administration quickly repudiated that report, the evidence is becoming harder and harder to deny.

COMPANY

PUBLIC SERVICE ELECTRIC AND GAS (PSEG) OF NEW JERSEY

Vision: Power plants can pollute less and still be profitable.

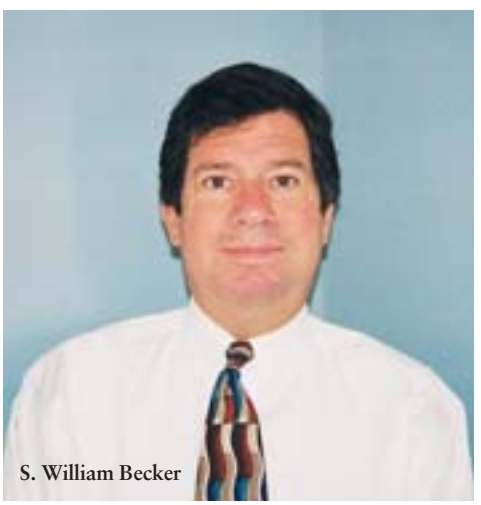

PSEG plant in Hamilton Township, N.J.

PUBLIC SERVICE ELECTRIC AND GAS has earned a reputation among environmentalists as the white knight of the utility industry. The company supports nationwide emissions standards for power plants, saying that rules would help level the industry's playing field and reduce business uncertainty. PSEG won plaudits for its response earlier this year to the Environmental Protection Agency's concerns about two coal-fired power plants in New Jersey. Instead of fighting the EPA's Clean Air Act enforcement actions in court, the utility quickly settled by agreeing to spend more than $300 million on state-of-the-art pollution controls. Scrubbers will remove 90 percent of the sulfur dioxide and 83 percent of the nitrogen oxide that the plants produce. Most significantly, PSEG also agreed to reduce the plant's output of carbon dioxide—the chief greenhouse gas—even though the step isn't required. That act set a fine precedent for the industry.

POLICY LEADER

S. WILLIAM BECKER
Executive director, State and Territorial Air Pollution Program Administrators

Vision: Reducing vehicle emissions will save lives.


S. William Becker

BILL BECKER'S JOB as the lobbyist for the nation's pollution-control agencies made him the prime mover behind one of the most important environmental accomplishments of 2002. In the last year of the Clinton administration, the Environmental Protection Agency announced a rule to cut 95 percent of diesel-truck emissions by 2007. But the cleanup plan was thrown into doubt when President George W. Bush ordered federal agencies to review all Clinton-initiated rules. To keep the plan alive, Becker assembled a coalition that included the Natural Resources Defense Council, the Clean Air Trust, the American Lung Association and even British Petroleum, which acknowledged it could cheaply produce the low-sulfur fuel that would be needed to cut emissions. The full-court press convinced the EPA not to ax the new rule. The plan overcame another hurdle this year when the D.C. Circuit Court of Appeals upheld the EPA's decision. The agency estimates that the rule will prevent 8,300 premature deaths each year.

UNIVERSITY OF VIRGINIA (*top*); PSEG (*middle*); COURTESY OF S. WILLIAM BECKER (*bottom*)

50 MANUFACTURING

BUSINESS LEADER

SUNLIN CHOU
Senior vice president and general manager, Technology and Manufacturing Group, Intel Corporation

Vision: The Moore's Law dictate of smaller, faster, cheaper chips should continue indefinitely.


Sunlin Chou

INTEL IS THE STANDARD-BEARER for Moore's Law—named after founder Gordon Moore, who almost four decades ago predicted that the number of transistors on a chip would double about every 18 months. The Intel executive who ensures that the credo prevails in the dozen or so Intel factories is Sunlin Chou, who coordinates the translation of increasingly complex technologies into reliable manufacturing.

In the past year Chou has overseen Intel's introduction of new materials for chip wiring and insulation as well as its lithographic process for patterning the 0.13-micron generation of chips. (At one time the industry believed that practical technology could not be pushed any smaller than the one-micron generation.) The relatively smooth rollout of these advanced materials and processes is a result of a manufacturing system established in the mid-1980s. Chou headed the first team that overhauled chipmaking at that time, when Intel faced a strong threat from Japanese semiconductor manufacturers. The key organizational innovation was to give the engineers on development teams responsibility for taking a new chip design all the way from the research stage through the first commercial production of high-quality chips. This approach eliminated the handoff from development to manufacturing teams, which usually entailed months or even years of additional tweaking. This seemingly simple change shortened the product introduction cycle for new chips from three to two years, contributing to Intel's emergence as the world's leading semiconductor company.

Chou also became a champion of Intel's "distributed research" model, in which the company marshals outside resources such as universities, national laboratories and start-up companies to help it identify and develop the best early-stage ideas into commercial products. "Sunlin's the one" who has led the transformation, says G. Dan Hutcheson of VLSI Research, a market research firm that tracks semiconductor technologies.

Intel's biggest current project that adheres to this model focuses on extreme ultraviolet lithography. Chou, an avid scuba diver and underwater photographer, heads a board that oversees research by several national laboratories on this technique, intended to allow the patterning of chips with features as small as 10 nanometers. Working with outside groups—and commissioning highly directed research endeavors—avoids the formation of large, central research facilities, which often have trouble aligning their research mission with that of the corporation's business goals. Extreme ultraviolet lithography may ensure that the Moore's Law Express continues to race along at least throughout the rest of Chou's career, if not forever.

INTEL CORPORATION

SCIENTIFIC AMERICAN 50

Scientific American
is pleased to honor these 50 individuals,
teams, companies and other organizations.
Through their many accomplishments
in 2001–2002, they have demonstrated clear,
progressive views of what
our technological future could be,
as well as the leadership, knowledge and expertise
essential to realizing those visions.
Congratulations.

RESEARCH LEADERS OF THE YEAR

Stephen Goff
Syngenta's Torrey Mesa
Research Institute

Huanming Yang
Beijing Genomics Institute

Jun Yu
University of Washington
Genome Center

Led the effort to sequence
the genome of rice,
the world's most important
food crop.

LISA MATTLE (*top*); COURTESY OF HUANMING YANG (*middle*); COURTESY OF JUN YU (*bottom*)

AGRICULTURE

ALLISON A. SNOW Ohio State University
Showed the potential for unintentional transfer of genetically modified traits to weedy plants.

G. STEVEN BURRILL Burrill & Company
Advanced the cause of biotechnology by demonstrating its prudent investment value.

SANDRA L. POSTEL Global Water Policy Project
Advocated sweeping changes aimed at preserving the world's dwindling supplies of freshwater.

PRODIGENE College Station, Tex.
Produced transgenic corn that could be the basis for an edible AIDS vaccine.

CHEMICALS AND MATERIALS

ANTHOULA LAZARIS and COSTAS KARATZAS
Nexia Biotechnologies
Created transgenic goats that can manufacture superstrong spider silk in their milk.

RANDY HOWARD Cargill Dow
Marketed "green" plastics made from corn that are economically competitive with conventional products.

JON S. CORZINE U.S. Senate, New Jersey
Legislated for higher security and safety standards at industrial facilities to defend against terrorism.

MOTOROLA Schaumburg, Ill.
Integrated components made of different semiconductors onto single high-performance chips.

COMMUNICATIONS

MARC GOLDBURG ArrayComm
Invented method for improving wireless services by beaming signals directly to mobile users.

MASOOD GARAHI MeshNetworks
Tested systems for forging ad hoc high-speed wireless networks of mobile devices.

LAWRENCE LESSIG Stanford University Law School
Argued against interpretations of copyright that could stifle innovation and discourse online.

XM SATELLITE RADIO Washington, D.C.
Offered nationwide satellite-based radio broadcasts with digital audio quality and no commercials.

COMPUTING

JOHN KUBIATOWICZ University of California, Berkeley
Designed a highly distributed data storage system that could be shared by millions of users simultaneously.

PAUL HORN IBM Research
Directed his company and others to build more robust computer systems needing less care and supervision.

ANN BEESON American Civil Liberties Union
Fought to ensure that personal freedoms would be preserved online and in digital media.

MATRIX SEMICONDUCTOR Santa Clara, Calif.
Developed vertically integrated microchips that could lower prices while boosting performance.

DEFENSE

JOAQUIN H. CASTRO Pratt & Whitney Space Propulsion
Led the team that designed and built a functional prototype of a scramjet engine.

GILMAN LOUIE In-Q-Tel
Used venture capital to help foster needed intelligence-gathering technologies for U.S. security.

LT. GEN. JOHN RIGGS
U.S. Army Objective Force Task Force
Oversaw the high-tech transformation of ground forces for fighting new kinds of wars.

NORTHROP GRUMMAN CORPORATION El Segundo, Calif.
Rapidly deployed its Global Hawk unmanned spy plane for reconnaissance in Afghanistan.

ENERGY

KEN DEERING Wind Turbine Company
Designed new wind turbines that are more efficient and produce more power.

MANFRED STEFENER Smart Fuel Cell Company
Led the commercial development of miniature fuel cells small enough to power mobile devices.

EDDIE O'CONNOR Airtricity
Guided Ireland's plans to build a massive wind-power station at sea.

SPECTROLAB and THE NATIONAL RENEWABLE ENERGY LABORATORY Sylmar, Calif., and Golden, Colo.
Demonstrated photovoltaic cells with record-breakingly high efficiencies.

ENVIRONMENT

MICHAEL E. MANN University of Virginia
Conducted influential research into global climate change that affected international policies.

JOAN BAVARIA Trillium Asset Management and Coalition for Environmentally Responsible Economies
Promoted social and environmental goals by guiding investments toward companies with responsible policies.

S. WILLIAM BECKER State and Territorial Air Pollution Program Administrators
Lobbied successfully for pollution controls that will cut automotive emissions.

PUBLIC SERVICE ELECTRIC AND GAS State of New Jersey
Responded constructively to concerns about polluting emissions from utilities.

MANUFACTURING

R. STANLEY WILLIAMS, PHILIP KUEKES and YONG CHEN
Hewlett-Packard Laboratories
JAMES HEATH University of California, Los Angeles
Invented nanotechnology devices that might eventually surpass those etched into chips.

SUNLIN CHOU Intel Corporation
Oversaw the development of technologies for making chips whose smallest features are about the size of a virus.

ALICE H. AMSDEN Massachusetts Institute of Technology
Identified strategies for economic development that could be of singular value to non-Western countries on the rise.

NANOOPTO CORPORATION Princeton, N.J.
Devised methods for integrating the disparate components of optical computing onto a single chip.

MEDICAL DIAGNOSTICS

GARY W. SMALL University of California, Los Angeles
Demonstrated that the medical imaging technology PET can give a clear, early diagnosis of Alzheimer's disease.

PETER D. MELDRUM Myriad Genetics
Led his company's development of diagnostic products based on patients' genetic information.

ERIC GOEMAERE
Doctors Without Borders/Médicins Sans Frontières
Brokered agreements making AIDS therapies more available to the poor in South Africa.

CELERA DIAGNOSTICS Alameda, Calif.
Found genes associated with various illnesses and began to develop new tests for diagnosing them early.

MEDICAL TREATMENTS

ANTHONY J. ATALA
Children's Hospital and Harvard Medical School
Demonstrated that cloning can be used to produce transplantable organs and tissues.

EMILIO A. EMINI Merck & Co.
Mobilized his company to invest substantially in AIDS vaccine research.

KOFI A. ANNAN United Nations
Formed the U.N. Global Fund to Fight AIDS, Tuberculosis and Malaria and lobbied for billions in funding.

IDEC PHARMACEUTICALS San Diego, Calif.
Introduced the first commercial radio-conjugated monoclonal antibody for fighting cancer.

TRANSPORTATION

DEAN KAMEN DEKA Research and Development Corporation
Invented his groundbreaking Segway personal transport to widen individuals' travel options.

HIROYUKI YOSHINO Honda Motor Co.
Directed his company's progressive position on improving fuel efficiency and lowering emissions.

FRAN PAVLEY California State Assembly
Legislated state automotive CO_2-emissions standards that will improve standards nationally.

XCOR AEROSPACE Mojave, Calif.
Built and tested extremely small rocket engines that might someday change the economics of launches.

GENERAL TECHNOLOGY

ALEXANDER PINES and JOHN CLARKE University of California, Berkeley, and Lawrence Berkeley National Laboratory
Demonstrated the theoretical feasibility of low-power MRI scanners for diverse medical uses.

JEFFREY IMMELT General Electric Company
Maintained his company's extensive commitment to funding basic research.

RUSH HOLT U.S. House of Representatives, New Jersey
Spearheaded efforts to resurrect the congressional advisory Office of Technology Assessment.

CAMBRIDGE DISPLAY TECHNOLOGY Cambridge, England
Developed and promoted the use of light-emitting polymers in commercial product displays.

BUSINESS LEADER OF THE YEAR

MARK GILBERT

Geoffrey Ballard

General Hydrogen Corporation

Advocated and oversaw the development of fuel cells as automotive energy sources.

RESEARCH LEADER

R. STANLEY WILLIAMS, PHILIP J. KUEKES, YONG CHEN and JAMES HEATH
Williams, director of quantum science research, Kuekes, member of the technical staff, Chen, researcher, Hewlett-Packard Laboratories; and Heath, professor of chemistry and biochemistry, University of California, Los Angeles

Vision: Self-assembling circuits for molecular computing could eventually supplant semiconductor microchips.


R. Stanley Williams


Philip J. Kuekes


Yong Chen


James Heath

NANOTECHNOLOGY ENTHUSIASTS DREAM of a time when circuits with molecule-size components might complement or replace semiconductor electronics. Crucial to that hope is the development of techniques suitable for manufacturing circuitry on that mind-bogglingly small scale. These investigators have received a series of patents that establish them as leaders in molecular computing. At a September conference in Sweden, Stanley Williams announced that Hewlett-Packard Laboratories had made a 64-bit memory device using molecular switches that fit inside a square micron and has a bit density 10 times as great as that of today's silicon memory chips. The labs built the circuits using nanoimprint lithography, a molding method pioneered by Stephen Y. Chou, founder of NanoOpto [*see profile below*]. Yong Chen received a patent in August for the lithography technique. And in a November 2001 patent, Williams, Philip Kuekes and James Heath detailed how to ensure that electrical signals in a complex grid of molecular logic circuits do not interfere with one another.

COMPANY

NANOOPTO CORPORATION

Vision: Building ever smaller optical components will improve the performance of the most powerful networks.

INTEGRATED CIRCUITS combine transistors, resistors and other electronic components on one monolithic chip. Now the start-up NanoOpto has begun to commercialize an innovative manufacturing technology that does the same for the filters, waveguides and laser components used in optical networking. The technique could bring great efficiencies to the manufacture of optical components, which until recently required hand assembly. The brainchild of Princeton University professor Stephen Y. Chou, NanoOpto's process relies on novel quartz or silicon molds to fashion features as small as 10 nanometers. This approach contrasts with conventional semiconductor manufacturing, which uses optical beams to carve out the analogous structures. Optical lithography, however, has difficulty patterning structures smaller than the wavelength of its light source. NanoOpto's tiny parts can potentially improve the performance of optical networks by bending light in ways that cannot be achieved with classical optical devices. In June, Chou also demonstrated the manufacture of nanoelectronic circuitry using a similar mold process.

POLICY LEADER

ALICE H. AMSDEN
Professor of political economy, Massachusetts Institute of Technology

Vision: One-size-fits-all economic policies are ill suited for poor countries looking to become industrialized.


Alice H. Amsden

ALICE AMSDEN'S INCISIVE ANALYSES of how nations from China to Mexico have developed a healthy industrial base in recent decades are making economists think hard about their policies. In her book *The Rise of "The Rest": Challenges to the West from Late-Industrializing Economies* (Oxford University Press, 2001), she extracts lessons for other societies that are now treading a similar path. One distinguishing characteristic of "the rest"—economies that successfully undertook industrial development—was a robust manufacturing experience that relied on technologies already commercialized elsewhere. Government development policies were a critical factor in building a manufacturing base. James M. Cypher of California State University at Fresno recently wrote of Amsden's work: "If you have time to read only one book on development economics in the next year, read this book.... From her meticulous work arise extremely convincing axioms and principles regarding the dynamics of economic development."

CARLOS GONZALEZ *San Francisco Chronicle* (*top: Williams, Kuekes and Heath*); HEWLETT-PACKARD LABORATORIES (*top: Chen*); COURTESY OF ALICE H. AMSDEN (*bottom*)

50 MEDICAL DIAGNOSTICS

RESEARCH LEADER

GARY W. SMALL
Director, Aging and Memory Research Center, University of California, Los Angeles

Vision: Medical scanners can provide a definitive, early diagnosis of Alzheimer's disease.

GARY SMALL DEVELOPED a technique that unveils the beginnings of Alzheimer's disease in people. Scientists around the world have sought such an early-warning marker ever since German physician Alois Alzheimer noticed clumps and snarls in the neurons of a woman who died of mental illness in 1906. These irregularities in the brain—now called amyloid plaques and tangles—serve as the primary sign of Alzheimer's, which ruins brain structures that serve memory and other mental abilities. Small's work focuses on assessing and treating the disease, which now afflicts 10 percent of people older than 65.

In the November 7, 2001, issue of the *Journal of the American Medical Association,* Small and his research team describe a study of 284 patients with symptoms of dementia. About half the group received a positron emission tomography brain scan (better known as a PET scan), clinical assessment and follow-up exams for at least two years. The other half received a PET scan and a onetime clinical assessment. Patients who later died were autopsied. Before the scan, patients were given an intravenous injection of fluorodeoxyglucose, which is taken up by the brain and reveals differences in glucose metabolism in regions of the brain that can be seen in a PET scan. In the first group, Small and his colleagues compared the initial PET scans with the subsequent course of the dementia and found that the scans predicted the outcome—getting or not getting Alzheimer's—with between 75 and 91 percent accuracy. In the second group, autopsies showed Alzheimer's in 70 percent of the patients, and their PET scans accurately predicted the disease's presence or absence in 88 percent of the cases.


Gary W. Small

Beyond simply looking at differences in brain metabolism, though, Small wanted to image the amyloid plaques and tangles. In the February issue of the *American Journal of Geriatric Psychiatry,* Small and his team describe injecting a protein called FDDNP, which included a radioactive marker, into 16 patients between the ages of 62 and 85. Half of them suffered from dementia. The FDDNP accumulated in brain regions rich in amyloid plaques and tangles, and Small and his colleagues concluded that greater accumulation of the protein correlated with lower scores on memory tests.

Until now, physicians have been limited to cognitive tests, whose results could be ambiguous. Only a brain autopsy could provide a certain diagnosis of Alzheimer's. Although no research confirms that plaques or tangles actually cause Alzheimer's, a person is more likely to experience more severe symptoms of Alzheimer's as the concentration of plaques and tangles increases. Small's noninvasive technique thus provides a potential tool for diagnosis and eventually perhaps some guidance for treatment. Small maintains that this method could lead to determining the levels of amyloid plaques and tangles long before dementia occurs.

U.C.L.A.

BUSINESS LEADER


Peter D. Meldrum

PETER D. MELDRUM
Director, president and CEO, Myriad Genetics

Vision: Understanding a patient's genetic makeup could be the key to better cancer prevention and therapy.

IN A DECADE OF RUNNING Myriad Genetics in Salt Lake City, Peter Meldrum's compassion for people and fascination with science turned his company into a leader in developing therapeutic and diagnostic products based on genes and proteins. Investigators at Myriad find the sequence of nucleotides in the human genome that make up disease-related genes and then decipher the jobs of the proteins made by those genes. With such information, Meldrum and his colleagues are devising a series of tests that reveal a patient's genetic predisposition for various cancers, including breast and ovarian. In the past year they launched two new tests for colon and skin cancers. To make their tests available commercially, Meldrum's team created two subsidiaries, Myriad Pharmaceuticals and Myriad Genetic Laboratories. The operations are collaborating with pharmaceutical leaders, including Abbott Laboratories, Bayer, and Eli Lilly and Company, to broaden the firms' lines of therapeutics.

POLICY LEADER

ERIC GOEMAERE
Head of Mission, Doctors Without Borders/ Médicins Sans Frontières

Vision: Effective antiretroviral treatments should be available and affordable in AIDS-plagued underdeveloped countries.

THE PERSISTENT ERIC GOEMAERE fights for better AIDS treatment in South Africa. Although more than 10 percent of the country's population is infected with HIV, the government had dragged its feet on providing modern antiretroviral treatments because some officials considered the therapies too expensive and complicated. That changed recently when Goemaere reached an agreement with the government of the Western Cape and began a program in Khayelitsha for distributing antiretrovirals to infected pregnant women. These drugs can reduce HIV symptoms and limit transmission of the virus from mother to child. To answer the government's objections, Goemaere imported less costly generic drugs and initiated programs to help patients take them as directed. The result: 92 percent of the mostly terminal-stage patients in the program ended up with undetectable levels of HIV. Now South Africa's government wants to make antiretroviral therapy available for mothers-to-be to protect unborn children.

Eric Goemaere

COMPANY

CELERA DIAGNOSTICS

Vision: Assessing specific groups of genetic markers will unveil the early stages of many diseases.

CELERA DIAGNOSTICS in Alameda, Calif., uses genetics to devise tests that reveal diseases at early stages. The company specializes in sequencing the genomes of individuals (producing genotypes) and doing it fast—it expects that it will soon generate many genotypes every day. Thus equipped, scientists can look at constellations—groups of genetic markers—that are turned on or off in healthy and diseased populations. New tests can check a patient's blood or tissue sample for the activity of genes in a constellation linked to a specific disease. Abbott Laboratories recently joined forces with Celera to take advantage of the smaller firm's genotyping and tests. Celera is already running large-scale searches for markers that would indicate early stages of chlamydia and hepatitis C, and it is developing an HIV test that will help medical scientists assess drug resistance in the virus.

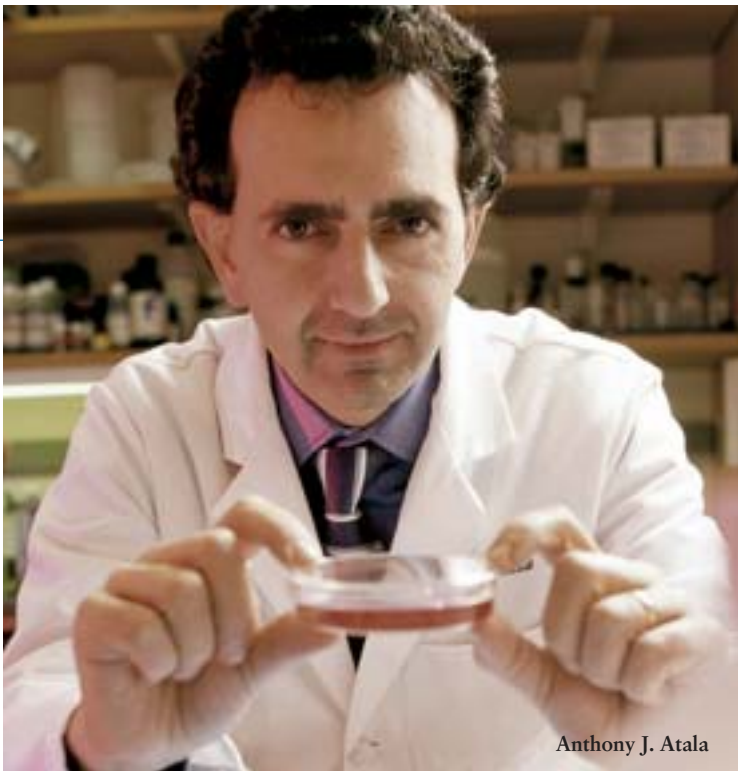
MYRIAD GENETICS, INC. (*top*); CHRISTIAN SCHWETZ (*bottom*)

50 MEDICAL TREATMENTS

RESEARCH LEADER

ANTHONY J. ATALA
Director of tissue engineering, Children's Hospital, Boston, and associate professor of surgery, Harvard Medical School

Vision: Cloned organs and tissues could treat a wide range of diseases.


Anthony J. Atala

FOR MORE THAN FIVE YEARS, Anthony Atala has pursued the goal of engineering spare body parts. Atala has demonstrated that tissue engineering can be used to generate organs and tissues that carry out normal functions once transplanted into a host animal—without being rejected by the animal's body. He has successfully constructed canine bladders by isolating bladder cells from dogs and growing them on sphere-shaped polymer forms. Once the regrown bladders are transplanted back into the donor dogs, they are able to function as usual. Atala is currently awaiting permission from the Food and Drug Administration to try the same procedure with human patients whose own organs must be removed because of diseases such as cancer.

Atala also has used cloning to create transplantable tissues in cows. First he teamed with scientists at Advanced Cell Technology (ACT) in Worcester, Mass.—the company that announced in November 2001 that it had generated the first cloned human embryo. Next Atala and researchers from ACT, the Mayo Clinic and the University of Miami School of Medicine made transplantable heart and skeletal muscle and kidney tissue. The group removed the genetic material from cow eggs and injected skin cells taken from the ears of other cows into the empty eggs. Technicians allowed the injected eggs to divide several times and then placed the early embryos into the wombs of cows that had been treated with hormones. After the embryos grew there for several weeks, the researchers isolated tissue from them and transplanted it underneath the skin of other cattle. The heart muscle "patches" were capable of beating spontaneously, and the kidney tissue could generate urine. The cows receiving the transplants showed no signs of rejecting the tissues.

Although human cloning remains controversial—Congress is still debating whether to ban or regulate the technology—Atala's work shows the promise of therapeutic cloning. Human applications would not require the embryos to be placed in a womb, because scientists have identified stem cells in very early embryos that can give rise to all tissues of the body. They culture the cells in various conditions, and the cells randomly and spontaneously form cardiac muscle, liver or kidney tissue, and so on; researchers are now trying to determine ways to order up a particular tissue. (Embryonic stem cells have not yet been isolated from cattle.) Human cloned tissue could be placed directly into a patient.

Replacement organs made using cloning and tissue engineering could be an important resource. At any given time in the U.S., roughly 80,000 people are on lists awaiting a transplant of an organ from a cadaver. Many die before a suitable organ becomes available or are forced to accept an organ that isn't a perfect match for their tissue type, which often leads to serious rejection problems. Even patients who receive a matched organ have no guarantees: they must take antirejection drugs for the rest of their lives.

LARRY MAGLOTT

BUSINESS LEADER

EMILIO A. EMINI
Senior vice president for vaccine research, Merck & Co.

Vision: Pharmaceutical companies can devise a vaccine that prevents people already infected with human immunodeficiency virus (HIV) from developing AIDS.


Emilio A. Emini

MANY RESEARCHERS have despaired of ever finding a vaccine against AIDS. Although people are living longer with HIV since the advent of antiretroviral drugs, no medication has yet been shown unequivocally to clear the infection. Accordingly, there has been no model of natural immunity for scientists to follow in designing a vaccine. Yet Emilio Emini has mobilized Merck, headquartered in Rahway, N.J., to spend millions on AIDS vaccine research, making it a standout among large pharmaceutical companies, which are often reluctant to develop vaccines. At a key AIDS conference this past February, Emini and his colleagues presented data that have revived hope for an AIDS vaccine. The results came from human trials of two vaccine formulations: one composed only of DNA encoding an HIV protein, the other made of the same snippet of DNA stitched inside an innocuous cold virus "vector." Both generated strong cellular immune responses in volunteers. Emini and his colleagues anticipate that the vaccine might help people infected with HIV to live even longer.

POLICY LEADER

KOFI A. ANNAN
Secretary-general, United Nations

Vision: With strong support from industrial nations, a truly international effort could stamp out the major killer infections.

JUST THREE DISEASES collectively killed 5.7 million people worldwide in 2001. For that reason, in June 2001 Kofi Annan formed the United Nations Global Fund to Fight AIDS, Tuberculosis and Malaria and called for members of the U.N. to raise $7 billion each year to bring the diseases under control around the globe. He succeeded in garnering $2.1 billion in monetary commitments for the fund in its first year, even though the U.S. pledged only $500 million. Annan continues to push the wealthy countries of the north and west to acknowledge the dangers these three diseases pose to global public health and to pay for interventions by fully funding the initiative. Not only does his activism encompass prevention efforts—such as donations of condoms and treated bed nets—but he has made clear that he expects the fund to help cover treatment costs for those who already have the diseases.

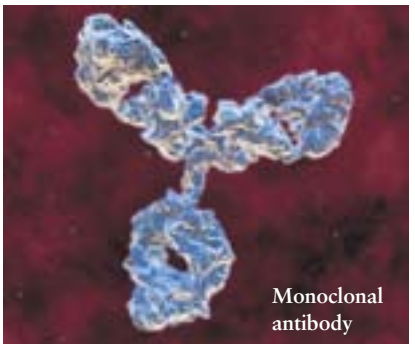

Kofi A. Annan

COMPANY

IDEC PHARMACEUTICALS

Vision: Monoclonal antibodies coupled to lethal molecules can selectively kill cancer cells.

MONOCLONAL ANTIBODIES are proteins of the immune system that bind to specific invaders and target them for destruction by immune cells. In the 1980s they were touted as "magic bullets" that would make it possible to cure cancer, but they fell flat in initial human tests. In 1998 Genentech made the first blockbuster monoclonal antibody–based drug, Herceptin, for women with metastatic breast cancer. Herceptin is thought to work by blocking receptors for growth factors on tumor cells. But for years, scientists have wanted to couple monoclonals with radioisotopes or toxins so they could directly kill the cancerous cells they target. Such conjugated monoclonal drugs have proved difficult to develop and to shepherd through the regulatory process. This past February, however, IDEC in San Diego won federal approval to market Zevalin, the first radioconjugated monoclonal antibody, for the treatment of a type of non-Hodgkin's lymphoma.


Monoclonal antibody

MERCK & CO. (*top*); NAJLAH FEANNY *Corbis SABA* (*middle*); JEFF JOHNSON (*bottom*)

50 TRANSPORTATION


Dean Kamen

RESEARCH LEADER

DEAN KAMEN
Founder, DEKA Research and Development Corporation

Vision: Novel types of transportation can free cities of traffic and greatly expand the mobility of disabled people.

FEW INVENTIONS IN RECENT YEARS have so captured the limelight as Dean Kamen's Segway, a battery-powered, adult-size two-wheeled transporter that rights itself if it starts to tip over in any direction. This past year Segway LLC, the company Kamen set up to commercialize his invention, began lending demonstration models to potential customers in business and government. Two aspects of the vehicle command attention: its control scheme and its power source. The controls employ five gyroscopes and 10 computers to stabilize the scooter, eliminating the need for brakes and steering wheels—the driver merely leans one way or the other to move or to stop. The power source is now based on standard batteries, but Kamen intends to replace them eventually with his souped-up variant of the Stirling engine, a fuel-efficient, external-combustion device often likened to a steam engine.

One bump in the road is the device's safety—some have argued that the vehicle's light weight offers little protection to the driver on the road, and its relatively high speed makes it dangerous to pedestrians on the sidewalk. Nevertheless, 18 states have approved the Segway for use on sidewalks.

Segway owes its fame not only to its charm and its promise of thinning urban traffic but also to the teasing way in which it was originally touted and then unveiled. Technology pundits who had been let in on the secret sang its praises, but then Kamen had to keep mum to secure patent rights and other commercial details. The media had a field day speculating about what was then code-named "IT," apparently for "individual transport."

Control themes have run through Kamen's inventive work ever since his childhood, when he rigged a system of pulleys to make his bed. In high school he came up with a way to automate audiovisual displays that found application in planetariums and public halls and gave him the cash he needed to continue his tinkering. With more than 150 patents to his credit, he has continued to automate and miniaturize technologies for personal use, particularly in medicine, where his insulin pump and his portable dialysis machine have allowed outpatients to enjoy levels of physiological control that hospitals once might have had difficulty achieving. Kamen founded his first biomedical company, AutoSyringe, in 1976.

Even the Segway has a biomedical cousin, the IBOT, which is actually a far more ambitious apparatus—as reflected in its estimated price of $25,000, eight times as much as the expected cost for the Segway. The IBOT's four wheels are yoked in two pairs that can each rotate around an axis. When aligned left to right, the pairs allow normal, motorized movement; when the alignment rotates, inchwormlike, the pairs flip over one another to climb stairs. And when aligned up and down, they stand on tiptoe so the seated rider can look a cocktail-party interlocutor in the eye.

SUZANNE PLUNKETT *AP Photo*

BUSINESS LEADER

HIROYUKI YOSHINO
CEO, Honda Motor Co.

Vision: Automakers should manufacture cars that burn less fuel more cleanly and that people will actually want to drive.

AN ENGINEER'S ENGINEER, Hiroyuki Yoshino symbolizes Honda's go-it-alone attitude to problems both technical and commercial. Last year, after he assumed stewardship of Honda, the company's U.S. division broke ranks with the major American car companies by declining to participate in an advertising campaign against a Senate bill to raise fuel-efficiency standards. It also refused to oppose a California bill to reduce greenhouse gas emissions. Yoshino's advocacy of applying the strict emissions standards for cars to sport utility vehicles has won praise from environmental groups. His stance is an extension of his engineering days, when he designed an engine so clean it did not require a catalytic converter to meet then current emissions standards. Honda generally works alone on fuel cells and hybrid vehicles, rather than forming development partnerships, as its rivals tend to do. With sales up, Yoshino's company has proved that it isn't all that hard, really, to be green.


Hiroyuki Yoshino

POLICY LEADER

FRAN PAVLEY
California State Assembly, 41st District

Vision: The fight against global warming should be waged on a regional as well as a national and international level.

LAST YEAR FRAN PAVLEY'S BILL to establish standards for automotive carbon dioxide emissions became law in California. The victory, by a single vote, capped two years' effort by the freshman legislator and former schoolteacher, who all along refused to weaken the bill in any way. "She took up the fight with great vigor despite strong opposition from industry—it was an act of courage," says Roland J. Hwang of the Natural Resources Defense Council. California, the fifth-largest economy in the world and home to 25 million cars, has long leaned on automakers to cut emissions. In the past, however, the state cared only about emissions that contributed to the formation of smog in California itself. Now, for the first time, Pavley's law will impose standards meant to improve the climate of the entire world.


Fran Pavley

COMPANY

XCOR AEROSPACE

Vision: Low-cost rocket engines could revitalize the aerospace industry.

XCOR IS A SMALL, SCRAPPY COMPANY built on a desert airfield in Mojave, Calif. A handful of the firm's engineers developed a liquid-oxygen/alcohol rocket the size of a soda can that can deliver 400 pounds of thrust. The team attached two of these rockets to a homebuilt single-passenger plane and got world-famous pilot Dick Rutan to put this bird—dubbed the E-Z Rocket—through a series of test flights. CNN was there to cover the flights (which began in July 2001 and are continuing), but the effort was more than just a publicity stunt. Starting and restarting this type of craft in midflight had never before been tried. Although XCOR has thus far limited the E-Z Rocket to low altitudes, a scaled-up version—which would cost about $10 million, the same as a Lear jet—could conceivably travel to the uppermost reaches of the atmosphere and make space tourism a reality.


E-Z Rocket

ITSUO INOUYE *AP Photo (top)*; COURTESY OF FRAN PAVLEY *(middle)*; RON SIDDLE/ANTELOPE VALLEY PRESS *AP Photo (bottom)*

COMPANY

CAMBRIDGE DISPLAY TECHNOLOGY

Vision: Plastic displays might one day replace cathode-ray tubes and liquid-crystal displays.

LEP display

THE WORLD glows with countless electronic displays, from watch faces to gigantic video billboards, almost all of which are based on cathode-ray or liquid-crystal technologies. But in the past year Cambridge Display Technology (CDT) in England has significantly improved the resolution and contrast of its prototype light-emitting polymer (LEP) displays. It has simultaneously become the engine behind the nascent LEP industry's aggressive drive to commercialization.

In the late 1980s University of Cambridge scientists Richard Friend and Andrew Holmes discovered that light-emitting diodes could be made of polymers. In 1992 they founded CDT to develop commercial applications. After almost a decade, the first consumer products containing LEP displays are now reaching the market; their niche is in small alphanumeric screens that show simple sets of segmented characters. Philips is selling an electric shaver that has a Cambridge LEP readout, and Delta Optoelectronics is marketing an MP3 player with the same innovation. In 2003 CDT expects its LEP displays to appear in cellular phones and handheld electronics. Instrument panels are another potential near-term market. Meanwhile Mark IV Industries in Amherst, N.Y., is working with CDT to develop much larger screens for road and transportation signage.

CDT's ultimate goal is for LEP displays to displace the cathode-ray tubes and liquid-crystal displays (LCDs) of televisions and computer monitors. The market research firm DisplaySearch predicts that the organic light-emitting diode market, of which LEPs are a major sector, will be $4 billion by 2007. CDT is fanning the flames by energetically licensing its technology and forming joint ventures with major electronics manufacturers, including Philips, Delta Electronics, DuPont Displays and Osram. The approach brings together CDT's expertise in organic light-emitting diodes and its partners' experience in making commercial electronic products.

Now that they are maturing, LEP displays have a variety of potential advantages over established technologies. Most notably, they can be made thin and flexible enough to roll up like a plastic sheet and can be manufactured in almost any shape. Unlike LCDs, LEPs do not need an ambient light source—typically provided by a backlight and filters—so they can be thinner and lighter and consume less power. LEPs also offer wider viewing angles than LCDs do, approaching 180 degrees. LEP displays are fast (having submicrosecond response times) and operate at low voltages (unlike field-emission displays); each pixel can be designed to emit any color in the visible spectrum simply by modifying its underlying polymer. Manufacturing them is potentially easier than making LCDs or plasma displays.

With Seiko Epson in Japan, CDT has developed and is now commercializing an ink-jet printing technique for manufacturing LEP displays. The partnership has already used this approach to craft high-resolution, full-color displays. It remains to be seen whether LEP displays the size of computer monitors can be mass-produced with the high performance and low cost of existing displays, but CDT plans to try.

CAMBRIDGE DISPLAY TECHNOLOGY


John Clarke


Alexander Pines

RESEARCH LEADER

ALEXANDER PINES and JOHN CLARKE
Pines, chemistry professor, University of California, Berkeley, and Lawrence Berkeley National Laboratory; Clarke, physics professor, U.C. Berkeley, and head of materials physics, LBNL

Vision: Medical magnetic resonance imaging machines can become far smaller, less expensive and therefore more versatile.

NUCLEAR MAGNETIC RESONANCE (NMR) and magnetic resonance imaging (MRI) machines rely on intense magnetic fields—fields so strong they can reel in metal objects from across the room. The powerful field—around one tesla, or 30,000 times the earth's magnetic field—teases apart shifts in the NMR response of atoms in the molecules of a person's body. In March researchers at U.C. Berkeley published results of NMR experiments that used fields as low as a few microteslas. Chemical shifts are indistinguishable in such ultraweak fields, but a second effect, called J coupling between atoms, is detectable. Rhodesian-born NMR pioneer Alexander Pines and English superconductor expert John Clarke led the collaboration. Although significant obstacles remain, the new technique could lead to inexpensive low-field MRI machines for doctors or even handheld body analyzers like those seen in *Star Trek*.

BUSINESS LEADER


Jeffrey Immelt

JEFFREY IMMELT
Chairman and CEO, General Electric Company

Vision: Investing in innovation will propel a company through times of economic uncertainty.

JEFFREY IMMELT TOOK over as CEO of General Electric on September 10, 2001. The next day saw the deaths of two employees to terrorism, a colossal loss for GE's insurance business and a drop in orders for the company's aircraft engines. In the coming months GE's stock slumped to roughly half its value. Yet in January 2002 Immelt announced plans to modernize and expand GE's research center in Niskayuna, N.Y., and to devote resources to five- to 10-year studies in nanotechnology, photonics, advanced propulsion and biotechnology—a big change from GE's classic focus on one- to two-year projects geared toward new products. Measured against spending by research behemoths such as IBM and Lucent Technologies, the new investment is not huge, but it signals a commitment to innovation in the face of business adversity.

POLICY LEADER

RUSH HOLT
U.S. Representative of New Jersey

Vision: The federal government needs better, unbiased scientific briefings and advice to guide intelligent decision making.


Rush Holt

REPRESENTATIVE RUSH HOLT IS ONE of two Ph.D. physicists in Congress (the other is Vern Ehlers of Michigan). Formerly a plasma physicist at Princeton University and now in his second congressional term, Holt is spearheading an effort to reestablish the Office of Technology Assessment, an agency that supplied Congress with expert analyses of scientific and technological issues from 1972 to 1995. His bill, H.R. 2148, would reinstate the office immediately. Opinions differ about how a new OTA would best be structured, but debates such as those on stem cells and cloning show how important it is to provide the top levels of government with better insight and perspective on such fundamental matters. Holt is also an ardent advocate of increasing federal nondefense spending on basic science and is a guardian of funding for education initiatives such as teacher training in math and science.

ROY KALTSCHMIDT *Lawrence Berkeley National Laboratory (top left)*; CLAYTON H. HEATHCOCK *(top right)*; OLIVIA HANLEY *AP Photo (middle)*; COURTESY OF RUSH HOLT *(bottom)*

CONTRIBUTORS TO THE SCIENTIFIC AMERICAN 50 include Mark Alpert, Steven Ashley, Graham P. Collins, Carol Ezzell, Mark Fischetti, W. Wayt Gibbs, Mike May, Philip E. Ross and Gary Stix.

A PICTURE LIKE THIS could not have been drawn with any confidence a decade ago, because no one had yet figured out what causes gamma-ray bursts—flashes of high-energy radiation that light up the sky a couple of times a day. Now astronomers think of them as the ultimate stellar swan song. A black hole, created by the implosion of a giant star, sucks in debris and sprays out some of it. A series of shock waves emits radiation.

The Brightest Explosions in the Universe

Every time a gamma-ray burst goes off, a black hole is born

By Neil Gehrels, Luigi Piro and Peter J. T. Leonard

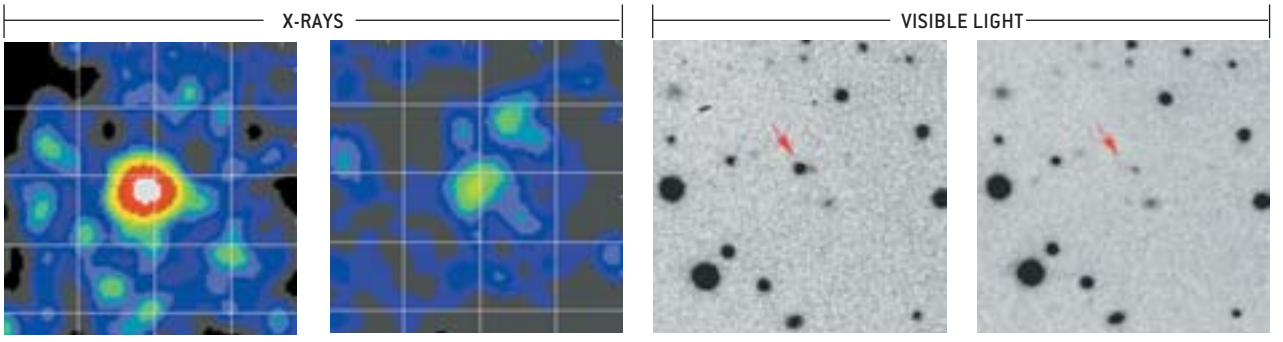
Early in the morning of January 23, 1999, a robotic telescope in New Mexico picked up a faint flash of light in the constellation Corona Borealis. Though just barely visible through binoculars, it turned out to be the most brilliant explosion ever witnessed by humanity. We could see it nine billion light-years away, more than halfway across the observable universe. If the event had instead taken place a few thousand light-years away, it would have been as bright as the midday sun, and it would have dosed Earth with enough radiation to kill off nearly every living thing.

The flash was another of the famous gamma-ray bursts, which in recent decades have been one of astronomy's most intriguing mysteries. The first sighting of a gamma-ray burst (GRB) came on July 2, 1967, from military satellites watching for nuclear tests in space. These cosmic explosions proved to be rather different from the man-made explosions that the

A (VERY) WARM AFTERGLOW

X-RAYS: Eight hours after a burst went off on February 28, 1997, astronomers using the BeppoSAX satellite—including one of the authors (Piro)—saw an x-ray afterglow for the first time. The second image was taken a couple days later, by which time the x-rays had faded by a factor of 20.

VISIBLE LIGHT: A comparably quick reaction by astronomers on La Palma in the Canary Islands allowed the same afterglow to be seen in visible light. Over the next week, the light dimmed to one sixth its original brightness, and as it did so, the surrounding galaxy slowly became apparent.



satellites were designed to detect. For most of the 35 years since then, each new burst merely heightened the puzzlement. Whenever researchers thought they had the explanation, the evidence sent them back to square one.

The monumental discoveries of the past several years have brought astronomers closer to a definitive answer. Before 1997, most of what we knew about GRBs was based on observations from the Burst and Transient Source Experiment (BATSE) onboard the Compton Gamma Ray Observatory. BATSE revealed that two or three GRBs occur somewhere in the observable universe on a typical day. They outshine everything else in the gamma-ray sky. Although each is unique, the bursts fall into one of two rough categories. Bursts that last less than two seconds are "short," and those that last longer—the majority—are "long." The two categories differ spectroscopically, with short bursts having relatively more high-energy gamma rays than long bursts do. The January 1999 burst emitted gamma rays for a minute and a half.

Arguably the most important result from BATSE concerned the distribution of the bursts. They occur isotropically—that is, they are spread evenly over the entire sky. This finding cast doubt on the prevailing wisdom, which held that bursts came from sources within the Milky Way; if they did, the shape of our galaxy, or Earth's off-center position within it, should have caused them to bunch up in certain areas of the sky. The uniform distribution led most astronomers to conclude that the instruments were picking up some kind of event happening throughout the universe. Unfortunately, gamma rays alone did not provide enough information to settle the question for sure. Researchers would need to detect radiation from the bursts at other wavelengths. Visible light, for example, could reveal the galaxies in which the bursts took place, allowing their distances to be measured. Attempts were made to detect these burst counterparts, but they proved fruitless.

Overview/*Gamma-Ray Bursts*

- For three decades, the study of gamma-ray bursts was stuck in first gear—astronomers couldn't settle on even a sketchy picture of what sets off these cosmic fireworks.
- Over the past five years, however, observations have revealed that bursts are the birth throes of black holes. Most of the holes are probably created when a massive star collapses, releasing a pulse of radiation that can be seen billions of light-years away.
- Now the research has shifted into second gear—fleshing out the theory and probing subtle riddles, especially the bursts' incredible diversity.

A Burst of Progress

THE FIELD TOOK a leap forward in 1996 with the advent of the x-ray spacecraft BeppoSAX, built and operated by the Italian Space Agency with the participation of the Netherlands Space Agency. BeppoSAX was the first satellite to localize GRBs precisely and to discover their x-ray "afterglows." The afterglow appears when the gamma-ray signal disappears. It persists for days to months, diminishing with time and degrading from x-rays into less potent radiation, including visible light and radio waves. Although BeppoSAX detected afterglows for only long bursts—no counterparts of short bursts have yet been identified—it made follow-up observations possible at last. Given the positional information from BeppoSAX, optical and radio telescopes were able to identify the galaxies in which the GRBs took place. Nearly all lie billions of light-years away, meaning that the bursts must be enormously powerful [see "Gamma-

MARK A. GARLICK (*preceding pages*); ENRICO COSTA *Institute of Space Astrophysics and Cosmic Physics, CNR* AND THE BEPPOSAX TEAM (*left*); PAUL J. GROOT *University of Amsterdam* (*right*)

Ray Bursts," by Gerald J. Fishman and Dieter H. Hartmann; SCIENTIFIC AMERICAN, July 1997]. Extreme energies, in turn, call for extreme causes, and researchers began to associate GRBs with the most extreme objects they knew of: black holes.

Among the first GRBs pinpointed by BeppoSAX was GRB970508, so named because it occurred on May 8, 1997. Radio observations of its afterglow provided an essential clue. The glow varied erratically by roughly a factor of two during the first three weeks, after which it stabilized and then began to diminish. The large variations probably had nothing to do with the burst source itself; rather they involved the propagation of the afterglow light through space. Just as Earth's atmosphere causes visible starlight to twinkle, interstellar plasma causes radio waves to scintillate. For this process to be visible, the source must be so small and far away that it appears to us as a mere point. Planets do not twinkle, because, being fairly nearby, they look like disks, not points.

Therefore, if GRB970508 was scintillating at radio wavelengths and then stopped, its source must have grown from a mere point to a discernible disk. "Discernible" in this case means a few light-weeks across. To reach that size, the source must have been expanding at a considerable rate—close to the speed of light.

The BeppoSAX and follow-up observations have transformed astronomers' view of GRBs. The old concept of a sudden release of energy concentrated in a few brief seconds has been discarded. Indeed, even the term "afterglow" is now recognized as misleading: the energy radiated during both phases is comparable. The spectrum of the afterglow is characteristic of electrons moving in a magnetic field at or very close to the speed of light.

The January 1999 burst (GRB990123) was instrumental in demonstrating the immense power of the bursts. If the burst radiated its energy equally in all directions, it must have had a luminosity of a few times 10^{45} watts, which is 10^{19} times as bright as our sun. Although the other well-known type of cosmic cataclysm, a supernova explosion, releases almost as much energy, most of that energy escapes as neutrinos, and the remainder leaks out more gradually than in a GRB. Consequently, the luminosity of a supernova at any given moment is a tiny fraction of that of a GRB. Even quasars, which are famously brilliant, give off only about 10^{40} watts.

If the burst beamed its energy in particular directions rather than in all directions, however, the luminosity estimate would be lower. Evidence for beaming comes from the way the afterglow of GRB990123, among others, dimmed over time. Two days into the burst, the rate of dimming increased suddenly, which would happen naturally if the observed radiation came from a narrow jet of material moving at close to the speed of light. Because of a relativistic effect, the observer sees more and more of the jet as it slows down. At some point, there is no more to be seen, and the apparent brightness begins to fall off more rapidly [*see illustration on next page*]. For GRB990123 and several other bursts, the inferred jet-opening angle is a few degrees. Only if the jet is aimed along our line of sight do we see the burst. This beaming effect reduces the overall energy emitted by the burst approximately in proportion to the square of the jet angle. For example, if the jet subtends 10 degrees, it covers about one 500th of the sky, so the energy requirement goes down by a factor of 500; moreover, for every GRB that is observed, another 499 GRBs go unseen. Even after taking beaming into account, however, the luminosity of GRB990123 was still an impressive 10^{43} watts.

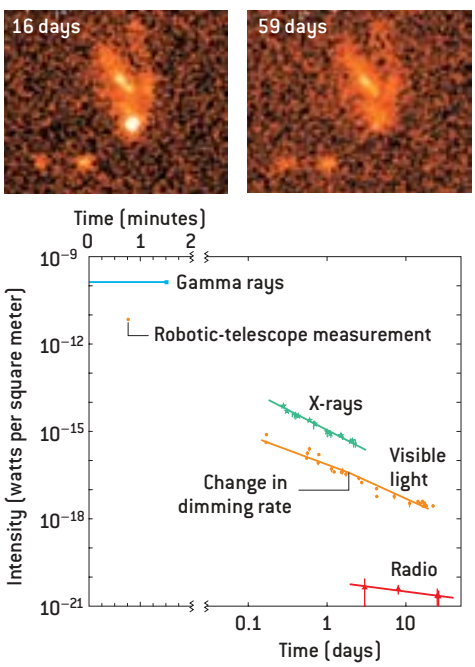
GRB-SUPERNOVA CONNECTION

ONE OF THE MOST interesting discoveries has been the connection between GRBs and supernovae. When telescopes went to look at GRB980425, they also found a supernova, designated SN1998-bw, that had exploded at about the same time as the burst. The probability of a chance coincidence was one in 10,000 [see "Bright Lights, Big Mystery," by George Musser; News and Analysis, SCIENTIFIC AMERICAN, August 1998].

A link between GRBs and supernovae has also been suggested by the detection of iron in the x-ray spectra of several bursts. Iron atoms are known to be synthesized and dumped into interstellar space by supernova explosions. If these atoms are stripped of their electrons and

FADING AWAY

BRIGHTEST GAMMA-RAY BURST yet recorded went off on January 23, 1999. Telescopes tracked its brightness in gamma rays (*blue in graph*), x-rays (*green*), visible light (*orange*) and radio waves (*red*). At one point, the rate of dimming changed abruptly—a telltale sign that the radiation was coming from narrow jets of high-speed material. About two weeks into the burst, after the visible light had dimmed by a factor of four million, the Hubble Space Telescope took a picture and found a severely distorted galaxy. Such galaxies typically have high rates of star formation. If bursts are the explosions of young stars, they should occur in just such a place.

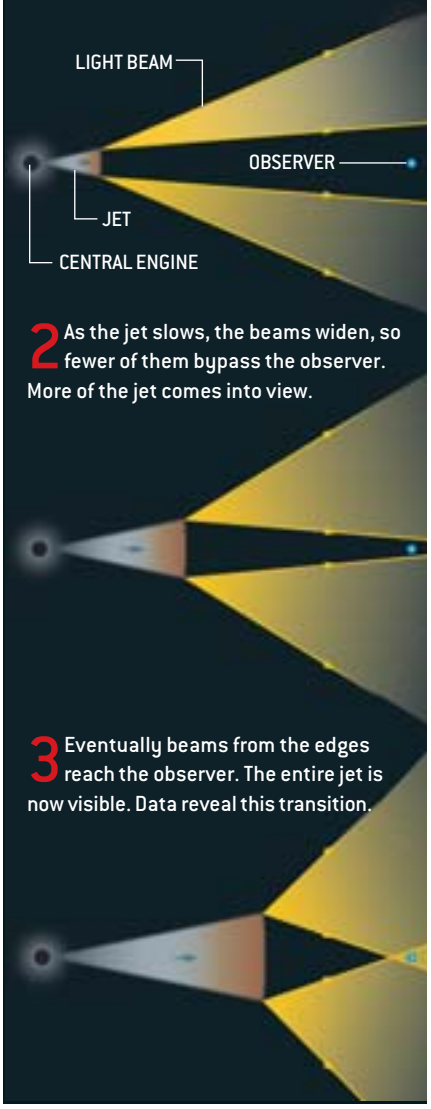


CORNELIA BLIK (*graph*); ANDREW FRUCHTER *Space Telescope Science Institute* AND NASA

BEAM LINES

RELATIVITY PLAYS TRICKS on observers' view of jets from gamma-ray bursts.

1 Moving at close to the speed of light, the jet emits light in narrow beams. Some beams bypass the observer.



2 As the jet slows, the beams widen, so fewer of them bypass the observer. More of the jet comes into view.

3 Eventually beams from the edges reach the observer. The entire jet is now visible. Data reveal this transition.

later hook up with them again, they give off light at distinctive wavelengths, referred to as emission lines. Early, marginal detections of such lines by BeppoSAX and the Japanese x-ray satellite ASCA in 1997 have been followed by more solid measurements. Notably, NASA's Chandra X-ray Observatory detected iron lines in GRB991216, which yielded a direct distance measurement of the GRB. The figure agreed with the estimated distance of the burst's host galaxy.

Additional observations further support the connection between GRBs and supernovae. An iron-absorption feature appeared in the x-ray spectrum of GRB990705. In the shell of gas around another burst, GRB011211, the European Space Agency's X-ray Multi-Mirror satellite found evidence of emission lines from silicon, sulfur, argon and other elements commonly released by supernovae.

Although researchers still debate the matter, a growing school of thought holds that the same object can produce, in some cases, both a burst and a supernova. Because GRBs are much rarer than supernovae—every day a couple of GRBs go off somewhere in the universe, as opposed to hundreds of thousands of supernovae—not every supernova can be associated with a burst. But some might be. One version of this idea is that supernova explosions occasionally squirt out jets of material, leading to a GRB. In most of these cases, astronomers would see either a supernova or a GRB, but not both. If the jets were pointed toward Earth, light from the burst would swamp light from the supernova; if the jets were aimed in another direction, only the supernova would be visible. In some cases, however, the jet would be pointed just slightly away from our line of sight, letting observers see both. This slight misalignment would explain GRB980425.

Whereas this hypothesis supposes that most or all GRBs might be related to supernovae, a slightly different scenario attributes only a subset of GRBs to supernovae. Roughly 90 of the bursts seen by BATSE form a distinct class of their own, defined by ultralow luminosities and long spectral lags, meaning that the high- and low-energy gamma-ray pulses arrive several seconds apart. No one knows why the pulses are out of sync. But whatever the reason, these strange GRBs occur at the same rate as a certain type of supernova, called Type Ib/c, which occurs when the core of a massive star implodes.

GREAT BALLS OF FIRE

EVEN LEAVING ASIDE the question of how the energy in GRBs might be generated, their sheer brilliance poses a paradox. Rapid brightness variations suggest that the emission originates in a small region: a luminosity of 10^{19} suns comes from a volume the size of one sun. With so much radiation emanating from such a compact space, the photons must be so densely packed that they should interact and prevent one another from escaping. The situation is like a crowd of people who are running for the exit in such a panic that that nobody can get out. But if the gamma rays are unable to escape, how can we be seeing GRBs?

The resolution of this conundrum, developed over the past several years, is that the gammas are not emitted immediately. Instead the initial energy release of the explosion is stored in the kinetic energy of a shell of particles—a fireball—moving at close to the speed of light. The particles include photons as well as electrons and their antimatter counterpart, positrons. This fireball expands to a diameter of 10 billion to 100 billion kilometers, by which point the photon density has dropped enough for the gamma rays to escape unhindered. The fireball then converts some of its kinetic energy into electromagnetic radiation, yielding a GRB.

The initial gamma-ray emission is most likely the result of internal shock waves within the expanding fireball. Those shocks are set up when faster blobs

JUAN VELASCO

THE AUTHORS

NEIL GEHRELS, LUIGI PIRO and PETER J. T. LEONARD bring both observation and theory to the study of gamma-ray bursts. Gehrels and Piro are primarily observers—the lead scientists, respectively, of the Compton Gamma Ray Observatory and the BeppoSAX satellite. Leonard is a theorist, and like most theorists, he used to think it unlikely that the bursts were bright enough to be seen across the vastness of intergalactic space. "I have to admit that the GRBs really had me fooled," he says. Gehrels is head of the Gamma Ray, Cosmic Ray and Gravitational Wave Astrophysics Branch of the Laboratory for High Energy Astrophysics at the NASA Goddard Space Flight Center. Piro is a member of the Institute of Space Astrophysics and Cosmic Physics of the CNR in Rome. Leonard works for Science Systems and Applications, Inc., in support of missions at Goddard.

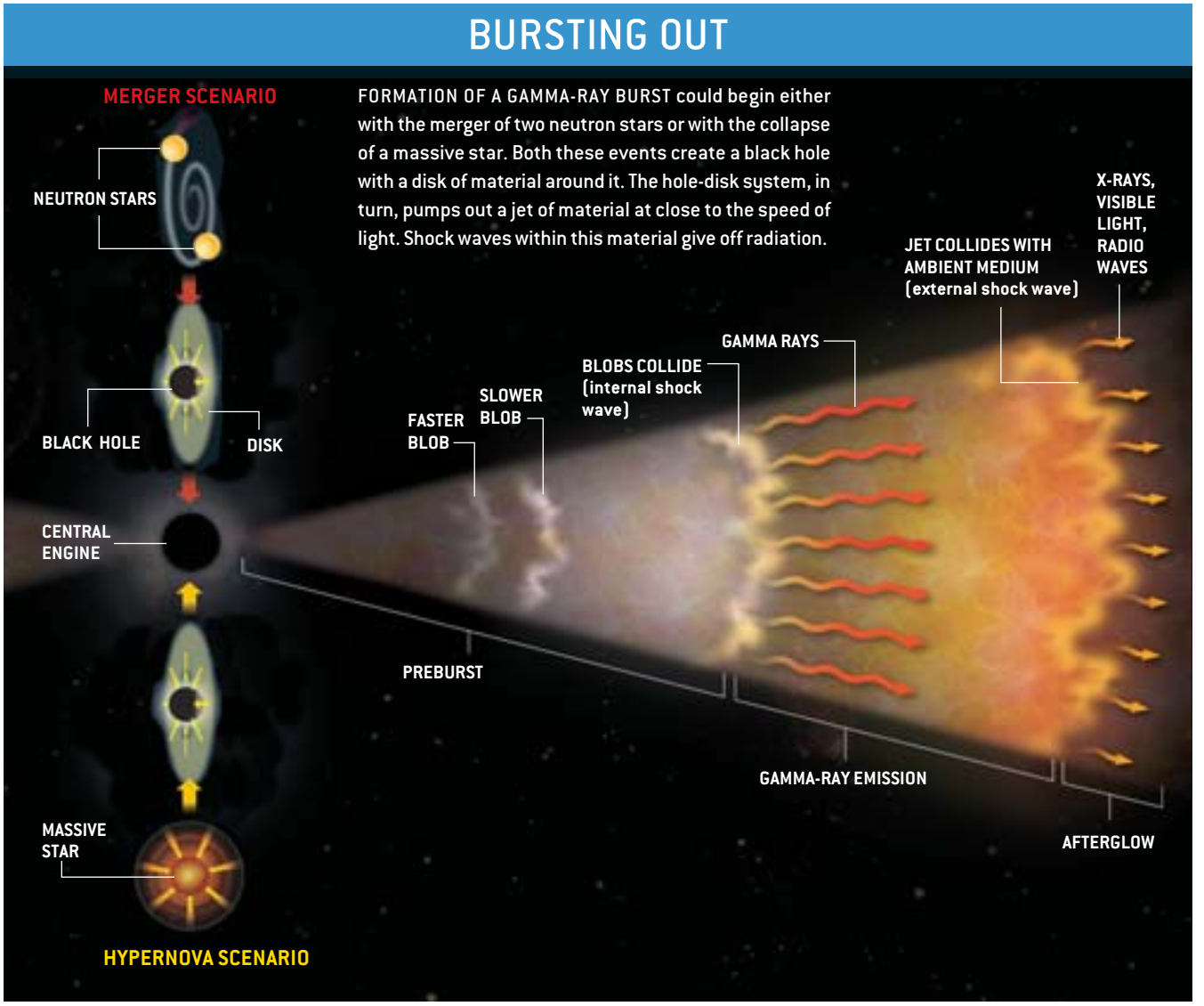
in the expanding material overtake slower blobs. Because the fireball is expanding so close to the speed of light, the timescale witnessed by an external observer is vastly compressed, according to the principles of relativity. So the observer sees a burst of gamma rays that lasts only a few seconds, even if it took a day to produce. The fireball continues to expand, and eventually it encounters and sweeps up surrounding gas. Another shock wave forms, this time at the boundary between the fireball and the external medium, and persists as the fireball slows down. This external shock nicely accounts for the GRB afterglow emission and the gradual degradation of this emission from gamma rays to x-rays to visible light and, finally, to radio waves.

Although the fireball can transform the explosive energy into the observed radiation, what generates the energy to begin with? That is a separate problem, and astronomers have yet to reach a consensus. One family of models, referred to as hypernovae or collapsars, involves stars born with masses greater than about 20 to 30 times that of our sun. Simulations show that the central core of such a star eventually collapses to form a rapidly rotating black hole encircled by a disk of leftover material.

A second family of models invokes binary systems that consist of two compact objects, such as a pair of neutron stars (which are ultradense stellar corpses) or a neutron star paired with a black hole. The two objects spiral toward each other and merge into one. Just as in the hypernova scenario, the result is the formation of a single black hole surrounded by a disk.

Many celestial phenomena involve a hole-disk combination. What distinguishes this particular type of system is the sheer mass of the disk (which allows for a gargantuan release of energy) and the lack of a companion star to resupply the disk (which means that the energy release is a one-shot event). The black hole and disk have two large reservoirs of energy: the gravitational energy of the disk and the rotational energy of the hole. Exactly how these would be converted into gamma radiation is not fully understood. It is possible that a magnetic field, 10^{15} times more intense than Earth's magnetic field, builds up during the formation of the

BURSTING OUT



JUAN VELASCO

disk. In so doing, it heats the disk to such high temperatures that it unleashes a fireball of gamma rays and plasma. The fireball is funneled into a pair of narrow jets that flow out along the rotational axis.

Because the GRB emission is equally well explained by both hypernovae and compact-object mergers, some other qualities of the bursts are needed to decide between these two scenarios. The association of GRBs with supernovae, for example, is a point in favor of hypernovae, which, after all, are essentially large supernovae. Furthermore, GRBs are usually found just where hypernovae would be expected to occur—namely, in areas of recent star formation within galaxies. A massive star blows up fairly soon (a few million years) after it is born, so its deathbed is close to its birthplace. In contrast, compact-star coalescence takes much longer (billions of years), and in the meantime the objects will drift all over the galaxy. If compact objects were the culprit, GRBs should not occur preferentially in star-forming regions.

Although hypernovae probably explain most GRBs, compact-star coalescence could still have a place in the big picture. This mechanism may account for the poorly understood short-duration GRBs. Moreover, additional models for GRBs are still in the running. One scenario produces the fireball via the extraction of energy from an electrically charged black hole. This model suggests that both the immediate and the afterglow emissions are consequences of the fireball sweeping up the external medium. Astronomers have come a long way in understanding gamma-ray bursts, but they still do not know precisely what causes these explosions, and they know little about the rich variety and subclasses of bursts.

All these recent findings have shown that the field has the potential for answering some of the most fundamental questions in astronomy: How do stars end their lives? How and where are black holes formed? What is the nature of jet outflows from collapsed objects?

Blasts from the Past

ONE OUTSTANDING question concerns the dark, or "ghost," GRBs. Of the roughly 30 GRBs that have been localized and studied at wavelengths other than gamma rays, about 90 percent have been seen in x-rays. In contrast, only about 50 percent have been seen in visible light. Why do some bursts fail to shine in visible light?

One explanation is that these GRBs lie in regions of star formation, which tend to be filled with dust. Dust would block visible light but not x-rays. Another intriguing possibility is that the ghosts are GRBs that happen to be very far away. The relevant wavelengths of light produced by the burst would be absorbed by intergalactic gas. To test this hypothesis, measurement of the distance via x-ray spectra will be crucial. A third possibility is that ghosts are optically faint by nature. Currently the evidence favors the dust explanation. High-sensitivity optical and radio investigations have identified the probable host galaxies of two dark GRBs, and each lies at a fairly moderate distance.

Another mystery concerns a class of events known as the x-ray-rich GRBs, or simply the x-ray flashes. Discovered by BeppoSAX and later confirmed by reanalysis of BATSE data, these bursts are now known to represent 20 to 30 percent of GRBs. They give off more x-radiation than gamma radiation; indeed, extreme cases exhibit no detectable gamma radiation at all.

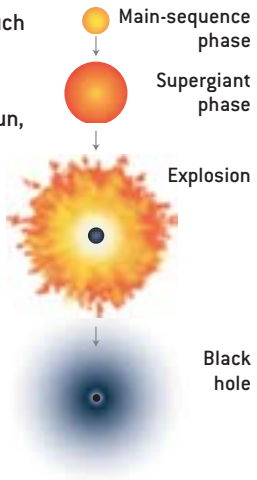
One explanation is that the fireball is loaded with a relatively large amount of baryonic matter such as protons, making for a "dirty fireball." These particles increase the inertia of the fireball, so that it moves more slowly and is less able to boost photons into the gamma-ray range. Alternatively, the x-ray flashes might come from very distant galaxies—even more distant than the galaxies proposed to explain the ghost GRBs. Cosmic expansion would then shift the gamma rays into the x-ray range, and intergalactic gas

CORNELIA BLIK

The Destinies of Massive Stars

STARS SPEND MOST OF THEIR LIVES in the relatively unexciting main-sequence evolutionary phase, during which they casually convert hydrogen into helium in their cores via nuclear fusion. Our sun is in this phase. According to basic stellar theory, stars more massive than the sun shine more brightly and burn their fuel more quickly. A star 20 times as massive as the sun can keep going for only a thousandth as long.

As the hydrogen in the core of a star runs out, the core contracts, heats up and starts to fuse heavier elements, such as helium, oxygen and carbon. The star thus evolves into a giant and then, if sufficiently massive, a supergiant star. If the initial mass of the star is at least eight times that of the sun, the star successively fuses heavier and heavier elements in its interior until it produces iron. Iron fusion does not release energy—on the contrary, it uses up energy. So the star suddenly finds itself without any useful fuel.



The result is a sudden and catastrophic collapse. The core is thought to turn into a neutron star, a stellar corpse that packs at least 40 percent more mass than the sun into a ball with a radius of only 10 kilometers. The remainder of the star is violently ejected into space in a powerful supernova explosion.

There is a limit to how massive a neutron star can be—namely, two to three times as massive as the sun. If it is any heavier, theory predicts it will collapse into a black hole. It can be pushed over the line if enough matter falls onto it. It is also possible that a black hole can be formed directly during the collapse. Stars born with masses exceeding roughly 20 solar masses may be destined to become black holes. The creation of these holes provides a natural explanation for gamma-ray bursts. *—N.G., L.P. and P.J.T.L.*

Classes of Gamma-Ray Bursts

BURST CLASS (SUBCLASS)	PERCENTAGE OF ALL BURSTS	TYPICAL DURATION OF INITIAL EMISSION (SECONDS)	INITIAL GAMMA-RAY EMISSION	AFTERGLOW X-RAY EMISSION	AFTERGLOW VISIBLE EMISSION	HYPOTHETICAL CENTRAL ENGINE	EXPLANATION FOR PECULIAR PROPERTIES
Long (normal)	25	20	✓	✓	✓	Energetic explosion of massive star	Not applicable
Long (ghosts or dark)	30	20	✓	✓	X	Energetic explosion of massive star	Extremely distant, obscured by dust, or intrinsically faint
Long (x-ray-rich or x-ray flashes)	25	30	X	✓	X	Energetic explosion of massive star	Extremely distant or weighed down by extra particles
Short	20	0.3	✓	?	?	Merger of pair of compact objects	Does not occur in a star-forming region, so ambient gas is less dense and external shocks are weaker

would block any visible afterglow. In fact, none of these x-ray flashes has a detectable visible-light counterpart, a finding that is consistent with this scenario. If either x-ray flashes or ghost GRBs are located in extremely distant galaxies, they could illuminate an era in cosmic history that is otherwise almost invisible.

The next step for GRB astronomy is to flesh out the data on burst, afterglow and host-galaxy characteristics. Observers need to measure many hundreds of bursts of all varieties: long and short, bright and faint, bursts that are mostly gamma rays, bursts that are mostly x-rays, bursts with visible-light afterglows and those without. Currently astronomers are obtaining burst positions from the second High Energy Transient Explorer satellite, launched in October 2000, and the Interplanetary Network, a series of small gamma-ray detectors piggybacking on planetary spacecraft. The Swift mission, scheduled for launch next fall, will offer multiwavelength observations of hundreds of GRBs and their afterglows. On discovering a GRB, the gamma-ray instrument will trigger automatic onboard x-ray and optical observations. A rapid response will determine whether the GRB has an x-ray or visible afterglow. The mission will be sensitive to short-duration bursts, which have barely been studied so far.

Another goal is to probe extreme gamma-ray energies. GRB940217, for example, emitted high-energy gamma rays for more than an hour after the burst, as observed by the Energetic Gamma Ray Experiment Telescope instrument on the Compton Gamma Ray Observatory. Astronomers do not understand how such extensive and energetic afterglows can be produced. The Italian Space Agency's AGILE satellite, scheduled for launch in 2004, will observe GRBs at these high energies. The supersensitive Gamma-Ray Large Area Space Telescope mission, expected to launch in 2006, will also be key for studying this puzzling phenomenon.

Other missions, though not designed solely for GRB discovery, will also contribute. The International Gamma-Ray Astrophysics Laboratory, launched on October 17, is expected to detect 10 to 20 GRBs a year. The Energetic X-ray Imaging Survey Telescope, planned for launch a decade from now, will have a sensitive gamma-ray instrument capable of detecting thousands of GRBs.

The field has just experienced a series of breakthrough years, with the discovery that GRBs are immense explosions occurring throughout the universe. Bursts provide us with an exciting opportunity to study new regimes of physics and to learn what the universe was like at the earliest epochs of star formation. Space- and ground-based observations over the coming years should allow us to uncover the detailed nature of these most remarkable beasts. Astronomers can no longer talk of bursts as utter mysteries, but that does not mean the puzzle is completely solved. SA

MORE TO EXPLORE

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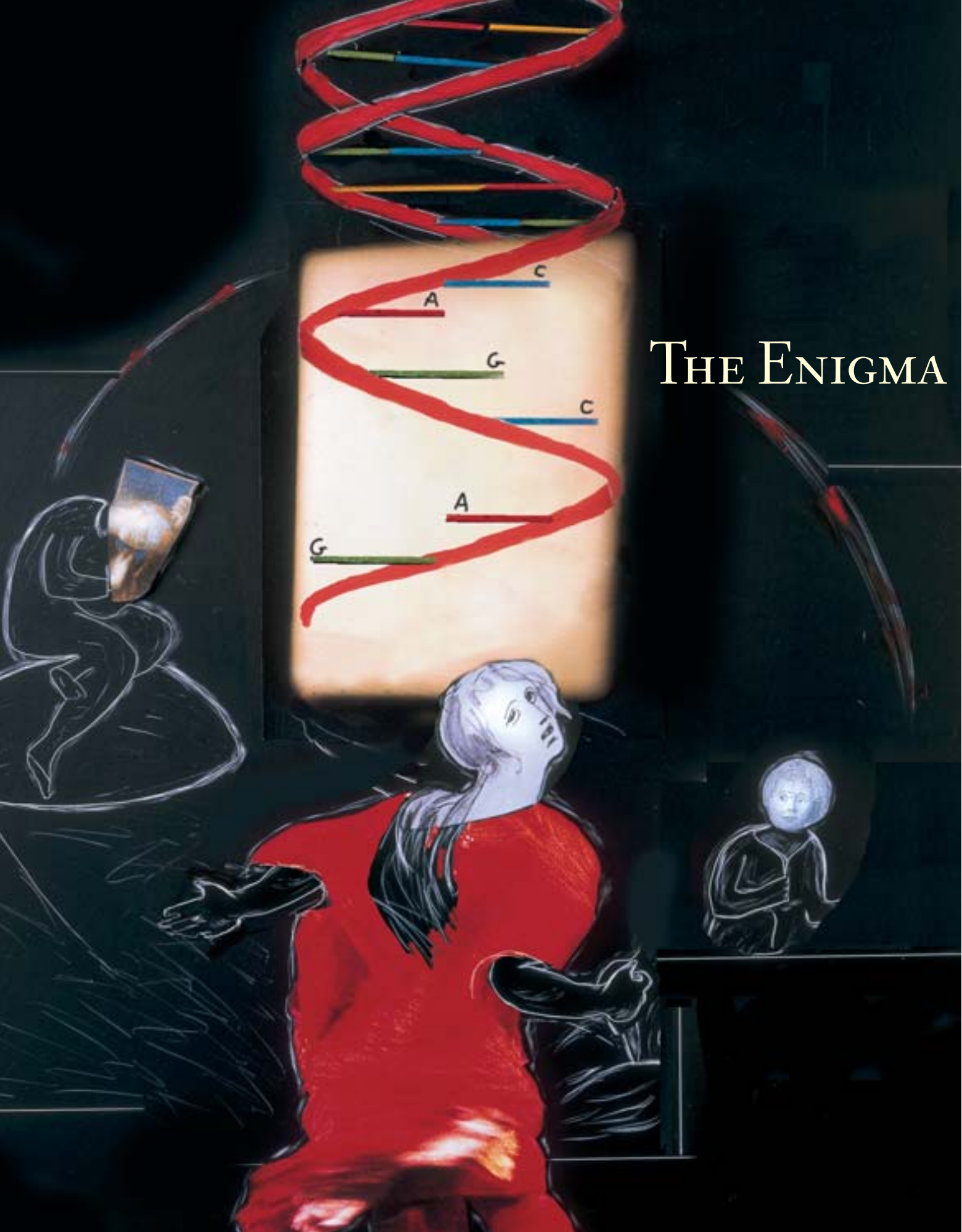


The Enigma

Nearly 10 years after scientists isolated the gene responsible for Huntington's, they are still searching for how it wreaks its devastation

OF HUNTINGTON'S DISEASE

By Elena Cattaneo, Dorotea Rigamonti and Chiara Zuccato

Unusual grimaces are normally the first sign that something is wrong. Next, affected people become more and more absentminded and begin to display involuntary gestures, especially when under psychological or physical stress. As the disease progresses, the dancelike movements—which may be confused with drunkenness—occur more frequently and become disabling. People lose their capacity to perform simple, everyday tasks and show impairments in intellectual abilities such as planning. In the later stages, depression and aggressiveness—and, in the most severe cases, dementia and psychosis—take over, reducing a formerly healthy, vital family member, friend or co-worker to a miserable, bedridden shadow.

This is the grim picture of Huntington's disease, a heritable disorder that commonly strikes people who have the predisposing gene during the prime of life, the 30s or 40s. No effective treatment exists, so the disease advances slowly but inexorably, generally leading to total disability and death after 15 or 20 years. Although Huntington's primarily affects the central nervous system, most individuals suffering from it eventually die from heart or respiratory complications, as a result of their being confined to bed, or from having sustained head injuries caused by frequent falls.

The gene that causes Huntington's disease was identified in 1993 by a coalition of 58 scientists from around the world, including James F. Gusella of Massachusetts General Hospital and Francis S. Collins, who was then at the University of Michigan at Ann Arbor. Shortly thereafter, genetic tests became available that enable people who have family members with Huntington's disease to determine whether they have inherited the mutant gene. Because the gene is dominant, those who inherit the mutant form are destined to acquire the disease and have a 50 percent chance of passing the gene on to each child they conceive. Some people choose to take the test to allow them to plan their lives better; others decide they would rather not know.

Scientists such as ourselves are trying to offer hope to families with Huntington's by working to understand more fully how the mutant gene causes the disease and how it might be circumvented to provide a treatment. We are finding evidence that the mutation underlying

TRAGEDY OF HUNTINGTON'S is that it strikes in midlife, causing involuntary, dancelike movements, mental impairment and anguish—thereby cutting the sufferer off from a normal life. At the root of the disorder is an extended repeat of the DNA sequence cytosine-adenine-guanine (CAG).

LESLIE JEAN-BART

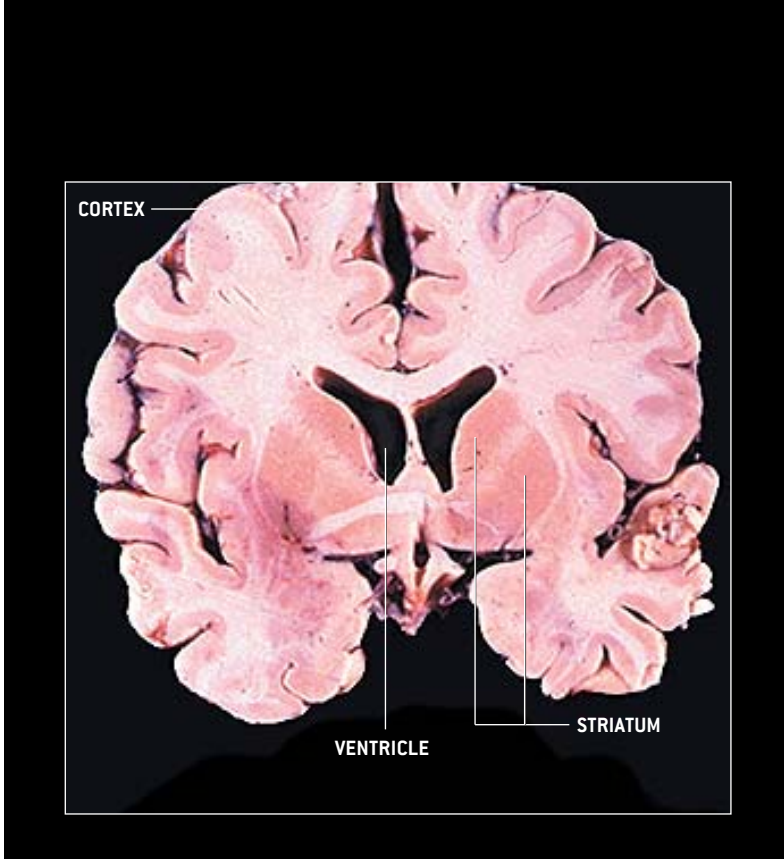
Huntington's is double-barreled: it not only encodes an abnormal protein that appears to be toxic to nerve cells, but the faulty protein can no longer prompt production of a key growth factor, starving a particular part of the brain. Animal studies—and early clinical trials involving humans—suggest that therapies involving growth factors might counter these effects. But the recent findings explain the pathology of Huntington's only partially, so continued research is needed to discern its complexities.

From Huntington's to *huntingtin*

HUNTINGTON'S DISEASE is named for George Huntington, a physician from Ohio. In 1872 Huntington reported extensively about a peculiar hereditary disease that he and his father—who was also a doctor—had observed in a family on Long Island, N.Y. Noting the grotesque and uncoordinated movements of the patients, he termed the disease "chorea," from the Greek word *choros,* for "dance." Today doctors recognize Huntington's as one of the most common hereditary disorders of the brain, affecting roughly one person in every 10,000.

The symptoms of Huntington's are caused by the degeneration of cells, or neurons, located in the striatum, a region deep within the brain that is part of a structure called the basal ganglia [*see illustration at right*]. These neurons normally work to shut off excitatory signals from the motor cortex, the part of the brain that dictates movement. When they die, the motor cortex becomes hyperactive, resulting in involuntary movements (also called chorea). It is less clear how the death of striatal neurons causes the disorder's psychological symptoms.

The gene that is mutated in Huntington's disease is dubbed *huntingtin,* and it lies at one end of chromosome 4. Genes are segments of the DNA double helix that encode the information for making proteins. The code consists of combinations of four simple units, called bases, named adenine (A), thymine (T), cytosine (C) and guanine (G). The bases pair with one another to form the rungs of the DNA helix's ladder: A pairs with T, and C pairs with G. When a cell needs to make new proteins, the helix untwists and the rungs split apart so the cell's machinery can read the code. A triplet of three bases codes for one of the 20 amino acids that are strung together in various combinations to make all the body's millions of distinct proteins.



When researchers pinpointed the *huntingtin* gene, they noted that even in normal people it contains a kind of molecular stutter in which the triplet CAG is repeated between nine and 35 times. (Such expanded repeats can occur in different genes as well and are associated with several other neurodegenerative diseases.) But in people with Huntington's, the stutter becomes especially prolonged—in some rare cases stretching to up to 250 repeats. Intriguingly, scientists have found that people with the most CAG repeats tend to develop the disease at an earlier age than those with a shorter stutter. And for unknown reasons, the number of CAG repeats can increase from generation to generation in families with Huntington's (this appears to happen more frequently when the mutated gene is inherited from the father).

The Theories

THE TRIPLET CAG CODES for the amino acid glutamine, which researchers denote with the letter Q. People with mutant forms of the *huntingtin* gene have huntingtin proteins that contain so-called polyglutamine sections consisting of 36 or more Qs. But why should extra glutamines in a protein cause disease?

The simplest explanation is that an extended stretch of polyglutamines destroys the huntingtin protein's ability to carry out its usual job in the brain. This loss of function hypothesis was initially dismissed because early studies found that huntingtin is made not only in the striatum—the region that shrinks in response to the disease—but in the rest of the brain as well and in other brain regions that do not appear to be affected during the course of Huntington's. In addition, humans have two copies of every gene—one from the mother and one from the father—so people with Huntington's should still have one good copy of *huntingtin* and thus should make a decent amount of the healthy protein. Similarly, people with Wolf-Hirschorn syndrome, a rare

Overview/*Huntington's Disease*

- Huntington's disease—which cripples and causes dementia in people in midlife—is a genetic disease that results from a mutation in a gene called *huntingtin* found on chromosome 4.
- Genetic tests for the disorder exist, but there is no cure.
- People destined to acquire Huntington's have a molecular stutter in *huntingtin* that causes them to make a mutant form of huntingtin protein in which the same amino acid, glutamine, repeats dozens of times.
- Mutant huntingtin appears to be toxic to key nerve cells in the brain. It also lacks the ability to turn on a necessary growth factor gene.

MICHIGAN STATE UNIVERSITY

BRAIN DEVASTATION of Huntington's occurs predominantly in the striatum, a region deep within the brain that is part of a structure called the basal ganglia. The striatum is full and healthy in a brain from someone who died of causes other than Huntington's (*left*); it is shrunken in a brain from a person who had the disorder (*right*).

disease in which a large region of chromosome 4—including one copy of the *huntingtin* gene—is deleted, do not show any symptoms of chorea.

An alternative, gain of function hypothesis holds that the *huntingtin* mutation yields a toxic form of the huntingtin protein. According to this view, the long polyglutamine stretch resulting from the *huntingtin* mutation transforms the shape of the mutant protein, enabling it to stick to several other proteins—notably normal huntingtin, which it disables. The binding could explain why the disease is inherited in a dominant fashion. In fact, the late Max F. Perutz of the Medical Research Council's Laboratory of Molecular Biology in Cambridge, England, and his co-workers determined that the polyglutamine stretches of mutant huntingtin fold into a form called a beta sheet, which is known to act as a glue between proteins. Erich E. Wanker of the Max Delbrück Center for Molecular Medicine in Berlin, Gillian P. Bates of Guy's Hospital in London and Marian DiFiglia of Massachusetts General Hospital and their colleagues have observed aggregates of mutant huntingtin in the brains of mouse models of the disease and in striatal and cortical neurons from people who died with Huntington's.

How these aggregates cause the neuronal damage observed in Huntington's remains strongly debated, however. One hypothesis is that proteasomes—cell structures that destroy worn-out or toxic proteins—are unable to dispose of the mutant huntingtin proteins because of their aberrant conformation. As a result, the mutated huntingtin accumulates unrestrained, killing cells. But the gain of function hypothesis cannot easily explain why brain regions besides the striatum are not affected.

Conversely, other hypotheses suggest that instead of being responsible for the disease, the aggregates might represent a defense mechanism to protect cells from the toxic effects of polyglutamine. Studying the role of these aggregates remains crucial to understanding Huntington's, and finding ways to prevent their formation or break them apart might lead to new drugs for the disease. Wanker and his colleagues have recently devised a laboratory test for identifying potential drugs that can prevent mutant huntingtin from forming aggregates.

Another line of research is based on identifying molecules that are specifically expressed in the striatum and that can interact with huntingtin. If such molecules become trapped in the aggregates, they could contribute to the toxicity. Researchers have so far identified three groups of proteins that interact with huntingtin, but none seems to account for the toxic nature of mutated huntingtin or to explain why only striatal neurons die in Huntington's disease.

A Lifesaver

TO SOLVE THIS PUZZLE, we and others—including Scott Zeitlin of Columbia University—have sought to determine the function of normal huntingtin in the brain. We started by examining the effects of using genetic engineering to insert either extra copies of normal *huntingtin* or mutant forms of the gene into neurons grown in culture dishes in the laboratory. In 2000 we reported that cells that overproduce normal huntingtin can persist when deprived of growth medium or under other conditions that would generally cause them to die. What is more, we found that normal huntingtin appears to keep neurons alive by halting the cascade of molecular events that usually leads to apoptosis, or programmed cell death. We concluded that normal huntingtin works as a lifesaving protein for neurons.

Zeitlin and his colleagues have extended these findings by generating so-called conditional knockout mice, in which both copies of the *huntingtin* gene can be switched off once the animals are mature. When the gene is inactivated, the mice stop making huntingtin protein and develop severe brain damage.

Zeitlin's group has also demonstrated that interrupting huntingtin production at various points in a mouse's life leads to the death of brain neurons by apoptosis. In addition, the researchers have shown that mice lacking the normal form of huntingtin

THE AUTHORS

ELENA CATTANEO, DOROTEA RIGAMONTI and *CHIARA ZUCCATO* are in the department of pharmacological sciences and at the Center of Excellence on Neurodegenerative Diseases at the University of Milan in Italy, where Cattaneo is a professor of pharmaceutical biotechnology. Cattaneo's research also involves the study of stem cells and their use for the treatment of neurodegenerative disorders such as Huntington's disease. Since 1995 she has collaborated on the Coalition for the Cure, an international research consortium promoted by the Huntington's Disease Society of America, and on the Cure HD Initiative, sponsored by the Hereditary Disease Foundation. She has been an investigator of the Italian Telethon Foundation since 1996. Among her awards and honors is a medal from the president of Italy, Carlo Azeglio Ciampi, for her work on stem cells and Huntington's. Rigamonti and Zuccato are postdoctoral associates in Cattaneo's laboratory. Both received their Ph.D.s in 1998: Rigamonti from the University of Milan and Zuccato from the University of Insubria in Varese.

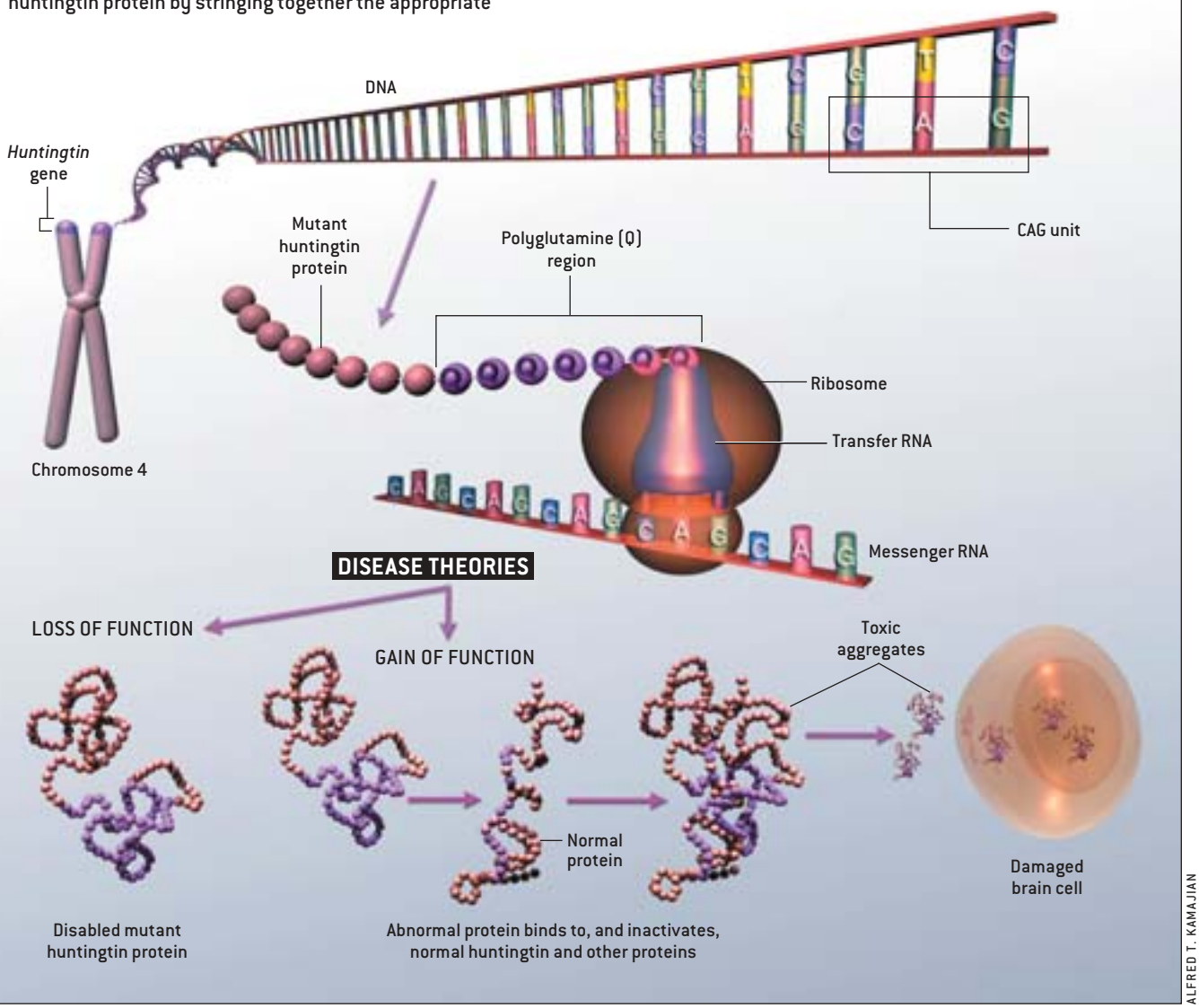
have very similar neurological symptoms to mice that express the mutant form of the protein. This observation suggests that the absence of normal huntingtin and the presence of mutant huntingtin might be different sides of the same coin.

But the mouse studies cannot explain why striatal neurons are targeted preferentially in Huntington's. To unravel this mystery, we and others have turned to studies of brain-derived neurotrophic factor (BDNF), a growth factor that is known to be crucial for the development and survival of neurons in the striatum. BDNF is typically produced in the cell bodies of neurons in the cortex and then travels to the striatum along fibers that span the two brain regions. Accordingly, we began to look for a connection between huntingtin and BDNF.

Intriguingly, we discovered that normal huntingtin stimu-

MOLECULAR BASIS OF HUNTINGTON'S

VARIOUS THEORIES might explain how Huntington's disease arises. The gene responsible for the disease—named *huntingtin*—lies at the tip of chromosome 4. Normally the gene contains between nine and 35 repeats of the DNA sequence cytosine-adenine-guanine (CAG). But in families with Huntington's, the gene usually has between 40 and 60 repeats. When the *huntingtin* gene is active, its DNA sequence is transcribed into messenger RNA, which directs the cell's protein-making machinery—transfer RNA and ribosomes—to make huntingtin protein by stringing together the appropriate sequence of amino acids. Because CAG encodes the amino acid glutamine (which scientists denote with the letter "Q"), mutant huntingtin contains a large, polyglutamine region. This region could cause disease by disabling the huntingtin protein (the loss of function theory), or by allowing it to stick to and inactivate normal huntingtin protein or other proteins (the gain of function theory). Such protein aggregates appear to be toxic to brain cells. The Huntington's mutation might also cause disease through a combination of these mechanisms. *—E.C., D.R. and C.Z.*



ALFRED T. KAMAJIAN

lates the production of BDNF in neurons grown in laboratory cultures. In particular, huntingtin appears to activate the "on" switch, or promoter, of the gene that encodes BDNF. This turns on the BDNF gene, prompting neurons to make more of the growth factor. In contrast, mutant huntingtin does not stimulate the BDNF promoter, resulting in a decrease in BDNF production. We also observed a link between huntingtin and BDNF in experiments involving mice genetically engineered by Michael R. Hayden and his colleagues at the University of British Columbia. We found that these mice, which overproduce normal huntingtin, have elevated amounts of BDNF in their brains, whereas those with mutant huntingtin do not.

Based on this information, we now speculate that Huntington's is a very complex disorder that does not conform neatly to our earlier hypotheses. Not only does the Huntington's mutation generate toxic aggregates that can kill brain cells directly, it also deprives the brain of normal huntingtin—which would otherwise turn on the gene for the growth factor BDNF. Indeed, these two aspects might be related. In 1999 Robert M. Friedlander of Brigham and Women's Hospital and his co-workers observed in genetically engineered mice that the mutant form of huntingtin can destroy the normal version.

Brain Rescue?

ARMED WITH A BETTER understanding of the complexities of Huntington's disease, we can now turn to devising better treatments for the disease. The drugs that are currently available alleviate just some of the symptoms of the disorder and can have serious side effects. Indeed, the drugs often ameliorate one symptom only to make another worse. Although doctors commonly prescribe sedatives to people with Huntington's to control their involuntary movements, these drugs also lower levels in the brain of the neurotransmitter dopamine, worsening the person's depressive symptoms. Antidepressant drugs lift the depression, but some types can exacerbate the chorea. Physicians use so-called neuroleptic drugs to treat patients with hallucinations and psychosis, but the doses must be kept low because these medications can also induce spastic movements. For several years, researchers in the U.S. and Europe have been conducting tests of riluzole, a drug whose specific mode of action is unknown but that is already in use for the neurological disorder amyotrophic lateral sclerosis (ALS, or Lou Gehrig's disease). Still, the drug appears to have limited success against either disorder.

More innovative trials for the treatment of Huntington's are aimed at replacing the damaged neurons with transplants of fetal tissue or at injecting or infusing neurotrophic factors such as BDNF. The first approach has yielded encouraging, though preliminary, results in patients in the early stages of Huntington's, but its use remains controversial in light of ethical questions concerning tissue derived from aborted fetuses. Marc Peschanski and his collaborators at INSERM in Creteil, France, for instance, have transplanted fetal neurons into the striata of five patients with Huntington's, and three have experienced appreciable improvements in their motor and intellectual function. New clinical trials are now being conducted in a larger number of patients. Meanwhile, to overcome the limited availability of fetal cells and the controversy surrounding them, researchers are now trying to grow neural stem cells in the laboratory for use in transplantation. But stem cells are less mature than fetal cells, and it is an open question whether stem cells will be able to develop and integrate fully into a patient's damaged brain. It is also unclear whether mutant huntingtin made by a patient's other neurons would disrupt the normal huntingtin made by engrafted fetal or stem cells.

The second approach is based on animal studies showing that ciliary neurotrophic factor (CNTF) can protect striatal cells from death. But it has been difficult to deliver the growth factor to the brain in sufficient amounts and in active form. Proteins such as BDNF and CNTF are broken down in the stomach when given orally; when administered by injection or infusion, they sometimes cannot cross the barrier of cells that protects the brain from substances circulating in the blood. Accordingly, Patrick Aebischer of the Swiss Federal Institute of Technology in Lausanne has designed a gene therapy protocol in which he and his co-workers implant semipermeable capsules containing cells genetically modified to deliver CNTF into the right ventricle of the brain. Having found in chimpanzees that the capsules release CNTF continuously, Aebischer's group has teamed up with Peschanski's to evaluate the strategy in a small number of patients. CNTF is being tried in people before BDNF because its effects in protecting striatal cells were discovered several years before the benefits of BDNF were known. Various research groups are now planning to test BDNF in animals and, depending on the results, in Huntington's sufferers.

The BDNF promoter might also offer a target for developing drugs against Huntington's disease. Drugs that mimic the natural function of huntingtin in turning on the BDNF gene might circumvent the huntingtin mutation. Because such drugs would act "downstream" of the huntingtin protein, it might not matter if a patient's normal huntingtin became tied up into aggregates with the mutant form of the protein. Indeed, we predict that the future of pharmacological therapy for Huntington's rests on drugs that can interfere with the toxicity of mutant huntingtin while restoring normal huntingtin's beneficial effects. Perhaps by unraveling the skeins of the mysteries of Huntington's, we will be able to provide hope for the next generation. SA

MORE TO EXPLORE

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The Web sites of the Huntington's Disease Society of America (**www.hdsa.org**) and the Hereditary Disease Foundation (**www.hdfoundation.org**) are useful resources on genetic testing for the disease and contain information for families with Huntington's.

How soon humanity will have to move inland to escape rising seas depends in great part on how quickly West Antarctica's massive ice sheet shrinks. Scientists are finally beginning to agree on what controls the size of the sheet and its rate of disintegration

On Thin Ice?

BY ROBERT A. BINDSCHADLER AND CHARLES R. BENTLEY

GARY BRAASCH

DISINTEGRATION OF ICE along Antarctica's coasts is replenished by snowfall farther inland. Scientists sound an alarm when they find evidence that ice is being lost faster than it is accumulating.

Twelve thousand years ago, as the earth emerged from the last ice age,

vast armadas of *Titanic*-size icebergs invaded the North Atlantic. Purged vigorously from the enormous ice sheets that smothered half of North America and Europe at the time, those icebergs displaced enough water to raise global sea level more than a meter a year for decades.

As the frozen north melted, the ice gripping the planet's southernmost continent remained essentially intact and now represents 90 percent of the earth's solid water. But dozens of scientific studies conducted over the past 30 years have warned that the ice blanketing West Antarctica—the part lying mainly in the Western Hemisphere—could repeat the dramatic acts of its northern cousins. Holding more than three million cubic kilometers of freshwater in its frozen clutches, this ice sheet would raise global sea level five meters (about 16 feet) if it were to disintegrate completely, swamping myriad coastal lowlands and forcing many of their two billion inhabitants to retreat inland.

Most Antarctic scientists have long concurred that the continent's ice has shrunk in the past, contributing to a rise in sea level that continued even after the northern ice sheets were gone. The experts also agree that the ice covering the eastern side of the continent is remarkably stable relative to that in West Antarctica, where critical differences in the underlying terrain make it inherently more erratic. But until quite recently, they disagreed over the likelihood of a catastrophic breakup of the western ice sheet in the near future. Many, including one of us (Bindschadler), worried that streams of ice flowing from the continent's interior toward the Ross Sea might undermine the sheet's integrity, leading to its total collapse in a few centuries or less. Others (including Bentley) pointed to the sheet's recent persistence, concluding that the sheet is reasonably stable.

For a time it seemed the debate might never be resolved. Agreement was hampered by scant data and the challenge of studying a continent shrouded half the year in frigid darkness. In addition, although areas of the ice sheet have drained quickly in the past, it is difficult to determine whether changes in the size or speed of the ice seen today are a reflection of normal variability or the start of a dangerous trend. In the past few years, though, a variety of field and laboratory studies have yielded a growing consensus on the forces controlling West Antarctica's future, leading experts in both camps to conclude that the ice streams pointing toward the Ross Sea are not currently as threatening as some of us had feared.

We remain puzzled, however, over the ice sheet's ultimate fate. New studies have revealed thinning ice in a long-neglected sector of West Antarctica, suggesting that a destructive process other than ice streams is operating there. And another region—the peninsula that forms Antarctica's northernmost arm—has recently experienced warmer summer temperatures that are almost certainly the reason behind an ongoing breakup of ice along its coasts.

Around the world temperatures have risen gradually since the end of the last ice age, but the trend has accelerated markedly since the mid-1990s with the increase of heat-trapping greenhouse gases in the atmosphere. So far the peninsula seems to be the only part of Antarctica where this recent climate trend has left its mark; average temperatures elsewhere have risen less or even cooled slightly in the past 50 years. Researchers are now scrambling to determine whether global warming is poised to gain a broader foothold at the bottom of the world.

Overview/*Antarctic Ice*

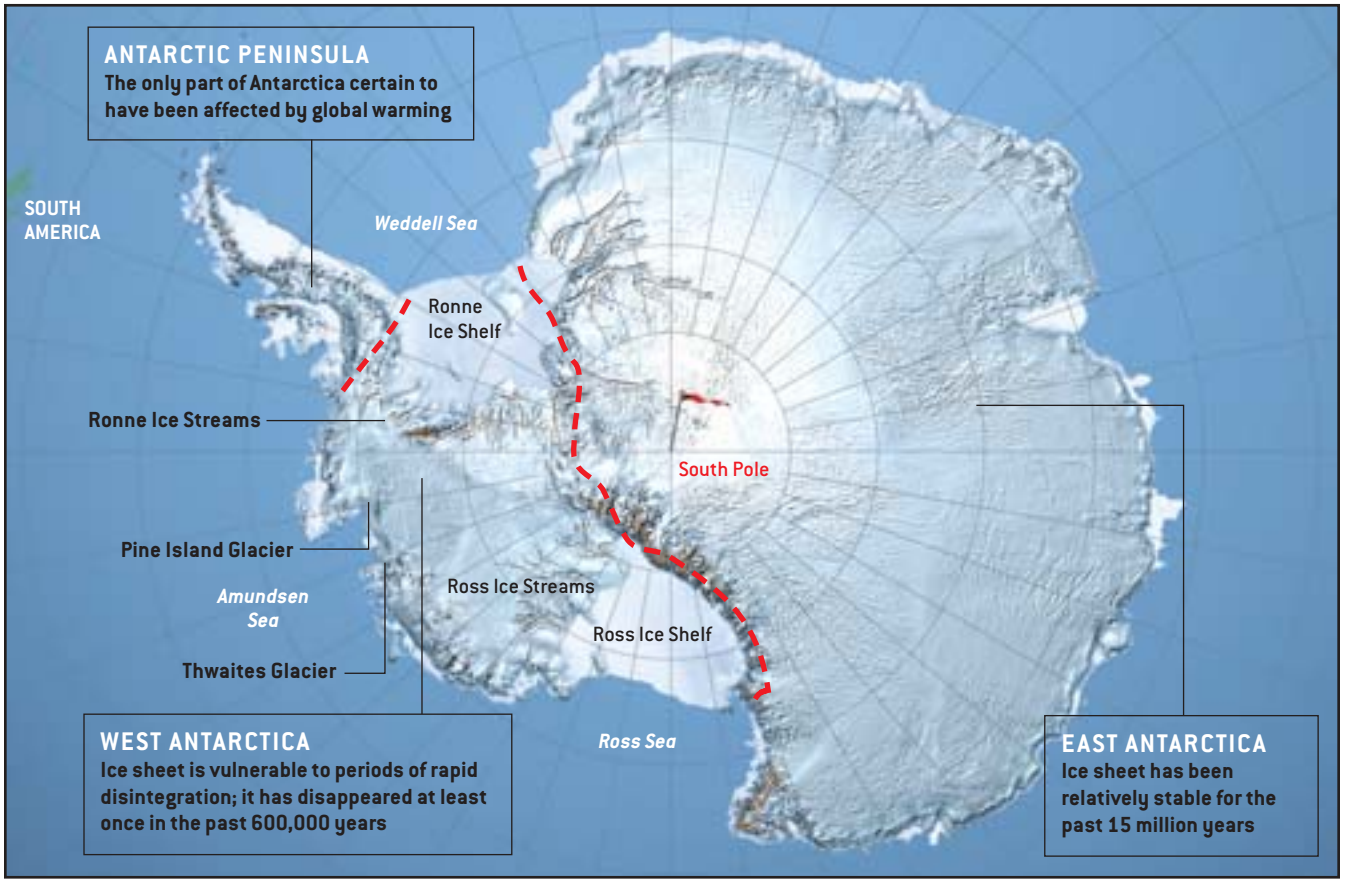
- For nearly three decades, numerous Antarctic experts warned that West Antarctica's ice sheet is in the midst of a rapid disintegration that could raise global sea level five meters in a few centuries or less.
- Many of those researchers now think that the ice sheet is shrinking much more slowly than they originally suspected and that sea level is more likely to rise half a meter or less in the next century.
- That consensus is not without its caveats. The ice sheet's poorly understood Amundsen sector now appears to be shrinking faster than previously thought.
- Global warming, which has so far played a negligible role in West Antarctica's fate, is bound to wield greater influence in the future.

Early Alarms

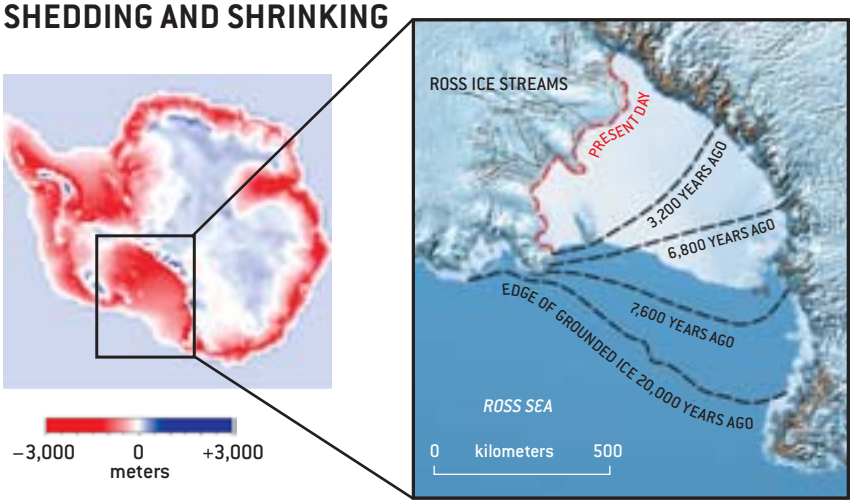
INDICATIONS THAT the West Antarctic ice sheet might be in the midst of a vanishing act first began cropping up about 30 years ago. In 1974 Johannes Weert-

PAST, PRESENT AND FUTURE?

ANTARCTICA'S THICK BLANKET OF ICE (*below*) has been contracting, mostly gradually but sometimes swiftly, since the height of the last ice age, 20,000 years ago. The greatest reduction has occurred in West Antarctica, where the ice sheet is considerably more fragile than its counterpart in the east. Because the western sheet has changed quickly in the past, scientists have been unsure whether recent dramatic ice losses reflect normal variability or the start of an ominous trend toward total collapse. In the wake of a catastrophic collapse, rapidly rising seas would flood coastal communities around the world. *—R.A.B. and C.R.B.*

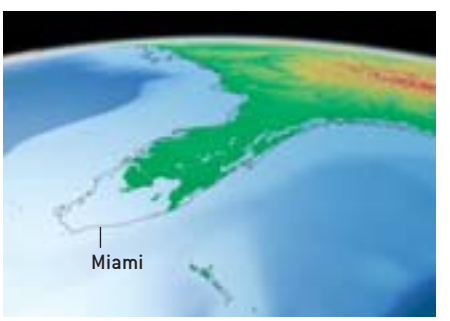


SHEDDING AND SHRINKING



CHANGE IN ICE THICKNESS since the last ice age (*above left*) translates into a loss (*red*) of about 5.3 million cubic kilometers, much of it from West Antarctica. The ice sheet's grounded edge, that reaching the seafloor, has shrunk particularly rapidly in the Ross Sea (*detail, right*) over the past 7,000 years, retreating some 700 kilometers inland.

THE WORST-CASE SCENARIO



COMPLETE COLLAPSE of West Antarctica's ice sheet would raise sea level five meters. Among the casualties would be southern Florida (*above*), where about a third of the famous peninsula would disappear underwater. Today West Antarctica contributes about 10 percent of the average sea-level rise of two millimeters a year.

DAVID FIERSTEIN (*main Antarctica map and Ross Ice Shelf map*); ROBERT A. BINDSCHADLER (*ice thickness map*); WILLIAM F. HAXBY (*Florida map*)

Chilly Realities

PREDICTING ANTARCTIC ICE SHEETS' response to changing climate and their influence on sea level is not always straightforward. Here are a few of the less obvious phenomena that scientists must take into account:

Ice need not melt to add to rising seas

Ice that was once on land contributes to global sea level as soon as it begins floating. Indeed, an iceberg—most of which sits below the ocean surface—is already displacing as much seawater as it will in liquid form. The same is true for ice shelves, the floating tongues

FLOATING ICEBERG belies its true size when viewed from above. Ninety percent of its mass lurks below the surface.

of ice that extend seaward from the edges of continents. In Antarctica, frigid temperatures—averaging about –34 degrees Celsius (–29 degrees Fahrenheit)—mean that very little of that continent's ice ever melts. That might change if global warming becomes more pervasive in the region, but at present Antarctica influences sea level only when solid ice, which is delivered to the coasts by coastal glaciers or by other natural conveyor belts called ice streams, breaks off or adds to existing ice shelves.

Ice can either accelerate or counteract the effects of global warming

Think of a snowy field in the bright sun. Ice and snow reflect much more solar energy back to space than dark oceans and land surfaces do. Such reflection tends to enable an already cold part of the atmosphere above the ice to stay cool, increasing the likelihood that more ice will form.

On the other hand, if global warming heats the atmosphere enough to begin melting the ice and exposing more of the darker surface below, then the region will absorb more solar energy and the air will become warmer still.

Global warming could either slow the rise of sea level or speed it up

Warmer air increases evaporation from the oceans and carries more moisture than cooler air does. So as global warming increases, more evaporated seawater from temperate areas could be transported to polar areas, where it would fall as snow. This process would be further enhanced if global warming were to melt significant amounts of sea ice and expose more of the ocean surface to the atmosphere. All else being equal, ocean water could be preserved as snow faster than it would reenter the sea, alleviating some of the rise in sea level. The catch is that global warming can also cause land ice to melt or break apart more quickly. The ultimate effect of global warming on ice sheets depends on which process dominates.

—R.A.B. and C.R.B.

man of Northwestern University published one of the most influential early studies, a theoretical analysis of West Antarctica based on the forces then thought to control the stability of ice sheets. By that time scientists were well aware that most of the land underlying the thick ice in West Antarctica sits far below sea level and once constituted the floor of an ocean. If all the ice were to become liquid, a mountainous landscape would appear, with valleys dipping more than two kilometers below the surface of the sea and peaks climbing two kilometers above it. Because the boundaries of West Antarctica are so sunken, ice at the edges makes extensive contact with the surrounding seawater, and a good deal extends—as floating ice shelves—onto the ocean surface.

Weertman's troubling conclusion was that any ice sheet that fills a marine basin is inherently unstable when global sea level is on the rise, which most scientists agree has been the case for the past 20,000 years. This instability arises because the edges of a marine ice sheet can be easily stressed or even lifted off the underlying sediment by the natural buoyant effects of water. (In contrast, the ice sheet in East Antarctica sits on a continent, most of which rests high above the deleterious influence of the sea.) The outcome of Weertman's simple calculation was that West Antarctica's ice sheet was on a course toward total collapse. Nothing short of a new ice age could alter this fate.

If Weertman's thinking was correct, it meant that the modern ice sheet was already a shrunken version of its former self. Many early discoveries lent support to this conclusion. Explorers found unusual piles of rock and debris (which only moving ice could have created) on mountain slopes high above the present surface of the ice, indicating that the ice was once much thicker. Likewise, deep gouges carved in the seafloor off the coast implied that the grounded edge of the ice sheet (the part resting on the seafloor) once extended farther out into the ocean [*see box on preceding page*]. Based on these kinds of limited observations, some researchers estimated that the ice sheet was originally as much as three times its

DAVID FIERSTEIN

present volume and that it was shrinking fairly slowly—at a rate that would lead to its complete disappearance in another 4,000 to 7,000 years.

The idea that West Antarctica could lurch much more rapidly toward collapse was not formulated until researchers started paying close attention to ice streams—natural conveyor belts hundreds of kilometers long and dozens of kilometers wide. Early investigators inferred that these streams owe their existence in part to tectonic forces that are pulling West Antarctica apart, thinning the crust and allowing an above-average amount of the earth's internal heat to escape. This extra warmth from below could melt the base of the ice sheet, providing a lubricated layer that would allow the ice to move rapidly down even the gentlest of slopes. Indeed, airborne surveys using ice-penetrating radar revealed in the 1970s that two networks of ice streams drain ice from the continent's interior and feed it to West Antarctica's two largest ice shelves, the Ross and the Ronne. As the ice reaches the seaward edge of these shelves, it eventually calves off as huge icebergs. As this dynamic picture of ice streams came to light, so did the first warnings that they harbored the potential to drain the entire ice sheet in a few centuries or less.

Streams of Uncertainty

DRIVEN BY THE NEW knowledge that the fate of the West Antarctic ice sheet would depend strongly on how fast these streams were removing ice from the continent, teams from NASA, Ohio State University and the University of Wisconsin–Madison set up summer research camps on and near the ice streams in 1983. Some scientists probed the interior of the streams with radar and seismic explosions; others measured their motion and deformation at the surface. They quickly found that these immense rivers race along at glaciologically breakneck speeds—at hundreds of meters a year, many times faster than the average mountain glacier.

Different field investigators sought explanations for the speed of the streams by melting narrow, kilometer-long holes through the ice to extract samples of the ancient seafloor below. Ground-up shells of marine organisms mixed with pebbles, clay and eroded rock, deposited there over many millennia, now form a bed of muddy paste that is so soft and well lubricated that the ice streams can glide along even more easily than earlier researchers expected. If they had instead found crystalline rock, like that underlying most continental ice sheets, including East Antarctica's, they would have concluded that the greater friction of that material had been inhibiting ice motion.

These realizations left wide open the possibility of swift drainage along the Ross ice streams. In contrast, British workers who were studying the Ronne ice streams on the other side of West Antarctica reassured the world that the prospects were not nearly so grim in their sector. But the scientists camped out near the Ross Ice Shelf had reason to believe that once the Ross ice streams carried away that region's one million cubic kilometers of ice, the rest of the sheet—including the area drained by the Ronne streams and part of the East Antarctic ice sheet—would surely follow.

In the 1990s researchers began to notice another potentially unsettling characteristic of the Ross ice streams: they are not only fast but fickle. Radar examinations of the hidden structure below the surface of the grounded ice revealed that the ice streams were not always in their present locations. Satellite imagery of the Ross Ice Shelf, which is composed of ice that has arrived over the past 1,000 years, discovered crevasses and other features that serve as a natural record of dramatic and unmistakable changes in the streams' rates of flow. Indeed, one stream known simply as "C" apparently stopped flowing suddenly a century and a half ago. Similarly, the Whillans ice stream has been decelerating over the past few decades. If the streams do come and go, as such findings implied, then their future would be much more difficult to predict than once assumed. The most alarming possibility was that the stagnant streams might start flowing again without warning. But reassurance against that prospect, at least for the near future, was soon to come.

Even if not sustained, regional collapse may have occurred during brief periods and could happen again.

About five years ago a slew of reports began providing key evidence that the ice sheet may not have thinned as much as previously estimated. In 2000 Eric J. Steig of the University of Washington used new techniques to analyze an old ice core recovered in 1968 from the heart of West Antarctica. The initial analysis had indicated that the ice was 950 meters higher during the last ice age than it is today, but Steig's improved interpretation reduced

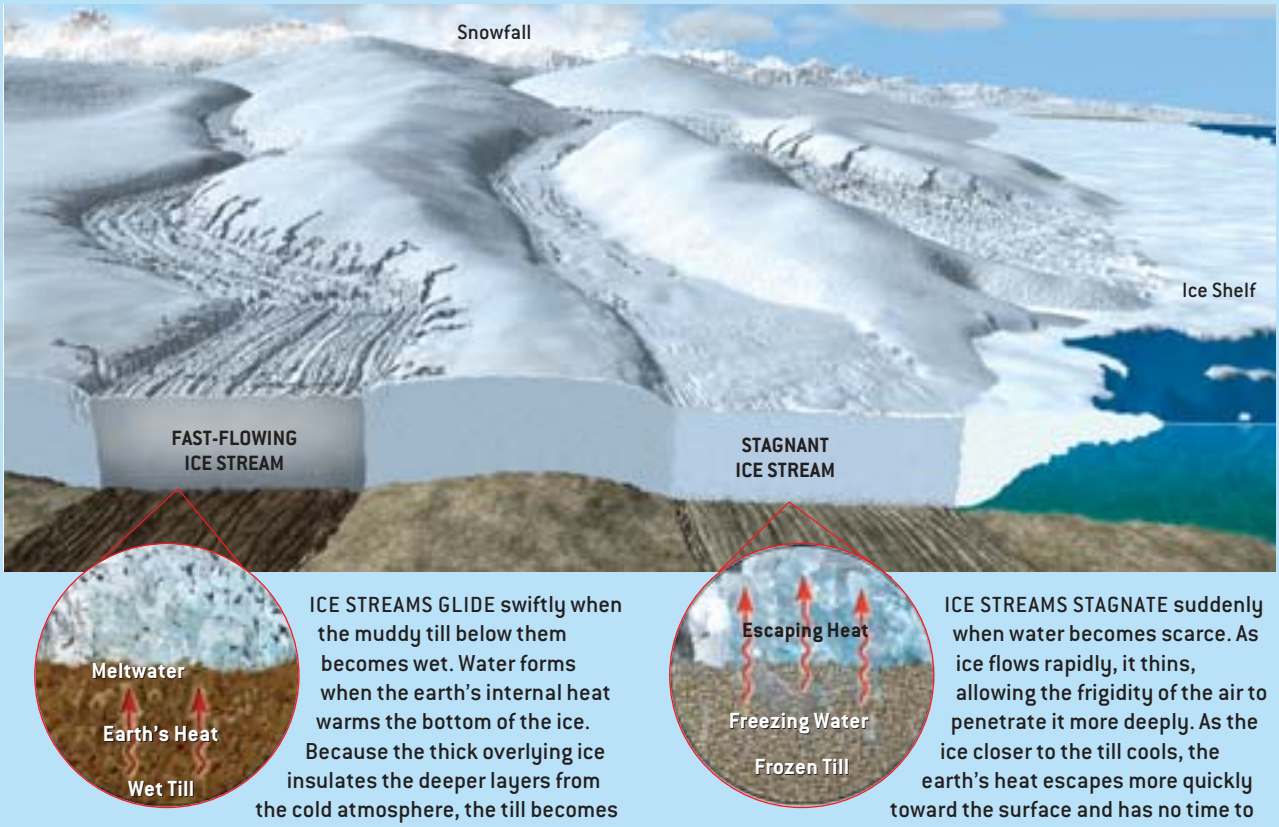
THE AUTHORS

ROBERT A. BINDSCHADLER and CHARLES R. BENTLEY have devoted most of their research careers to investigating the West Antarctic ice sheet and the continent below it. In 23 years at the NASA Goddard Space Flight Center, Bindschadler has led 12 field expeditions to the frozen land down under. Now a senior research fellow at Goddard, he has developed numerous remote-sensing technologies for glaciological application—measuring ice velocity and elevation using satellite imagery and monitoring melting of the ice sheet by microwave emissions, to name just two. Bentley's first visit to West Antarctica lasted 25 months, during which he led an exploratory traverse of the ice sheet as part of the 1957–58 International Geophysical Year expedition. He returned regularly as a member of the geophysics faculty at the University of Wisconsin–Madison until his retirement in 1998.

GARY BRAASCH

SLIP SLIDING AWAY

IMMENSE ICE STREAMS shuttle ice to West Antarctica's coasts at speeds of hundreds of meters a year, feeding more than 400 cubic kilometers to ice shelves annually. They could thus drain the ice sheet in 7,000 years or less if snowfall did not replenish it. Reassuring findings indicate, however, that the streams can stagnate for long periods. Whether they stop or go depends on how much liquid water exists at the base of the ice: a lot makes a stream move quickly; too little slows it down. *—R.A.B. and C.R.B.*



ICE STREAMS GLIDE swiftly when the muddy till below them becomes wet. Water forms when the earth's internal heat warms the bottom of the ice. Because the thick overlying ice insulates the deeper layers from the cold atmosphere, the till becomes warm enough to melt the base of the stream. Meltwater then seeps into the till, which becomes extremely soft and smears easily under the weight of the overlying ice.

ICE STREAMS STAGNATE suddenly when water becomes scarce. As ice flows rapidly, it thins, allowing the frigidity of the air to penetrate it more deeply. As the ice closer to the till cools, the earth's heat escapes more quickly toward the surface and has no time to melt ice at the base. This heat loss freezes the water in the till, making it stiff and sticky. Unless water from upstream keeps the till pliable, the stream grinds to a halt.

that difference to 200 meters. In the mountains of the Executive Committee Range, John O. Stone, another University of Washington researcher, clocked the thinning of the ice sheet by measuring the radioactive by-products of cosmic rays, which have decayed at a known rate since the moment when ice retreat left rock outcrops freshly exposed. These observations put severe limits on the original size of the ice sheet, suggesting that it could have been no more than two and a half times as large as it is today.

By early 2001 scientists on both sides of the debate over the future of West Antarctica's ice sheet were still able to maintain their points of view. Reconciling solid but contradictory evidence required everyone to recognize that great variability on shorter timescales can also appear as lesser variability on longer timescales. Since then, improved measurements of the motion of the Ross ice streams have confirmed that new snowfall is generally keeping pace with ice loss in this sector, meaning that almost no overall shrinkage is occurring at present. And by late 2001 most Antarctic scientists—including both of us—could finally agree that the Ross ice streams are *not* causing the ice to thin at this time. Variations in snowfall versus ice discharge over the past millennium seem to have averaged out—a sign that the ice sheet is less likely to make sudden additions to rising seas than some investigators had expected.

But scientists engaged in this debate know all too well that the dynamic nature of the ice streams dictates that this reconciliation explains only what is going on today. Looking further back in time, for instance, geologic evidence near the U.S. McMurdo Station suggests that the ice sheet retreated through that area very rapidly around 7,000 years ago. Thus, even if not sustained, this type of regional collapse may have occurred during brief periods and could happen again.

To gain a better handle on the future stability of the ice sheet, researchers have also developed a firmer understanding of the forces that control the flow of ice within streams, including an explanation for why the streams can stop, start and change velocity on different timescales [*see box above*]. It turns out that sediment (also called till) and water in the seabed

DAVID FIERSTEIN

are in control over days and years, but global climate, principally through air temperature and sea level, dominates over millennia. This and other new information will make it possible to build more reliable computer models of how the streams might behave centuries hence.

Weak Underbelly Exposed

THAT THE AREA of the West Antarctic ice sheet drained by the Ross ice streams is in less danger of imminent collapse is good news. But in the past couple of years it has become clear that not all sections of West Antarctica behave in the same way. While field-workers were concentrating their efforts on the ice streams feeding the Ross and Ronne ice shelves, several satellite sensors were patiently collecting data from another sector of the ice sheet, the poorly understood region adjacent to the Amundsen Sea. There groups from the U.S. and Great Britain have discovered that the glaciers in this mysterious area are disappearing at an even faster rate than had been originally hypothesized for the Ross ice streams.

After poring over millions of ice-elevation measurements made from space during the 1980s and 1990s, Duncan J. Wingham of University College London and H. Jay Zwally of the NASA Goddard Space Flight Center showed independently that the parts of the ice sheet that feed the Pine Island and Thwaites glaciers are thinning, the latter at more than 10 centimeters a year. These results mesh beautifully with another recent report, by Eric Rignot of the Jet Propulsion Laboratory in Pasadena, Calif. Using radar interferometry, a technique capable of detecting ice movement as small as a few millimeters, Rignot observed that both glaciers are delivering ice increasingly quickly to the Amundsen Sea *and* shrinking toward the continent's interior. As a result, they currently contribute between 0.1 and 0.2 millimeter a year to global sea-level rise—up to 10 percent of the total. At that rate these glaciers would drain 30 percent of the total ice sheet in 7,500 to 15,000 years, or much faster if a catastrophe like the one hypothesized earlier for the Ross sector were to occur.

This new evidence is no surprise to glaciologists such as Terence J. Hughes of the University of Maine, who long ago dubbed the Amundsen sector "the weak underbelly of the West Antarctic ice sheet." But logistical limitations have discouraged field observations in this remote region for decades—it is far from any permanent research station and is renowned as one of the cloudiest regions on the earth. In addition, unique qualities of the Amundsen Sea glaciers may mean that the hard-won knowledge from the Ross sector will be inapplicable there. The surfaces of the glaciers slope more steeply toward the sea than do the ice streams, for example. And because the glaciers dump their ice directly into the sea instead of adding ice to an existing ice shelf, some scientists have argued that this region may be further along in the disintegration process than any other part of Antarctica.

Turning Up the Heat

UNCERTAINTY OVER the vulnerability of the Amundsen Sea sector is but one of several unknowns that scientists still must address. Increasing temperatures related to global warming could begin creeping toward the South Pole from the Antarctic Peninsula, where the summertime atmosphere has already warmed by more than two degrees C since the 1950s. Even seemingly subtle changes in air temperature could trigger disintegration of ice shelves that are relatively stable at present. Evidence reported this year also suggests that warmer ocean waters mixing from lower latitudes may be melting the ice sheet's grounded edges faster than previously assumed, along with reducing the amount of ice in the Amundsen Sea.

Conveniently for those of us living in the world today, the West Antarctic ice sheet appears to possess more helpful feedbacks—such as those that can cause fast-moving ice streams to stagnate for centuries on end—than either its North American or European cousins long gone. Their destruction occurred suddenly as a result of a few degrees of warming, and yet much of West Antarctica's ice survived. Weertman's early model seems to have oversimplified the ice sheet's own dynamics, which so far have exerted enough control over its size to avoid, or at least forestall, a swift demise.

Based on what we know so far, we predict—albeit cautiously—that the ice sheet will continue shrinking, but only over thousands of years. If that is correct, West Antarctica's average effect on sea level could be roughly double its historic contribution of two millimeters a year. That means this ice sheet would add another meter to sea level only every 500 years. But before anyone breathes a sigh of relief, we must remember that this remarkable ice sheet has been surprising researchers for more than 30 years—and could have more shocks in store. SA

So far the ice sheet's own dynamics have exerted enough control over its size to avoid a swift demise.

GARY BRAASCH

MORE TO EXPLORE

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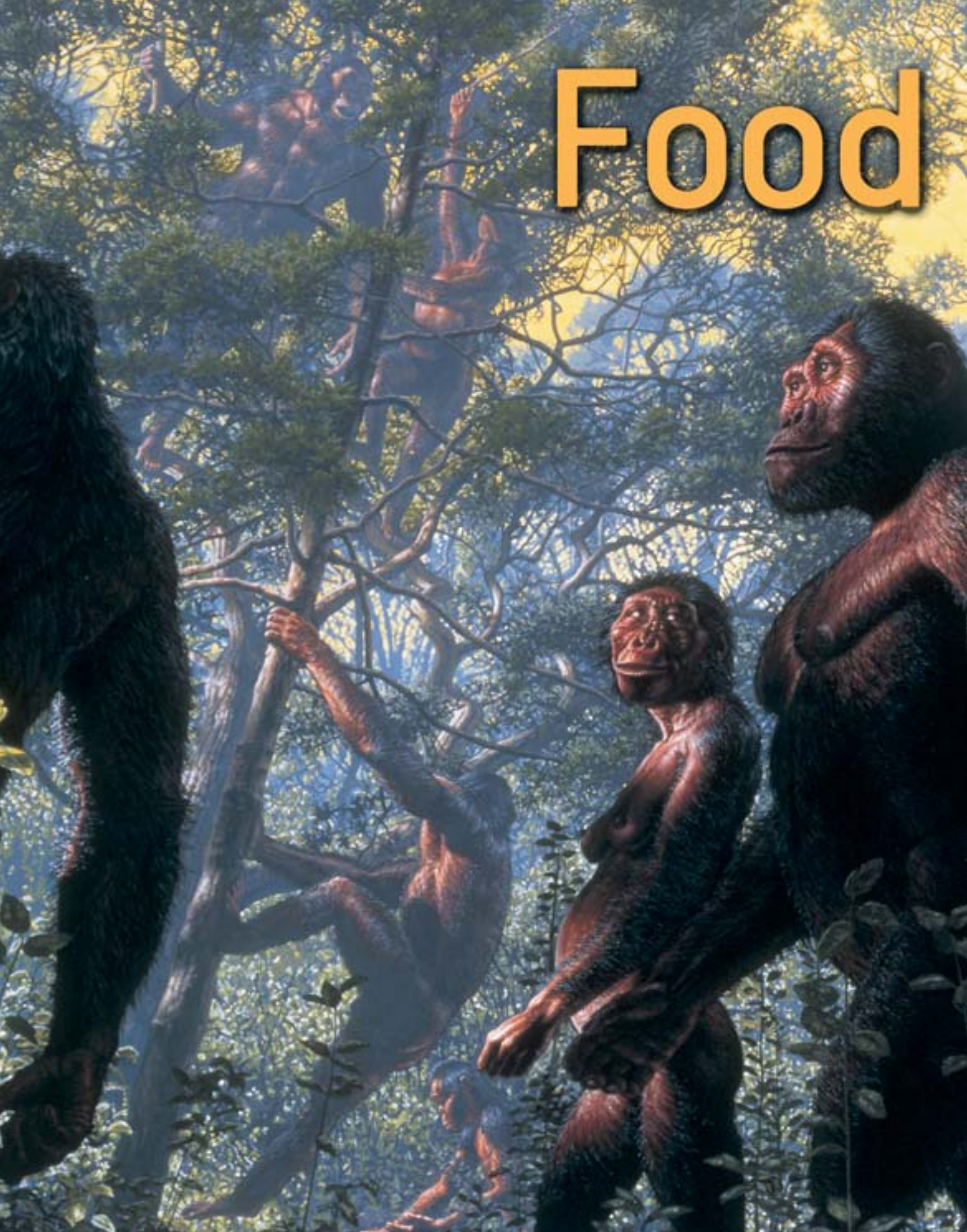
West Antarctic research program Web site: **www.glacier.rice.edu/**

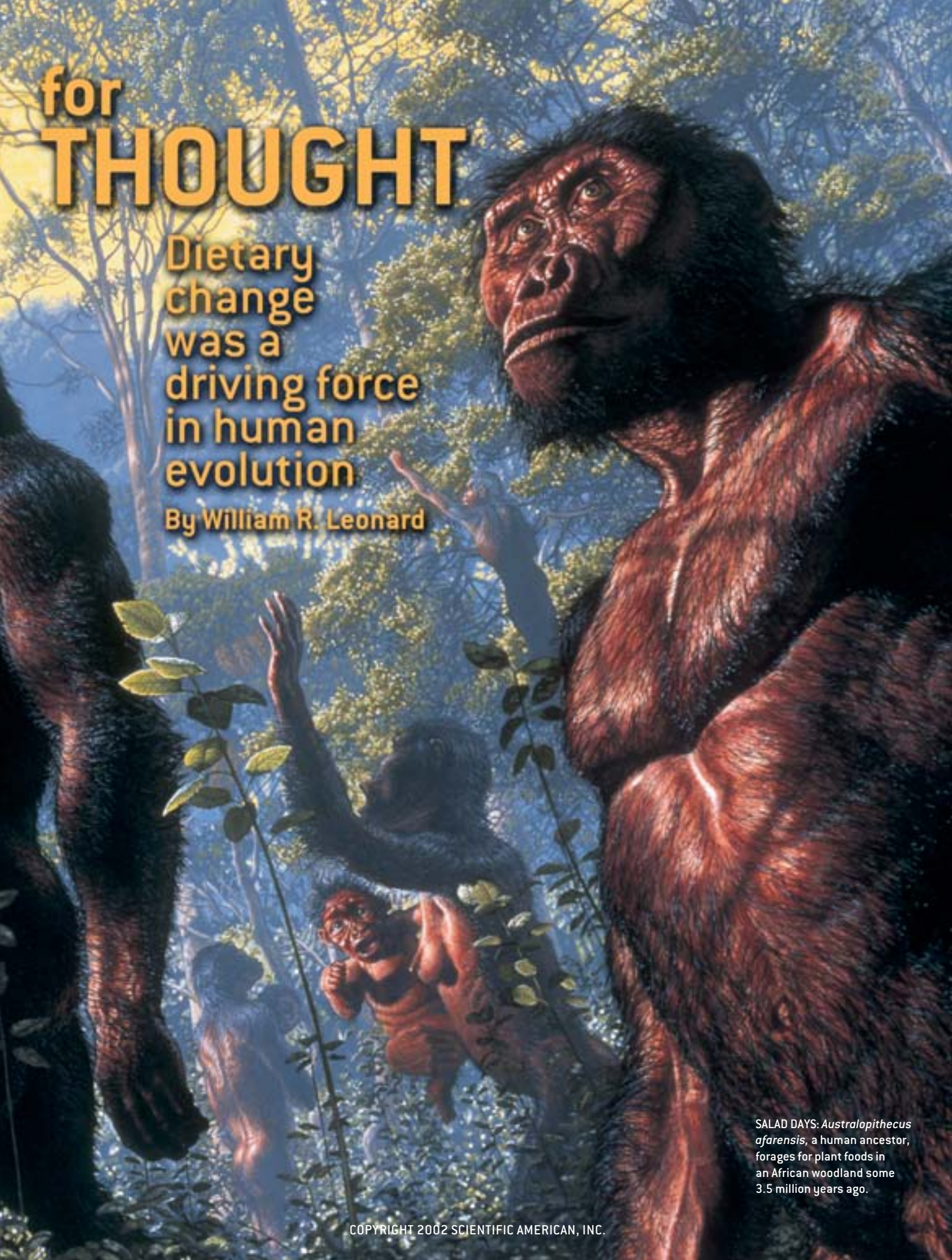
Food



for THOUGHT

Dietary change was a driving force in human evolution

By William R. Leonard



SALAD DAYS: *Australopithecus afarensis*, a human ancestor, forages for plant foods in an African woodland some 3.5 million years ago.

SKELETAL REMAINS indicate that our ancient forebears the australopithecines were bipedal by four million years ago. In the case of *A. afarensis* (*right*), one of the earliest hominids, telltale features include the arch in the foot, the nonopposable big toe, and certain characteristics of the knee and pelvis. But these hominids retained some apelike traits—short legs, long arms and curved toes, among others—suggesting both that they probably did not walk exactly like we do and that they spent some time in the trees. It wasn't until the emergence of our own genus, *Homo* (a contemporary representative of which appears on the left), that the fully modern limb and foot proportions and pelvis form required for upright walking as we know it evolved.

We humans are strange primates.

We walk on two legs, carry around enormous brains and have colonized every corner of the globe. Anthropologists and biologists have long sought to understand how our lineage came to differ so profoundly from the primate norm in these ways, and over the years all manner of hypotheses aimed at explaining each of these oddities have been put forth. But a growing body of evidence indicates that these miscellaneous quirks of humanity in fact have a common thread: they are largely the result of natural selection acting to maximize dietary quality and foraging efficiency. Changes in food availability over time, it seems, strongly influenced our hominid ancestors. Thus, in an evolutionary sense, we are very much what we ate.

Accordingly, what we eat is yet another way in which we differ from our primate kin. Contemporary human populations the world over have diets richer in calories and nutrients than those of our cousins, the great apes. So when and how did our ancestors' eating habits diverge from those of other primates? Further, to what extent have modern humans departed from the ancestral dietary pattern?

Scientific interest in the evolution of human nutritional requirements has a long history. But relevant investigations started gaining momentum after 1985, when S. Boyd Eaton and Melvin J. Konner of Emory University published a seminal paper in the *New England Journal of Medicine* entitled "Paleolithic Nutrition." They argued that the prevalence in modern societies of many chronic diseases—

JOHN GURCHE (*preceding pages* and *above*)

obesity, hypertension, coronary heart disease and diabetes, among them—is the consequence of a mismatch between modern dietary patterns and the type of diet that our species evolved to eat as prehistoric hunter-gatherers. Since then, however, understanding of the evolution of human nutritional needs has advanced considerably—thanks in large part to new comparative analyses of traditionally living human populations and other primates—and a more nuanced picture has emerged. We now know that humans have evolved not to subsist on a single, Paleolithic diet but to be flexible eaters, an insight that has important implications for the current debate over what people today should eat in order to be healthy.

To appreciate the role of diet in human evolution, we must remember that the search for food, its consumption and, ultimately, how it is used for biological processes are all critical aspects of an organism's ecology. The energy dynamic between organisms and their environments—that is, energy expended in relation to energy acquired—has important adaptive consequences for survival and reproduction. These two components of Darwinian fitness are reflected in the way we divide up an animal's energy budget. Maintenance energy is what keeps an animal alive on a day-to-day basis. Productive energy, on the other hand, is associated with producing and raising offspring for the next generation. For mammals like ourselves, this must cover the increased costs that mothers incur during pregnancy and lactation.

The type of environment a creature inhabits will influence the distribution of energy between these components, with harsher conditions creating higher maintenance demands. Nevertheless, the goal of all organisms is the same: to devote sufficient funds to reproduction to ensure the long-term success of the species. Thus, by looking at the way animals go about obtaining and then allocating food energy, we can better discern how natural selection produces evolutionary change.

Becoming Bipeds

WITHOUT EXCEPTION, living nonhuman primates habitually move around on all fours, or quadrupedally, when they are on the ground. Scientists generally assume therefore that the last common ancestor of humans and chimpanzees (our closest living relative) was also a quadruped. Exactly when the last common ancestor lived is unknown, but clear indications of bipedalism—the trait that distinguished ancient humans from other apes—are evident in the oldest known species of *Australopithecus,* which lived in Africa roughly four million years ago. Ideas about why bipedalism evolved abound in the paleoanthropological literature. C. Owen Lovejoy of Kent State University proposed in 1981 that two-legged locomotion freed the arms to carry children and foraged goods. More recently, Kevin D. Hunt of Indiana University has posited that bipedalism emerged as a feeding posture that enabled access to foods that had previously been out of reach. Peter Wheeler of Liverpool John Moores University submits that moving upright allowed early humans to better regulate their body temperature by exposing less surface area to the blazing African sun.

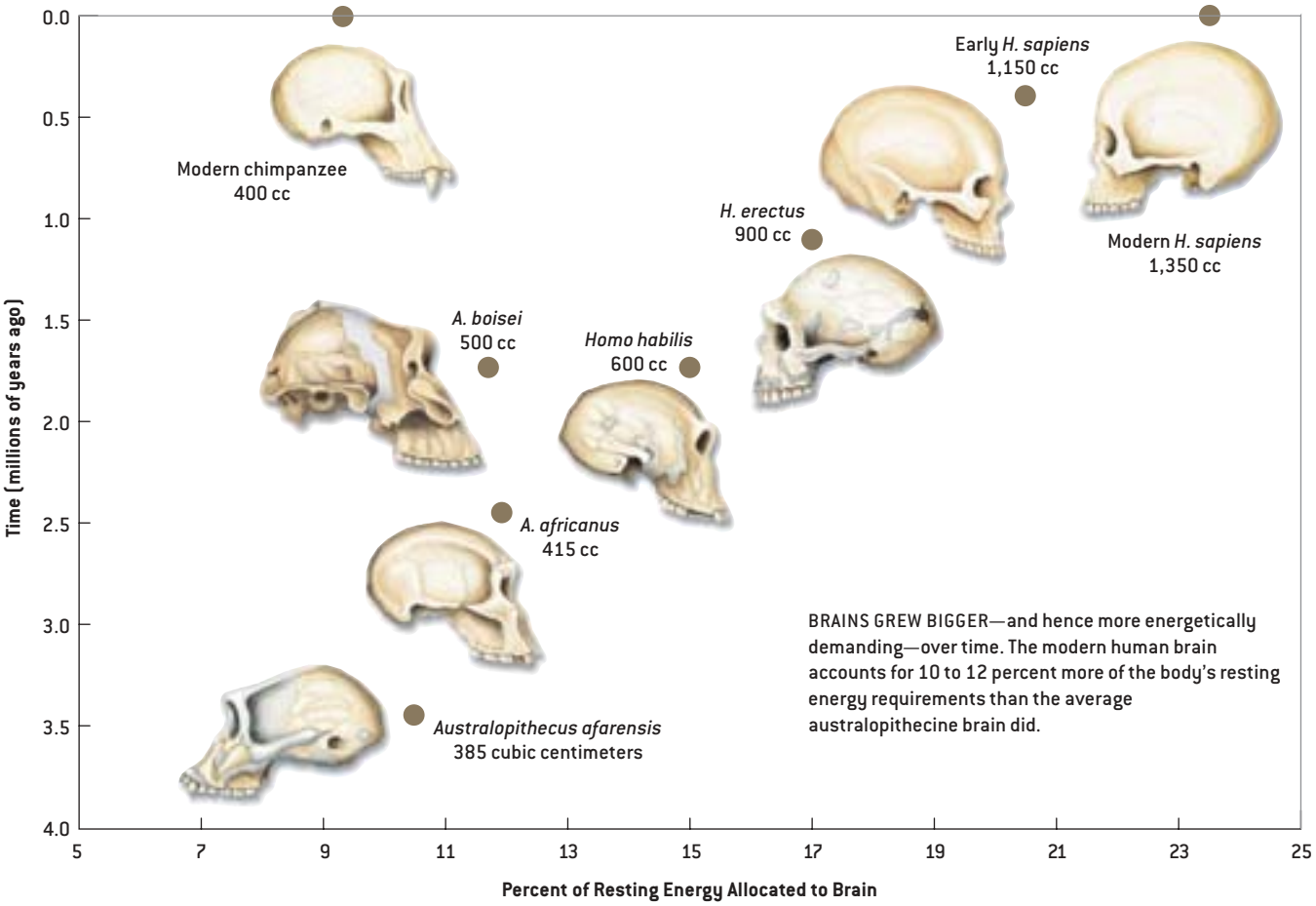
The list goes on. In reality, a number of factors probably selected for this type of locomotion. My own research, conducted in collaboration with my wife, Marcia L. Robertson, suggests that bipedalism evolved in our ancestors at least in part because it is less energetically expensive than quadrupedalism. Our analyses of the energy costs of movement in living animals of all sizes have shown that, in general, the strongest predictors of cost are the weight of the animal and the speed at which it travels. What is striking about human bipedal movement is that it is notably more economical than quadrupedal locomotion at walking rates.

Apes, in contrast, are not economical when moving on the ground. For instance, chimpanzees, which employ a peculiar form of quadrupedalism known as knuckle walking, spend some 35 percent more calories during locomotion than does a typical mammalian quadruped of the same size—a large dog, for example. Differences in the settings in which humans and apes evolved may help explain the variation in costs of movement. Chimps, gorillas and orangutans evolved in and continue to occupy dense forests where only a mile or so of trekking over the course of the day is all that is needed to find enough to eat. Much of early hominid evolution, on the other hand, took place in more open woodland and grassland, where sustenance is harder to come by. Indeed, modern human hunter-gatherers living in these environments, who provide us with the best available model of early human subsistence patterns, often travel six to eight miles daily in search of food.

These differences in day range have important locomotor implications. Because apes travel only short distances each day, the potential energetic benefits of moving more efficiently are very small. For far-ranging foragers, however, cost-effective walking saves many calories in maintenance energy needs—calories that can instead go toward reproduction. Selection for energetically efficient locomotion is therefore likely to be more intense

Overview/*Diet and Human Evolution*

- The characteristics that most distinguish humans from other primates are largely the results of natural selection acting to improve the quality of the human diet and the efficiency with which our ancestors obtained food. Some scientists have proposed that many of the health problems modern societies face are consequences of a discrepancy between what we eat and what our Paleolithic forebears ate.
- Yet studies of traditionally living populations show that modern humans are able to meet their nutritional needs using a wide variety of dietary strategies. We have evolved to be flexible eaters. The health concerns of the industrial world, where calorie-packed foods are readily available, stem not from deviations from a specific diet but from an imbalance between the energy we consume and the energy we expend.



among far-ranging animals because they have the most to gain.

For hominids living between five million and 1.8 million years ago, during the Pliocene epoch, climate change spurred this morphological revolution. As the African continent grew drier, forests gave way to grasslands, leaving food resources patchily distributed. In this context, bipedalism can be viewed as one of the first strategies in human nutritional evolution, a pattern of movement that would have substantially reduced the number of calories spent in collecting increasingly dispersed food resources.

Big Brains and Hungry Hominids

NO SOONER HAD humans perfected their stride than the next pivotal event in human evolution—the dramatic enlargement of the brain—began. According to the fossil record, the australopithecines never became much brainier than living apes, showing only a modest increase in brain size, from around 400 cubic centimeters four million years ago to 500 cubic centimeters two million years later. *Homo* brain sizes, in contrast, ballooned from 600 cubic centimeters in *H. habilis* some two million years ago up to 900 cubic centimeters in early *H. erectus* just 300,000 years later. The *H. erectus* brain did not attain modern human proportions (1,350 cubic centimeters on average), but it exceeded that of living nonhuman primates.

From a nutritional perspective, what is extraordinary about our large brain is how much energy it consumes—roughly 16 times as much as muscle tissue per unit weight. Yet although humans have much bigger brains relative to body weight than do other primates (three times larger than expected), the total resting energy requirements of the human body are no greater than those of any other mammal of the same size. We therefore use a much greater share of our daily energy budget to feed our voracious brains. In fact, at rest brain metabolism accounts for a whopping 20 to 25 percent of an adult human's energy needs—far more than the 8 to 10 percent observed in nonhuman primates, and more still than the 3 to 5 percent allotted to the brain by other mammals.

By using estimates of hominid body size compiled by Henry M. McHenry of the University of California at Davis, Robertson and I have reconstructed the proportion of resting energy needs that would have been required to support the brains of our ancient ancestors. Our calculations suggest that a typical, 80- to 85-pound australopithecine with a brain size of 450 cubic centimeters would have devoted about 11 percent of its resting energy to the brain. For its part, *H. erectus,* which weighed in at 125 to 130 pounds and had a brain size of some 900 cubic centimeters, would have earmarked about 17 percent of its resting energy—that is,

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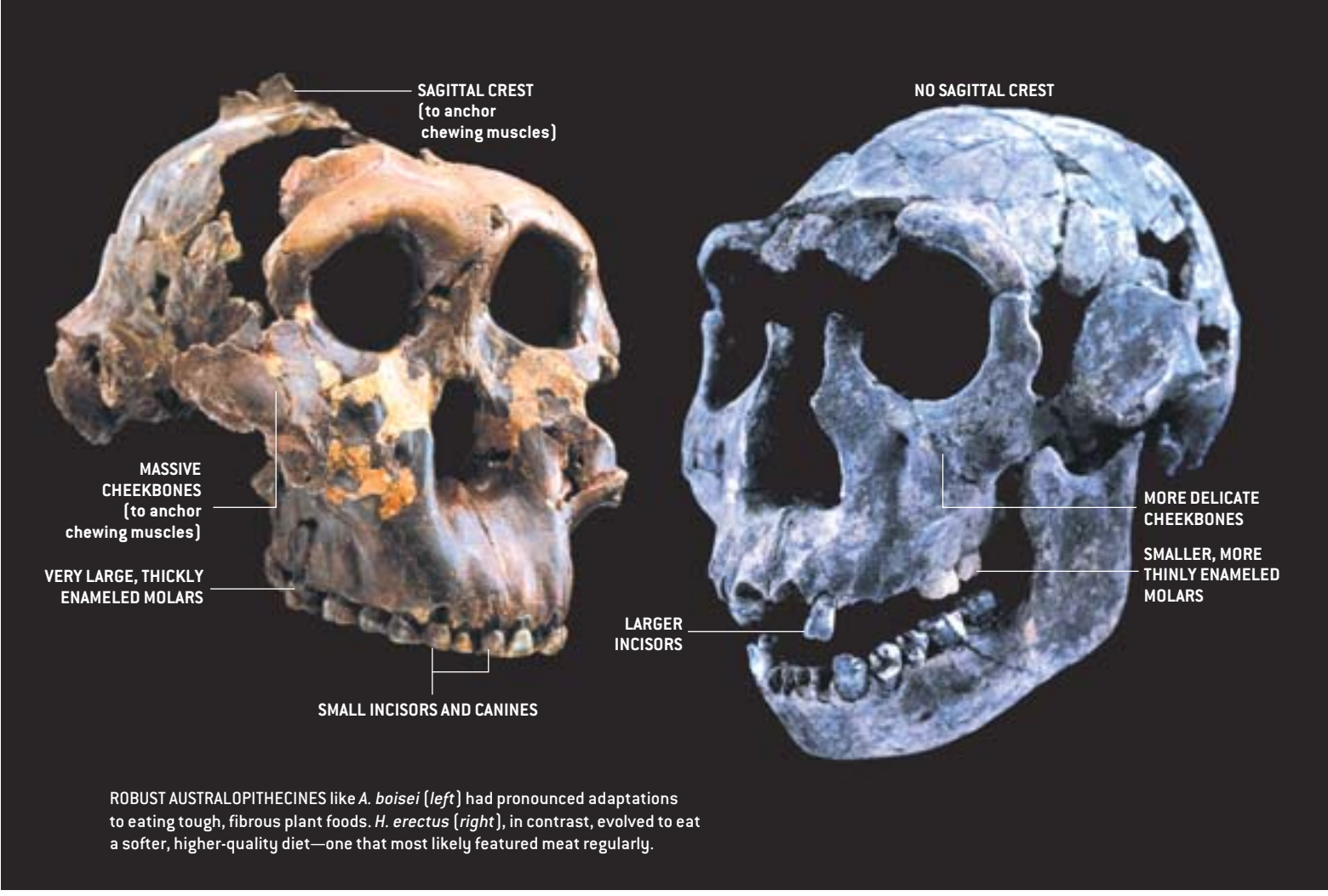

ROBUST AUSTRALOPITHECINES like *A. boisei* (*left*) had pronounced adaptations to eating tough, fibrous plant foods. *H. erectus* (*right*), in contrast, evolved to eat a softer, higher-quality diet—one that most likely featured meat regularly.

about 260 out of 1,500 kilocalories a day—for the organ.

How did such an energetically costly brain evolve? One theory, developed by Dean Falk of Florida State University, holds that bipedalism enabled hominids to cool their cranial blood, thereby freeing the heat-sensitive brain of the temperature constraints that had kept its size in check. I suspect that, as with bipedalism, a number of selective factors were probably at work. But brain expansion almost certainly could not have occurred until hominids adopted a diet sufficiently rich in calories and nutrients to meet the associated costs.

Comparative studies of living animals support that assertion. Across all primates, species with bigger brains dine on richer foods, and humans are the extreme example of this correlation, boasting the largest relative brain size and the choicest diet [see "Diet and Primate Evolution," by Katharine Milton; SCIENTIFIC AMERICAN, August 1993]. According to recent analyses by Loren Cordain of Colorado State University, contemporary hunter-gatherers derive, on average, 40 to 60 percent of their dietary energy from animal foods (meat, milk and other products). Modern chimps, in comparison, obtain only 5 to 7 percent of their calories from these comestibles. Animal foods are far denser in calories and nutrients than most plant foods. For example, 3.5 ounces of meat provides upward of 200 kilocalories. But the same amount of fruit provides only 50 to 100 kilocalories. And a comparable serving of foliage yields just 10 to 20 kilocalories. It stands to reason, then, that for early *Homo,* acquiring more gray matter meant seeking out more of the energy-dense fare.

Fossils, too, indicate that improvements to dietary quality accompanied evolutionary brain growth. All australopithecines had skeletal and dental features built for processing tough, low-quality plant foods. The later, robust australopithecines—a dead-end branch of the human family tree that lived alongside members of our own genus—had especially pronounced adaptations for grinding up fibrous plant foods, including massive, dish-shaped faces; heavily built mandibles; ridges, or sagittal crests, atop the skull for the attachment of powerful chewing muscles; and huge, thickly enameled molar teeth. (This is not to say that australopithecines never ate meat. They almost certainly did on occasion, just as chimps do today.) In contrast, early members of the genus *Homo,* which descended from the gracile australopithecines, had much smaller faces, more delicate jaws, smaller molars and no sagittal crests—despite being far larger in terms of

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DAVID BRILL

INTO THE FIRE

EATING MORE ANIMAL FOODS is one way of boosting the caloric and nutrient density of the diet, a shift that appears to have been critical in the evolution of the human lineage. But might our ancient forebears have improved dietary quality another way? Richard Wrangham of Harvard University and his colleagues recently examined the importance of cooking in human evolution. They showed that cooking not only makes plant foods softer and easier to chew, it substantially increases their available energy content, particularly for starchy tubers such as potatoes and manioc. In their raw form, starches are not readily broken down by the enzymes in the human body. When heated, however, these complex carbohydrates become more digestible, thereby yielding more calories.

The researchers propose that *Homo erectus* was probably the first hominid to apply fire to food, starting perhaps 1.8 million years ago. They argue that early cooking of plant foods (especially tubers) enabled this species to evolve smaller teeth and bigger brains than those of their predecessors. Additionally, the extra calories allowed *H. erectus* to start hunting—an energetically costly activity—more frequently.

From an energetics perspective, this is a logical enough line of reasoning. What makes the hypothesis difficult to swallow is the archaeological evidence Wrangham's team uses to make its case. The authors cite the East African sites of Koobi Fora and Chesowanja, which date to around 1.6 million and 1.4 million years ago, respectively, to indicate control of fire by *H. erectus*. These localities do indeed exhibit evidence of fires, but whether hominids were responsible for creating or harnessing the flames is a matter of some debate. The earliest unequivocal manifestations of fire use—stone hearths and burned animal bones from sites in Europe—are only some 200,000 years old.

Cooking was clearly an innovation that considerably improved the quality of the human diet. But it remains unclear when in our past this practice arose. —*W.R.L.*

EARLY COOKING of plant foods, especially tubers, enabled brain expansion, argue Richard Wrangham of Harvard University and his colleagues.

overall body size than their predecessors. Together these features suggest that early *Homo* was consuming less plant material and more animal foods.

As to what prompted *Homo*'s initial shift toward the higher-quality diet necessary for brain growth, environmental change appears to have once more set the stage for evolutionary change. The continued desiccation of the African landscape limited the amount and variety of edible plant foods available to hominids. Those on the line leading to the robust australopithecines coped with this problem morphologically, evolving anatomical specializations that enabled them to subsist on more widely available, difficult-to-chew foods. *Homo* took a different path. As it turns out, the spread of grasslands also led to an increase in the relative abundance of grazing mammals such as antelope and gazelle, creating opportunities for hominids capable of exploiting them. *H. erectus* did just that, developing the first hunting-and-gathering economy in which game animals became a significant part of the diet and resources were shared among members of the foraging groups. Signs of this behavioral revolution are visible in the archaeological record, which shows an increase in animal bones at hominid sites during this period, along with evidence that the beasts were butchered using stone tools.

These changes in diet and foraging behavior did not turn our ancestors into strict carnivores; however, the addition of modest amounts of animal foods to the menu, combined with the sharing of resources that is typical of hunter-gatherer groups, would have significantly increased the quality and stability of hominid diets. Improved dietary quality alone cannot explain *why* hominid brains grew, but it appears to have played a critical role in enabling that change. After the initial spurt in brain growth, diet and brain expansion probably interacted synergistically: bigger brains produced more complex social behavior, which led to further shifts in foraging tactics and improved diet, which in turn fostered additional brain evolution.

A Movable Feast

THE EVOLUTION of *H. erectus* in Africa 1.8 million years ago also marked a third turning point in human evolution: the initial movement of hominids out of Africa. Until recently, the locations and ages of known fossil sites suggested that early *Homo* stayed put for a few hundred thousand years before venturing out of

I. DEVORE *Anthro-Photo File*

the motherland and slowly fanning out into the rest of the Old World. Earlier work hinted that improvements in tool technology around 1.4 million years ago—namely, the advent of the Acheulean hand ax—allowed hominids to leave Africa. But new discoveries indicate that *H. erectus* hit the ground running, so to speak. Rutgers University geochronologist Carl Swisher III and his colleagues have shown that the earliest *H. erectus* sites outside of Africa, which are in Indonesia and the Republic of Georgia, date to between 1.8 million and 1.7 million years ago. It seems that the first appearance of *H. erectus* and its initial spread from Africa were almost simultaneous.

The impetus behind this newfound wanderlust again appears to be food. What an animal eats dictates to a large extent how much territory it needs to survive. Carnivorous animals generally require far bigger home ranges than do herbivores of comparable size because they have fewer total calories available to them per unit area.

Large-bodied and increasingly dependent on animal foods, *H. erectus* most likely needed much more turf than the smaller, more vegetarian australopithecines did. Using data on contemporary primates and human hunter-gatherers as a guide, Robertson, Susan C. Antón of Rutgers University and I have estimated that the larger body size of *H. erectus*, combined with a moderate increase in meat consumption, would have necessitated an eightfold to 10-fold increase in home range size compared with that of the late australopithecines—enough, in fact, to account for the abrupt expansion of the species out of Africa. Exactly how far beyond the continent that shift would have taken *H. erectus* remains unclear, but migrating animal herds may have helped lead it to these distant lands.

As humans moved into more northern latitudes, they encountered new dietary challenges. The Neandertals, who lived during the last ice ages of Europe, were among the first humans to inhabit arctic environments, and they almost certainly would have needed ample calories to endure under those circumstances. Hints at what their energy requirements might have been come from data on traditional human populations that live in northern settings today. The Siberian reindeer-herding populations known as the Evenki, which I have studied with Peter Katzmarzyk of Queen's University in Ontario and Victoria A. Galloway of the University of Toronto, and the Inuit (Eskimo) populations of the Canadian Arctic have resting metabolic rates that are about 15 percent higher than those of people of similar size living in temperate environments. The energetically expensive activities associated with living in a northern climate ratchet their caloric cost of living up further still. Indeed, whereas a 160-pound American male with a typical urban way of life requires about 2,600 kilocalories a day, a diminutive, 125-pound Evenki man needs more than 3,000 kilocalories a day to sustain himself. Using these modern northern populations as benchmarks, Mark Sorensen of Northwestern University and I have estimated that Neandertals most likely would have required as many as 4,000

NEANDERTAL HUNTERS

TO RECONSTRUCT what early humans ate, researchers have traditionally studied features on their fossilized teeth and skulls, archaeological remains of food-related activities, and the diets of living humans and apes. Increasingly, however, investigators have been tapping another source of data: the chemical composition of fossil bones. This approach has yielded some especially intriguing findings with regard to the Neandertals.

Michael Richards, now at the University of Bradford in England, and his colleagues recently examined isotopes of carbon (^{13}C) and nitrogen (^{15}N) in 29,000-year-old Neandertal bones from Vindija Cave in Croatia. The relative proportions of these isotopes in the protein part of human bone, known as collagen, directly reflect their proportions in the protein of the individual's diet. Thus, by comparing the isotopic "signatures" of the Neandertal bones to those of other animals living in the same environments, the authors were able to determine whether the Neandertals were deriving the bulk of their protein from plants or from animals.

The analyses show that the Vindija Neandertals had ^{15}N levels comparable to those seen in northern carnivores such as foxes and wolves, indicating that they obtained almost all their dietary protein from animal foods. Earlier work hinted that inefficient foraging might have been a factor in the subsequent demise of the Neandertals. But Richards and his collaborators argue that in order to consume as much animal food as they apparently did, the Neandertals had to have been skilled hunters. These findings are part of a growing body of literature that suggests Neandertal subsistence behavior was more complex than previously thought [see "Who Were the Neandertals?" by Kate Wong; SCIENTIFIC AMERICAN, April 2000]. —*W.R.L.*

NEANDERTAL MEALS consisted mostly of meat (from, for example, reindeer), according to analyses of bone chemistry.

HELLIO & VAN INGEN *Photo Researchers, Inc.*

AFRICAN EXODUS began as soon as *H. erectus* evolved, around 1.8 million years ago, probably in part because it needed a larger home range than that of its smaller-bodied predecessors.

kilocalories a day to survive. That they were able to meet these demands for as long as they did speaks to their skills as foragers [*see box on preceding page*].

Modern Quandaries

JUST AS PRESSURES to improve dietary quality influenced early human evolution, so, too, have these factors played a crucial role in the more recent increases in population size. Innovations such as cooking, agriculture and even aspects of modern food technology can all be considered tactics for boosting the quality of the human diet. Cooking, for one, augmented the energy available in wild plant foods [*see box on page 112*]. With the advent of agriculture, humans began to manipulate marginal plant species to increase their productivity, digestibility and nutritional content—essentially making plants more like animal foods. This kind of tinkering continues today, with genetic modification of crop species to make "better" fruits, vegetables and grains. Similarly, the development of liquid nutritional supplements and meal replacement bars is a continuation of the trend that our ancient ancestors started: gaining as much nutritional return from our food in as little volume and with as little physical effort as possible.

Overall, that strategy has evidently worked: humans are here today and in record numbers to boot. But perhaps the strongest testament to the importance of energy- and nutrient-rich foods in human evolution lies in the observation that so many health concerns facing societies around the globe stem from deviations from the energy dynamic that our ancestors established. For children in rural populations of the developing world, low-quality diets lead to poor physical growth and high rates of mortality during early life. In these cases, the foods fed to youngsters during and after weaning are often not sufficiently dense in energy and nutrients to meet the high nutritional needs associated with this period of rapid growth and development. Although these children are typically similar in length and weight to their U.S. counterparts at birth, they are much shorter and lighter by the age of three, often resembling the smallest 2 to 3 percent of American children of the same age and sex.

In the industrial world, we are facing the opposite problem: rates of childhood and adult obesity are rising because the energy-rich foods we crave—notably those packed with fat and sugar—have become widely available and relatively inexpen-

VARIOUS DIETS can satisfy human nutritional requirements. Some populations subsist almost entirely on plant foods; others eat mostly animal foods. Although Americans consume less meat than do a number of the traditionally living people described here, they have on average higher cholesterol levels and higher levels of obesity (as indicated by body mass index) because they consume more energy than they expend and eat meat that is higher in fat.

Population	Energy Intake (kilocalories/day)	Energy from Animal Foods (%)	Energy from Plant Foods (%)	Total Blood Cholesterol (milligrams/deciliter)	Body Mass Index (weight/height squared)
HUNTER-GATHERERS					
!Kung (Botswana)	2,100	33	67	121	19
Inuit (North America)	2,350	96	4	141	24
PASTORALISTS					
Turkana (Kenya)	1,411	80	20	186	18
Evenki (Russia)	2,820	41	59	142	22
AGRICULTURALISTS					
Quechua (Highland Peru)	2,002	5	95	150	21
INDUSTRIAL SOCIETIES					
U.S.	2,250	23	77	204	26

Note: Energy intake figures reflect the adult average (males and females); blood cholesterol and body mass index (BMI) figures are given for males. Healthy BMI = 18.5–24.9; overweight = 25.0–29.9; obese = 30 and higher.

LAURIE GRACE (*map*)

sive. According to recent estimates, more than half of adult Americans are overweight or obese. Obesity has also appeared in parts of the developing world where it was virtually unknown less than a generation ago. This seeming paradox has emerged as people who grew up malnourished move from rural areas to urban settings where food is more readily available. In some sense, obesity and other common diseases of the modern world are continuations of a tenor that started millions of years ago. We are victims of our own evolutionary success, having developed a calorie-packed diet while minimizing the amount of maintenance energy expended on physical activity.

The magnitude of this imbalance becomes clear when we look at traditionally living human populations. Studies of the Evenki reindeer herders that I have conducted in collaboration with Michael Crawford of the University of Kansas and Ludmila Osipova of the Russian Academy of Sciences in Novosibirsk indicate that the Evenki derive almost half their daily calories from meat, more than 2.5 times the amount consumed by the average American. Yet when we compare Evenki men with their U.S. peers, they are 20 percent leaner and have cholesterol levels that are 30 percent lower.

These differences partly reflect the compositions of the diets. Although the Evenki diet is high in meat, it is relatively low in fat (about 20 percent of their dietary energy comes from fat, compared with 35 percent in the average U.S. diet), because free-ranging animals such as reindeer have less body fat than cattle and other feedlot animals do. The composition of the fat is also different in free-ranging animals, tending to be lower in saturated fats and higher in the polyunsaturated fatty acids that protect against heart disease. More important, however, the Evenki way of life necessitates a much higher level of energy expenditure.

Thus, it is not just changes in diet that have created many of our pervasive health problems but the interaction of shifting diets and changing lifestyles. Too often modern health problems are portrayed as the result of eating "bad" foods that are departures from *the* natural human diet—an oversimplification embodied by the current debate over the relative merits of a high-protein, high-fat Atkins-type diet or a low-fat one that emphasizes complex carbohydrates. This is a fundamentally flawed approach to assessing human nutritional needs. Our species was not designed to subsist on a single, optimal diet. What is remarkable about human beings is the extraordinary variety of what we eat. We have been able to thrive in almost every ecosystem on the earth, consuming diets ranging from almost all animal foods among populations of the Arctic to primarily tubers and cereal grains among populations in the high Andes. Indeed, the hallmarks of human evolution have been the diversity of strategies that we have developed to create diets that meet our distinctive metabolic requirements and the ever increasing efficiency with which we extract energy and nutrients from the environment. The challenge our modern societies now face is balancing the calories we consume with the calories we burn. SA

A DIVERSITY OF DIETS

THE VARIETY OF SUCCESSFUL dietary strategies employed by traditionally living populations provides an important perspective on the ongoing debate about how high-protein, low-carbohydrate regimens such as the Atkins diet compare with those that underscore complex carbohydrates and fat restriction. The fact that both these schemes produce weight loss is not surprising, because both help people shed pounds through the same basic mechanism: limiting major sources of calories. When you create an energy deficit—that is, when you consume fewer calories than you expend—your body begins burning its fat stores and you lose weight.

The larger question about healthy weight-loss or weight-maintenance diets is whether they create eating patterns that are sustainable over time. On this point it appears that diets that severely limit large categories of foods (carbohydrates, for example) are much more difficult to sustain than are moderately restrictive diets. In the case of the Atkins-type regimen, there are also concerns about the potential long-term consequences of eating foods derived largely from feedlot animals, which tend to contain more fat in general and considerably more saturated fats than do their free-ranging counterparts.

In September the National Academy of Sciences's Institute of Medicine put forth new diet and exercise guidelines that mesh well with the ideas presented in this article. Not only did the institute set broader target ranges for the amounts of carbohydrates, fat and protein that belong in a healthy diet—in essence, acknowledging that there are various ways to meet our nutritional needs—the organization also doubled the recommended amount of moderately intense physical activity to an hour a day. By following these guidelines and balancing what we eat with exercise, we can live more like the Evenki of Siberia and other traditional societies—and more like our hominid ancestors. —*W.R.L.*

MORE TO EXPLORE

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Order in Pollock's Chaos

Computer analysis is helping to explain the appeal of Jackson Pollock's paintings. The artist's famous drips and swirls create fractal patterns, similar to those formed in nature by trees, clouds and coastlines

By Richard P. Taylor

BLUE POLES: NUMBER 11, 1952 exemplifies Pollock's trademark interweaving swirls of paint, which evolved through a series of depositions over the course of making a painting, a period of six months in the case of *Blue Poles*. (enamel and aluminum paint on canvas, 210 cm by 486.8 cm)

NATIONAL GALLERY OF AUSTRALIA, CANBERRA. © 2002 POLLOCK-KRASNER FOUNDATION/ARTISTS RIGHTS SOCIETY (ARS), NEW YORK

In a drunken, suicidal state on a stormy March night, Jackson Pollock (1912–1956) laid down the foundations of his masterpiece *Blue Poles: Number 11, 1952*. He unrolled a large canvas across the floor of his windswept barn and, using a wooden stick, dripped the canvas with household paint from an old can.

This was not the first time the artist had dripped a painting onto canvas. In contrast to the broken lines painted by conventional brush contact, Pollock had developed a technique in which he poured a constant stream of paint onto horizontal canvases to produce uniquely continuous trajectories. This deceptively simple act polarized opinion in the art world. Was this primitive painting style driven by raw genius, or was he simply a drunk who mocked artistic traditions?

I had always been intrigued by Pollock's work because, in addition to my life as a physicist, I painted abstract art. Then, in 1994, I decided to put my scientific career on hold and to paint full-time. I left the physics department of the University of New South Wales and headed off to the Manchester School of Art in England, which had a reputation for a "sink or swim" approach to painting. In the bleak month of February, the school packed us students off to the Yorkshire moors in the north of England, telling us that we had one week to paint what we saw. But a violent snowstorm made the task impossible, so I sat down with a few friends, and we came up with the idea of making nature paint for us.

To do this, we assembled a huge structure out of tree branches blown down by the storm. One part of the structure acted like a giant sail, catching the motions of the wind swirling around it. This motion was then transferred to another part of the struc-

ture that held paint containers, and these dripped a pattern corresponding to the wind's trajectory onto a canvas on the ground. As another large storm began to move through, we decided to retreat indoors, leaving the structure to paint through the night. The next day the storm had passed—and the image it left behind looked like a Pollock!

Suddenly, the secrets of Jackson Pollock seemed to fall into place for me: he must have adopted nature's rhythms when he painted. At this point, I realized I would have to head back into science to determine whether I could identify tangible traces of those rhythms in his artwork.

Art Anticipates Science

DURING POLLOCK'S ERA, nature was assumed to be disordered, operating essentially randomly. Since that time, however, two fascinating areas of study have emerged to yield a greater understanding of nature's rules.

During the 1960s, scientists began to examine how natural systems, such as the weather, change with time. They found that these systems are not haphazard; instead, lurking underneath is a remarkably subtle form of order. They labeled this behavior "chaotic," and a new scientific field called chaos theory grew up to explain nature's dynamics. Then, in the 1970s, a new form of geometry emerged to describe the patterns that these chaotic processes left behind. Given the name "fractals" by their discoverer, Benoit Mandelbrot, the new forms looked nothing like traditional Euclidean shapes. In contrast to the smoothness of artificial lines, fractals consist of patterns that recur on finer and finer magnifications, building up shapes of immense complexity. The paintings created by our branch contraption suggested to me that the seemingly random swirls in Pollock's paintings might also possess some subtle order, that they might in fact be fractals.

A crucial feature in characterizing a fractal pattern is the fractal dimension, or *D*, which quantifies the scaling relation among the patterns observed at different magnifications. For Euclidean shapes, dimension is a simple concept described by the familiar integer values. For a smooth line (containing no fractal structure), *D* has a value of 1; for a completely filled area, its value is 2. For a fractal pattern, however, the repeating structure causes the line to occupy area. *D* then lies in the range between 1 and 2; as the complexity and richness of the repeating structure increase, its value moves closer to 2.

To figure out how all this might apply to Pollock's paintings, I went back to my lab at New South Wales, where I turned to the computer for help in quantifying the patterns on his canvases. It would have been impossible to perform this kind of analysis without the precision and computational power provided by such equipment. So I enlisted two colleagues who had special computer expertise—Adam Micolich, who was researching fractal analysis techniques for his doctorate in semiconductor devices, and David Jonas, an expert in image-processing techniques.

We started our investigation by scanning a Pollock painting into the computer [*see opposite page*]; we then covered it with a computer-generated mesh of identical squares. By analyzing which squares were occupied by the painted pattern and which were empty, we were able to calculate the statistical qualities of the pattern. And by reducing the square size, we were able to look at the pattern at what amounts to a finer magnification. Our analysis examined pattern sizes ranging from the smallest speck of paint up to approximately a meter. Amazingly, we found the patterns to be fractal. And they were fractal over the entire size range—the largest pattern more than 1,000 times as big as the smallest. Twenty-five years before their discovery in nature, Pollock was painting fractals.

The Aesthetic Pull of Fractals

TAKING THIS SURPRISING finding a step further, I wondered whether the fractal nature of Pollock's paintings might contribute to their appeal. Only within the past decade have researchers begun to

A Brief History of Fractals

- Fractal geometry developed from Benoit Mandelbrot's studies of complexity in the 1960s and 1970s. Mandelbrot coined the term "fractal" from the Latin *fractus* ("broken") to highlight the fragmented, irregular nature of these forms.
- Fractals display self-similarity—that is, they have a similar appearance at any magnification. A small part of the structure looks very much like the whole.
- Self-similarity comes in two flavors: exact and statistical. The artificial tree (*left series*) displays an exact repetition of patterns at different magnifications. For the real tree (*right*), the patterns don't repeat exactly; instead the statistical qualities of the patterns repeat. Most of nature's patterns obey statistical self-similarity, and so do Pollock's paintings.
- Fractals are characterized in terms of their "dimension," or complexity. The dimension is not an integer, such as the 1, 2 and 3 dimensions familiar from Euclidean geometry. Instead fractal dimensions are fractional; for example, a fractal line has a dimension between 1 and 2.

ARTIFICIAL TREE
Exact Self-Similarity

REAL TREE
Statistical Self-Similarity

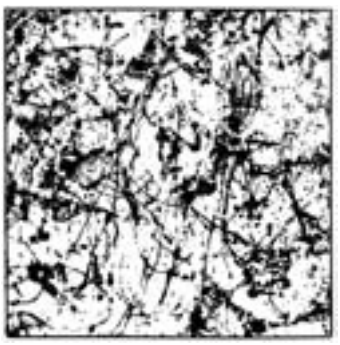
COURTESY OF RICHARD P. TAYLOR

ANALYZING POLLOCK'S TECHNIQUE

COMPUTER-ASSISTED ANALYSIS of Pollock's paintings reveals that the artist built up layers of paint in a carefully developed technique that created a dense web of fractals. Pollock was occasionally photographed while painting [*see illustration on page 121*], which gave me and my colleagues Adam Micolich and David Jonas more insight into his technique.

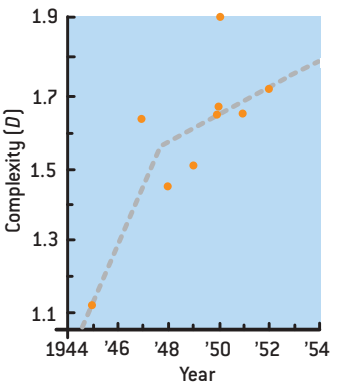
Autumn Rhythm, 1950, oil on canvas, 266.7 cm by 525.8 cm

1 We began by scanning a painting into a computer. We could then separate the painting into its different colored patterns and analyze the fractal content of each pattern. We also looked at the cumulative pattern as the layers were added one by one to build the total picture. A detail from the black layer of *Autumn Rhythm* is shown at the right.



2 We covered the painting with a computer-generated mesh of identical squares. We then had the computer assess the statistical qualities of the pattern by analyzing which squares are occupied by the pattern (*blue*) and which are empty (*white*). Reducing the mesh size (*bottom*) is equivalent to looking at the statistical qualities of patterns at a finer magnification. We found the patterns to be fractal over the entire size range.

3 Studying the paintings chronologically showed that the complexity of the fractal patterns, *D,* increased as Pollock refined his technique. One *D* value is clearly an outlier—1.9 in 1950, a work that Pollock later destroyed (the analysis is based on a photograph). He may have thought this image was too dense or too complex and subsequently scaled back.



D = 1 nonfractal | *D* = 1.1 | *D* = 1.6 | *D* = 1.9 | *D* = 2 nonfractal

The evolution in *D* value had a profound effect on the appearance of the paintings. For fractals described by a low *D,* the repeating patterns build a smooth, sparse image. If the *D* value is closer to 2, however, the repeating patterns create a shape full of intricate, detailed structure.

WHAT EMERGES FROM BOTH the computer analysis and the examination of the photographs is evidence of a very systematic, deliberate painting process. Pollock started by painting small, localized "islands" of trajectories across the canvas. This is interesting because some of nature's patterns start with small nucleations that then spread and merge. He next painted longer, extended trajectories that linked the islands, gradually submerging them in a dense fractal web of paint. This stage of the painting formed an anchor layer: it actually guided the artist's subsequent painting actions. During the linking process, the painting's complexity (its *D* value) increased over a timescale of less than a minute. After this rapid activity, Pollock would take a break. He would then return to the canvas, and over a period lasting from two days to six months, he would deposit further layers of different-colored trajectories on top of the black anchor layer. Essentially, he was fine-tuning the complexity established by the anchor layer. Even when Pollock had finished painting, he took steps that maximized the fractal character, cropping to remove the outer regions where the fractal quality deteriorated. —*R.P.T.*

investigate visual preferences for fractal patterns. Using computer-generated fractals of various *D* values, Clifford A. Pickover of the IBM Thomas J. Watson Research Center found that people expressed a preference for fractal patterns with a value of 1.8. Then, generating fractals by a different computer method, Deborah J. Aks and Julien C. Sprott of the University of Wisconsin–Madison came up with much lower preferred values of 1.3. Although the discrepancy might indicate that no *D* value is preferred over any other—that instead the aesthetic quality of fractals depends on how the fractals are generated—I suspected the existence of a universally preferred value.

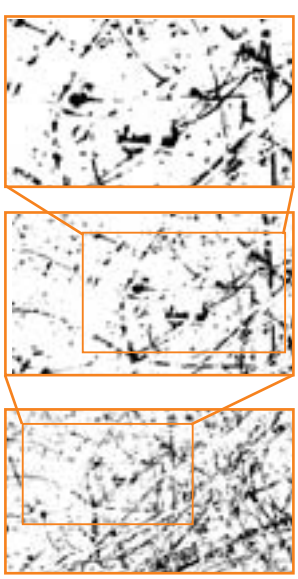
To see whether I was correct, I again sought assistance from experts—this time psychologists who study visual perception. Working with Branka Spehar of the University of New South Wales, Colin Clifford, now at the University of Sydney, and Ben Newell of University College London, I investigated three fundamental categories of fractals: natural (such as trees, mountains and clouds), mathematical (computer simulations) and human (cropped sections of Pollock's paintings). In visual perception tests, participants con-

ALL DRIP PAINTINGS ARE NOT CREATED EQUAL

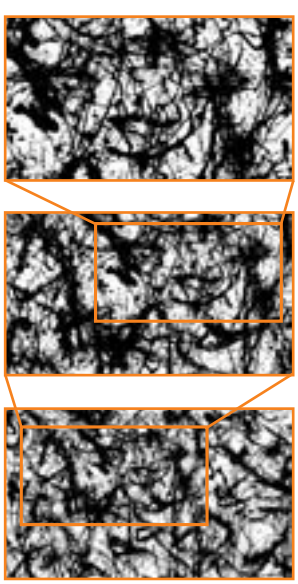
ARE FRACTALS an inevitable consequence of dripping paint? No. Consider the drip painting at the right, which is not a Pollock. Working with Ted P. Martin of the University of Oregon, I applied our computer analysis technique [*see box on preceding page*] to the image, examining its complexity at finer and finer magnifications. We found that the patterns at different magnifications were not described by the same statistics; in other words, they were not fractal. Indeed, when the painting was magnified, we could see that the dripped lines quickly ran out of structure (*left series below*). As a consequence, the pattern at high magnification looked very different from that at low magnification. A Pollock painting (*right series*), in contrast, displays the same general qualities when viewed at different magnifications, regardless of the location and sizes of the segments chosen. The same magnification sequence was used for both paintings.

Because the statistical qualities of fractals repeat at different magnifications, *D* will not change over the various magnifications. It remains constant for the Pollock painting (*red in graph below*), whereas for the non-Pollock (*yellow*), it varies with pattern size, confirming that the painting is not fractal. My colleagues and I examine pattern sizes up to one meter but concentrate on sizes ranging from one to 10 millimeters, because we have found that this is the most sensitive region for distinguishing between a Pollock and a non-Pollock.

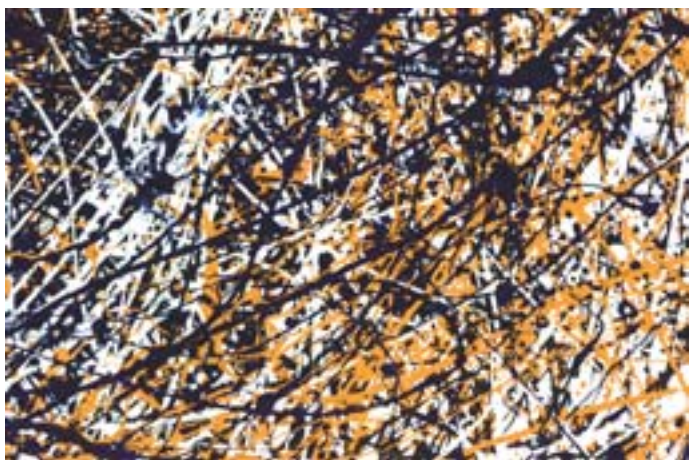
We have also analyzed five drip paintings sent to us by collectors who suspected their acquisitions might have been created by Pollock. Despite superficial similarities with Pollock's work, none of the paintings contained fractal patterns. The fractals are the product of the specific technique Pollock devised, and all the 20 drip paintings of his that we have analyzed have this fractal composition. We could therefore conclude that each of the five paintings sent to us for analysis was produced by someone other than Pollock. Fractality, then, offers a promising test for authenticating a Pollock drip painting. Further, because the *D* value of the artist's work rose through the years, following a rather predictable trend, the analysis of the fractals can also be applied to date an authentic Pollock painting. *—R.P.T.*



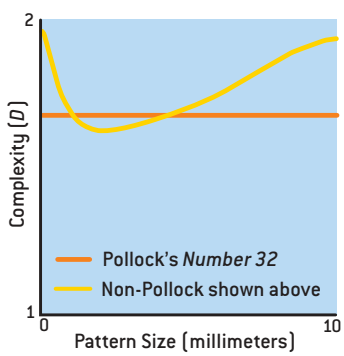
Non-Pollock drip painting



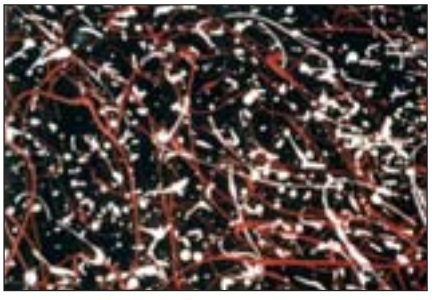
Pollock's *Number 32, 1950*



Non-Pollock drip painting, vinyl paint on canvas, 244 cm by 122 cm



COURTESY OF RICHARD P. TAYLOR (*non-Pollock drip painting*); KUNSTSAMMLUNG NORDRHEIN-WESTFALEN, DÜSSELDORF, ©2002 POLLOCK-KRASNER FOUNDATION/ARTISTS RIGHTS SOCIETY (ARS), NEW YORK (*detail of Number 32, 1950*); ALICIA CALLE (*graph*)



POLLOCK, shown above with Lee Krasner in 1950 while at work on *One,* famously said, "My concern is with the rhythms of nature." At the right, from top to bottom, are the natural patterns created by seaweed, Pollock's 1947 painting *Full Fathom Five,* and the author's "accidental Pollock," produced by a windstorm.

sistently expressed a preference for *D* values in the range of 1.3 to 1.5, regardless of the pattern's origin. More recently, I teamed up with psychologist James A. Wise of Washington State University, and we showed that this visual appreciation has an effect on the observer's physiological condition. Using skin conductance tests to measure stress levels, we found that midrange *D* values also put people at ease. Of course, these inquiries are just a beginning; still, it is interesting to note that many of the fractal patterns surrounding us in nature have *D* values in this same range—clouds, for example, have a value of 1.3.

What is the *D* value of Pollock's work? Interestingly, the value increased over the decade that he made drip paintings, from 1.12 in 1945 up to 1.7 in 1952 and even up to 1.9 in a painting that Pollock destroyed. It is curious that Pollock would have spent 10 years refining his drip technique to yield high-*D* fractals if people prefer low-range to midrange values. The increased intricacy of high *D* values, however, may engage the attention of viewers more actively than the "relaxing" midrange fractals and thus may have been intuitively attractive to the artist. My current work at the University of Oregon is addressing this possibility, using eye-tracking apparatus to examine the way people look at fractals and at Pollock's paintings.

Clearly, the computer's expertise in detecting the fundamental characteristics of painted patterns offers art historians and theoreticians a promising new tool. It will join infrared, ultraviolet and x-ray analysis, which art experts already employ routinely, in a growing collection of scientific methods for investigating such features of art as the images hidden underneath subsequent layers of paint. Perhaps it may even be able to throw a narrow beam of light into those dim corners of the mind where great paintings exert their power. SA

THE AUTHOR

RICHARD P. TAYLOR began puzzling over the paintings of Jackson Pollock while head of the condensed-matter physics department at the University of New South Wales in Australia. He is now a professor of physics at the University of Oregon, where he continues his analysis of Pollock's work and investigates chaos and fractals in a variety of physical systems. He also has a master's degree in art theory, with a focus on Pollock, from the University of New South Wales.

MORE TO EXPLORE

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Fractal Analysis of Pollock's Drip Paintings. R. P. Taylor, A. P. Micolich and D. Jonas in *Nature,* Vol. 399, page 422; June 3, 1999.

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INK-JET PRINTING

Superhot Dots

Want to see a micromachined marvel in action? Look inside an ink-jet printer. The basic guts are mechanical: a stepper motor turns a belt that moves the print head assembly back and forth across the target page. The assembly holds the ink cartridges. Instructions on what to print are sent through a wire ribbon that bends with the moving assembly. But that's where the microscopic world takes charge.

Piezoelectric printers (Epson) have a permanent print head in the assembly; the cartridge just supplies ink. The head charges vibrating crystals that push ink droplets out tiny nozzles. In thermal ink-jet, or "bubble-jet," printers (Canon, Hewlett-Packard) the print head is inside the ink cartridge, which includes all the microtechnology and an integrated circuit—quite a feat for $20. The head superheats ink so an exploding vapor bubble jettisons a droplet through a nozzle. In either design, the print head may contain 360 to 600 jets in less than a square inch. Each jet is fed by its own ink channel and is triggered many times a second by its own resistor or crystal. "Everyone talks about MEMS [microelectromechanical systems] these days," observes Frank L. Cloutier, chief technology officer at Hewlett-Packard's Imaging and Printing Group in Corvallis, Ore. "This is MEMS, and we've been doing it for 18 years."

A jet can place a droplet anywhere on a page to within one ten-thousandth of an inch. The dot it makes has a cross section one fourth to one tenth the size of a human hair, and dots can be packed with a resolution of up to 4,800 by 1,200 an inch on high-quality paper.

Ink-jet printers have become so inexpensive that profit margins are thin, but manufacturers make good money on the cartridges. The print heads are so sophisticated, Cloutier says, that further refinements might not improve print resolution in a way noticeable to the human eye. Therefore, he maintains, the future lies in ever better inks. A top priority is compounds that dry faster on the page yet won't dry in the nozzle and won't fade; they will allow better pixel density and faster print times for speedy, photograph-like images.

—Mark Fischetti

IN A THERMAL INK-JET PRINTER, the ink cartridge contains the print head, which fires numerous droplets simultaneously to form letters or pixels on a page. The printer sends firing instructions through address contacts to an integrated circuit that forms the back of the print head. A transistor for each jet tells it when to fire a four-picoliter droplet toward the page.

THERMAL PRINT HEADS deliver a short voltage pulse that heats a tantalum-aluminum thin-film resistor that's only 100 atoms thick. The resistor (*right* and *opposite page*) superheats ink to 300 degrees Celsius for less than one millionth of a second. Ink molecules vaporize in an expanding bubble that forces a droplet of ink out the jet nozzle. By then the film has already cooled and the bubble collapses, creating a vacuum that draws in more ink from the reservoir via capillary action.

DANIELS & DANIELS; SOURCE: NIELS NIELSEN *Hewlett-Packard Company (inset)*

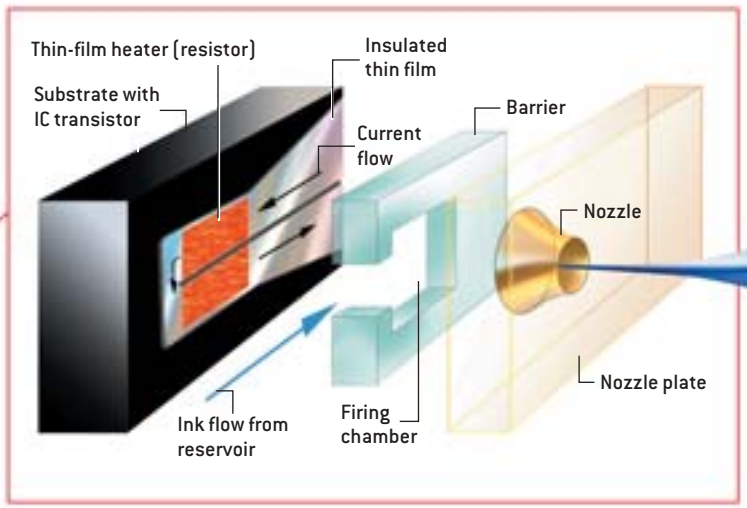
DID YOU KNOW . . .

➤ TADPOLE DROPS: Ink-jet printers are so named because each tiny droplet is forced out a jet nozzle. High-speed photography shows that the droplet looks like a tadpole or sperm—just a head and tail, as depicted below. Surface tension keeps the droplet clinging to the reservoir, so it elongates. Once the tail breaks free, static forces pull it back into the head just as the head hits the paper.

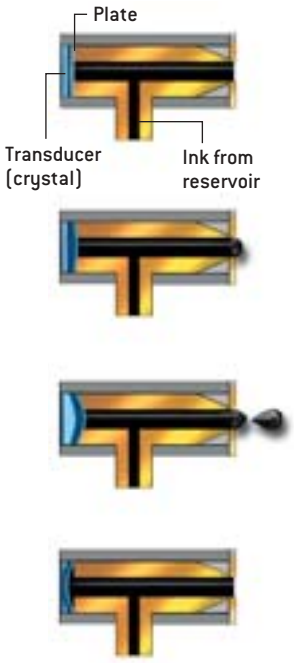
➤ KNOCKOFFS: Manufacturers can make generic ink cartridges for name-brand piezo printers by molding the proper cartridge shape and filling it with ink. Because thermal cartridges contain a complex (and patented) print head, remanufacturers must collect empty or recycled cartridges and refill them.

➤ PAPER IMAGE: When an ink droplet hits uncoated, or "plain," paper, it is absorbed below the paper's surface by the randomly oriented paper fibers. This characteristic causes the "dot" on the page to feather out in an asymmetric splotch. Coated stock is finished with a waxy film that holds ink in the thin surface layer so it forms a precise circle. Reducing the "bloom" among dots results in higher print resolution. The best coatings—on so-called photographic paper—reduce bloom the most, allowing the highest resolution.

➤ CMYK: Printers use the same basic ink hues common to printing presses: cyan, magenta, yellow and black, called CMYK. High-end machines add light cyan and light magenta for a photographic tone.



PIEZOELECTRIC PRINT HEADS send an electric current to a piezo crystal in a transducer, causing the crystal to vibrate. As the crystal bends toward the nozzle, it presses against a vibration plate that forces out one droplet of ink. As it bends back, it pulls the plate, drawing in more ink from the reservoir.



This month's topic was suggested by reader Larry Flammer. Have an idea for a future column? Send it to workingknowledge@sciam.com

Getting Real

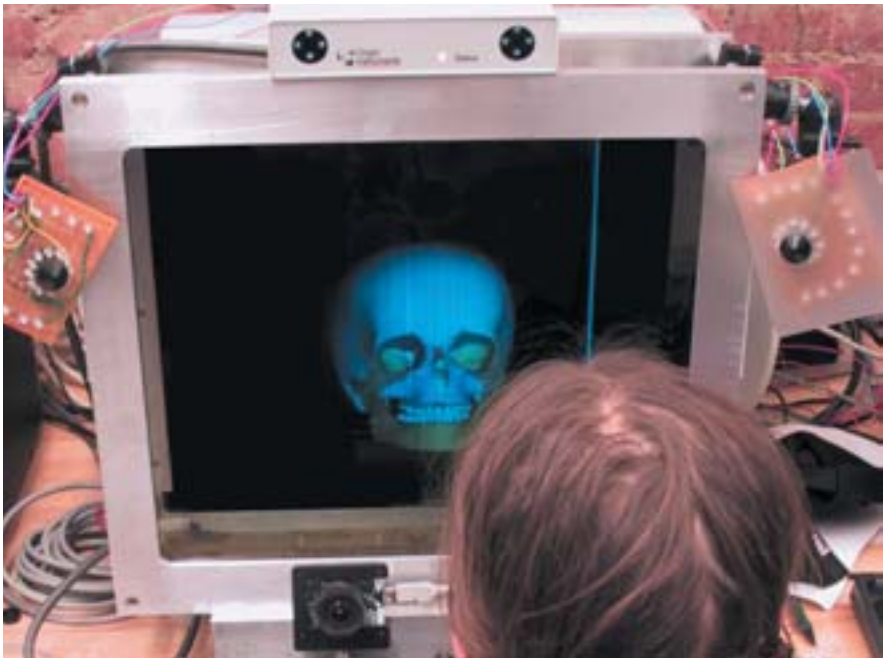
WHAT'S NEXT IN COMPUTER DISPLAYS? DEPTH AND SHADOWS **BY MARK ALPERT**

Nearly 20 years ago I had the dubious honor of viewing *Jaws 3-D*, one of the sequels to the infamous shark-attack movie. With my theater ticket I received a pair of cardboard 3-D glasses, with red cellophane in one lens and blue in the other. Feeling very stupid, I sat in the front row and donned the glasses only when the lights went down. I remember absolutely nothing about the movie's plot, but I recall with great clarity some of the 3-D effects. The opening sequence featured a severed fish head, which seemed to be floating gruesomely just inches from my face. I was still young enough at the time to think that this was pretty cool.

Fast-forward to 2002. I'm sitting in a darkened room at the Media Research Laboratory at New York University, staring at a device called an autostereoscopic display. The setup looks very odd: a computer monitor lies on its side, and a sheet of liquid crystal—called a parallax barrier—is positioned about three inches in front of the screen. On each side of the screen is a small camera surrounded by tiny infrared lights. When the system is turned on, I see a ghostly 3-D image floating in the space between the screen and the parallax barrier. It's a skeletal model of a human foot, with the tarsals, metatarsals and phalanges highlighted in different colors. The image slowly rotates, and it seems just as gruesomely real as that severed fish head from *Jaws 3-D*. But now I'm not wearing any red-and-blue glasses.

Standing behind me are Ken Perlin, the laboratory's director, and several colleagues who have worked on the project since 1998. Most previous attempts to create 3-D computer graphics have displayed two images on the screen and required users to wear either polarized glasses (which filter out one image for each eye) or shutter glasses (which alternately block the view from each eye). Perlin and his colleagues decided to eliminate the need for cumbersome eyewear. Their system also displays two images, one for the left eye and one for the right, but the images are interleaved on the screen. The result is a jagged mishmash of vertical strips. (Because a typical computer monitor scans horizontal lines, the system designers simply turn the screen on its side to produce the vertical effect.)

The parallax barrier turns this mishmash into a 3-D image. Think of this device as a picket fence between the viewer and the screen. The liquid-crystal sheet—in technical terms, a pi-cell—forms vertical black stripes that move rapidly from left to right. At any one moment, the user's left eye observes a striped view of one image (as if seen behind a fence) and the right eye observes a similar view of another image. The stripes prevent the left eye from seeing the image meant for the right, and vice versa. Because this fence moves so quickly—every sixtieth of a sec-



HERE'S LOOKING AT YOU: This autostereoscopic display shows a 3-D image with the help of a parallax barrier (*in front of screen*) and two infrared cameras (*on either side*) that track the user's eyes. The device was conceived at the Media Research Laboratory at New York University.

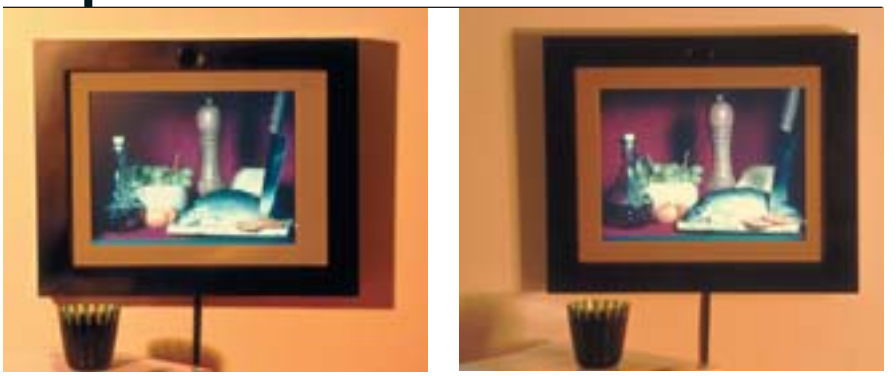
NEW YORK UNIVERSITY CENTER FOR ADVANCED TECHNOLOGY

ond the parallax barrier cycles through three positions—the user doesn't perceive the stripes. Instead each eye sees a full image, which is oriented according to the eye's position. That is where the infrared lights come in; the cameras track the positions of the user's eyes by measuring the reflection of the light off the user's retinas. Only one user at a time can see the 3-D image.

I tested the limits of the autostereoscopic display by moving my head in a variety of ways, jutting it up and down and back and forth. The system adjusted the image of the skeletal foot to match my movements, allowing me to view the thing from practically any angle. Occasionally I glimpsed some distracting black gaps in the image, perhaps caused by stray reflections of the infrared beams. The skeletal foot also appeared a bit dim because the moving stripes of the parallax barrier block some of the screen's light. Perlin assured me that this problem could be fixed by employing a brighter screen to compensate.

As I gazed at the 3-D foot, it occurred to me that surgeons might find this kind of display quite useful. But the first applications of the technology are more likely to be entertainment-oriented: N.Y.U.'s Media Research Lab is conferring with a software company about developing 3-D displays for computer game systems. (As if those games aren't grisly enough already!) It also occurred to me that the purveyors of Internet pornography might have their own reasons for promoting such displays. The members of Perlin's team wisely declined to comment on this prospect.

At Columbia University, just a few miles north of N.Y.U., researchers at the Columbia Automated Vision Environment (CAVE) laboratory are working on another display technology that promises to enhance the realism of computer graphics. Called the Lighting Sensitive Display, this device can judge the direction of the exterior light striking a computer screen and then adjust the image on the screen so that it has the appropriate



LIGHTING SENSITIVE DISPLAY developed at Columbia University changes the shadows and reflections in an image to match the exterior light. Note how the pepper mill's shadow shifts from right to left.

shadows and reflections. Shree Nayar, the head CAVE man, led me into another darkened room in which a flat-panel display hung on the wall like a painting. On the screen was a still life containing a bowl of grapes, a decanter of wine, a pepper mill and a dead fish on a cutting board. (Why do dead fish keep floating to the surface of this story?) Embedded in the screen's wooden frame was a hemispherical camera with a wide-angle lens that could detect light sources anywhere in the room.

Nayar handed me a gooseneck lamp and urged me to wave it in front of the display. As I moved the lamp, the image of the still life changed: the shadow of the pepper mill moved from left to right, glints of light appeared and disappeared on the grapes, and the decanter sparkled. The effects were almost instantaneous—the screen can change at 15 frames per second. Although the resolution was not quite good enough to show the tiny reflections off the scales of the fish, it was nonetheless an impressive show.

The story of how Nayar and his colleagues developed the Lighting Sensitive Display is equally impressive. At first they considered ray tracing, the technique used by computer animators to cast shadows on their cartoon landscapes, but they soon realized that this method was too computationally intensive to change the image quickly enough. Instead they decided to photograph an object under hundreds of different lighting conditions and store all these images in the system's memory. (Photographing the still life took so long that Nayar says the fish began to stink.) When the embedded camera detects a light source at a certain angle, the screen quickly calls up from memory the image with the appropriate shadows and reflections.

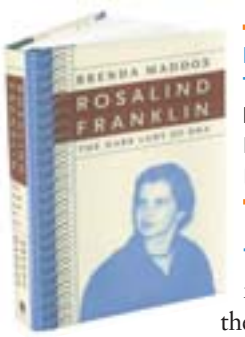
Because this approach involved a huge amount of data, Nayar's team developed an ingenious way to compress the information: divide the image into many parts using a Cartesian grid. Moving the exterior light doesn't change every part of an image; many parts don't change at all, and other parts change very little. So there is no need for the display system to store more than one or two images for each of the less changeable parts. Using this compression method, Nayar's group was able to reduce the system's memory requirement from an unwieldy four gigabytes to a more manageable 10 megabytes.

Nayar says the technology could have some educational uses. His group has already created a high-quality rendering of Michelangelo's *David* that can be viewed with the Lighting Sensitive Display. Nayar himself is an amateur painter, which perhaps explains why his fish-and-fruit image resembles a still life by one of the 17th-century Dutch masters. "The Dutch were obsessed with getting the fruit right," he says. "To show the translucency of the grapes, they used layers of oil and put the highlights beneath the surface." Maybe the typical computer user doesn't require quite the same photorealism on his or her screen, but it's nice to see that graphics designers are at least aiming high. SA

COLUMBIA AUTOMATED VISION ENVIRONMENT

The Twisted Road to the Double Helix

ROSALIND FRANKLIN'S STUNNINGLY CLEAR X-RAY PHOTOGRAPHS ELUCIDATED THE STRUCTURE OF DNA, BUT HER CONTRIBUTION WAS IGNORED AT THE TIME **BY DEAN H. HAMER**



ROSALIND FRANKLIN: THE DARK LADY OF DNA
by Brenda Maddox
HarperCollins, 2002
($29.95)

The aphorism "history is always written by the victors" is as true for science as for geopolitics. Certainly it was the case for the discovery in 1953 of the double helical structure of DNA, the most important discovery in 20th-century biology. The victors were James Watson and Francis Crick, who together with Maurice Wilkins shared the 1962 Nobel Prize for crossing the finish line first. The loser was Rosalind Franklin, who produced the x-ray data that most strongly supported the structure but was not properly acknowledged for her contributions.

According to Watson's best-selling 1968 account of the great race, *The Double Helix,* Franklin was not even a contender, much less a major contributor. He painted her as a mere assistant to Wilkins who "had to go or be put in her place" because she had the audacity to think she might be able to work on DNA on her own. Worse yet, she "did not emphasize her feminine qualities," lamented Watson, who refers to her only as "Rosy." "The thought could not be avoided," he concluded, "that the best home for a feminist was in another person's lab."

Franklin never had a chance to respond; she died of ovarian cancer in 1958. Her good friend Anne Sayre did offer a rebuttal in *Rosalind Franklin and DNA,* but that biography is too polemical and pedantic to be either persuasive or a good read.

Now, just in time for the 50th anniversary of the double helix, noted British biographer Brenda Maddox has produced a more balanced, nuanced and informed version of the tale. *Rosalind Franklin: The Dark Lady of DNA* is neither a paean to Franklin nor a condemnation of her competitors. It's simply the story of a scientist's life as gleaned from extensive correspondence, published and unpublished manuscripts, laboratory notebooks, and interviews with many of the protagonists.

It was an interesting life. Franklin, the daughter of a prominent Jewish family, was an "alarmingly clever" girl who spent her free time doing arithmetic for pleasure. She was educated at a series of academically rigorous schools culminating in the University of Cambridge, where, despite the fact that women were still excluded from receiving an undergraduate degree, she managed a Ph.D. in physical chemistry and developed the experimental style that was to characterize all her subsequent work—an approach that was meticulous, albeit sometimes overly cautious.

Then it was off to Paris, where she applied the new techniques of x-ray diffraction to the structure of coal. In France, Franklin bloomed both as a scientist, authoring numerous independent publications, and as a young woman free from the constraints of family and stuffy British society. It was a happy and productive period, as were her final years at Birkbeck College in London, where she collaborated with Aaron Klug on the structure of the tobacco mosaic virus.

Alas, the central and most important two years of her career were spent in the far less hospitable environment of the biophysics unit at King's College London. There she immediately locked horns with Wilkins over who would get to study the structure of DNA—a subject that had been largely ignored during World War II, with its emphasis on more practical matters, but was increasingly regarded as *the* problem in structural biology. Wilkins, who had been researching the matter for years, had seniority but little insight or good data. It was Franklin, a newcomer to biology, who made the critical observation that DNA exists in two distinct forms, A and B, and produced the sharpest pictures of both. They reached a compromise that Franklin would work

FRANKLIN'S PROMISING CAREER in science was cut short by her death from cancer at age 37.

COURTESY OF HARPERCOLLINS

on the A form and Wilkins on the B and went their separate ways.

Or so Franklin thought. In fact, Wilkins, in a weekend visit to Cambridge, spilled the King's beans to Watson and Crick, who soon thereafter began the model building. Although their approach was less meticulous than Franklin's, it was also far quicker. A few months later it was Watson's turn to visit London, where Wilkins showed him Franklin's startlingly clear x-ray photograph of the B form. On the train back to Cambridge, Watson drew the pattern from memory on the margin of his newspaper. Yet just two months later, in their historic letter to *Nature,* he and Crick claimed, "We were not aware of the details of the results presented [in accompanying papers from Franklin's and Wilkins's groups] ... when we devised our structure."

How did Watson and Crick, with the complicity of Wilkins, get away with so brazenly heisting "Rosy's" data? Maddox offers several theories. The most obvious is Franklin's position as a female researcher at an institution where women were still not allowed to set foot in the senior common room. There was also the matter of anti-Semitism. Franklin's family may have anglicized their name, but her uncle was the first High Commissioner of Palestine, and she was active in Jewish relief groups. She felt isolated, even ostracized, in a school where theology was the largest department and "there were swirling cassocks and dog collars everywhere."

We'll probably never know the full story, but Maddox's book shines new light on one of the key characters in the tale of the double helix. Rosalind Franklin may not have had the intuition of some of her competitors, but what she did possess was equally important: integrity. SA

Dean H. Hamer is a molecular geneticist at the National Cancer Institute. He is author of the upcoming The God Gene *and co-author of* Living with Our Genes *and* The Science of Desire.

THE EDITORS **RECOMMEND**

THE EMERGENCE OF EVERYTHING: HOW THE WORLD BECAME COMPLEX

by Harold J. Morowitz. Oxford University Press, New York, 2002 ($28)

"We are clearly at the beginning of viewing science from the new perspective of emergence," Morowitz writes. "I believe that it will provide insights into the evolutionary unfolding of our universe, our solar system, our biota, and our humanity." Emergence is the opposite of reductionism. "In the domain of emergence, the assumption is made that both actual systems as well as models operate by selection from the immense space and variability of the world of the possible, and in carrying out this selection, new and unanticipated properties emerge." Morowitz, professor of biology and natural philosophy at George Mason University, provides 28 examples of emergence, from the primordium through the appearance of hominids to their progression to philosophy and the spiritual. His argument is closely reasoned and rich in scientific and philosophical background.

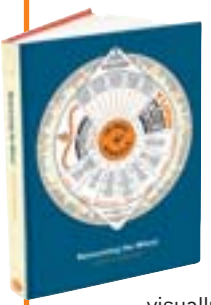
BEHIND DEEP BLUE: BUILDING THE COMPUTER THAT DEFEATED THE WORLD CHESS CHAMPION

by Feng-hsiung Hsu. Princeton University Press, Princeton, N.J., 2002 ($27.95)

It was 1949 when the eminent mathematician Claude E. Shannon suggested how to program a computer to play chess. "At that time, many renowned computer scientists believed that the Computer Chess Problem—creating a chess computer that could beat the World Champion—would be solved within a few years." It was, in fact, 48 years before the IBM computer Deep Blue—capable of searching 200 million possible chess positions per second—defeated world champion Garry Kasparov. Hsu, now a research scientist at the Western Research Lab of Compaq Computer, was the system architect for Deep Blue. He makes an exciting tale of computer chess evolution and the Kasparov match. Is Deep Blue intelligent? No, Hsu says: "It is only a finely-crafted tool that exhibits intelligent behavior in a limited domain."

REINVENTING THE WHEEL

by Jessica Helfand. Princeton Architectural Press, New York, 2002 ($24.95)



"Twentieth-century volvelles—often referred to as 'wheel charts'—offer everything from inventory control to color calibration, mileage metering to verb conjugation. They anticipate animal breeding cycles and calculate radiation exposure, measure chocolate consumption and quantify bridge tips, chart bird calls, convert metrics, and calculate taxes." Starting as a collector of wheel charts, Helfand (a design critic and lecturer on graphic design at Yale University) came to recognize how old the concept is and to marvel at how many uses it has found. Focusing on the proliferation of these devices in the 20th century, she presents pictures and descriptions of nearly 100 of them. Her book is therefore visually intriguing. But it also ventures deep into the philosophy of the devices. Despite their wide range of content, Helfand writes, "these paper artifacts are somehow philosophically united in their unique approach to information design."

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

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Ask the Experts

Do scents affect people's moods or work performance? Rachel S. Herz, an assistant professor of psychology at Brown University, explains.
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This award, the first of its kind from SCIENTIFIC AMERICAN, honors 50 individuals, teams, companies and other organizations whose accomplishments during the previous year demonstrate that they have a clear, progressive view of the technological future, as well as the leadership, knowledge and expertise needed to make that vision a reality. Find exclusive interviews online with some of the winners.

Claude E. Shannon: Founder of Information Theory

Quantum information science is a young field; its underpinnings are still being laid by a large number of researchers. Classical information science, in contrast, sprang forth about 50 years ago, from the work of one remarkable man: Claude E. Shannon. In a landmark 1948 paper written at Bell Labs, Shannon defined in mathematical terms what information is and how it can be transmitted in the face of noise. What had been viewed as quite distinct modes of communication—the telegraph, telephone, radio and television—were unified in a single framework.

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Plumbers

BY DENNIS E. SHASHA

The director of a government organization shares confidences with nine advisers. To his dismay, however, some of his most intimate thoughts have lately been appearing in newspapers the day after he reveals them. A common technique for discovering leakers is to tell each suspect some unique piece of information (a tidbit) and then see if it spreads. But the director discovers that this approach will not be good enough: news editors will print a story only if at least three advisers attest to the tidbit. He is quite sure there are no more than three leakers.

He has a dilemma. If he tells a tidbit to everyone, it will certainly be reported, but he will not have learned anything. If he tells a tidbit to one or two people, it won't be reported. He can choose a different tidbit for each triplet of people, but nine confidants can form 84 triplets—too many. He arrives at the following strategy: he will tell a tidbit to foursomes, one tidbit a day. Once a leak occurs, he will narrow down the number of triplets that remain suspect. One of his goals is to provoke no more than two leaks—one from a foursome and, at most, one from a threesome. Another goal is to find a sequence of foursomes such that he can guarantee getting one of them to produce a leak and can zero in on a leaking triplet using at most 25 tidbits. Can you help him?

To warm up, suppose the director tells a tidbit to advisers 1, 2, 3 and 4 the first day without a leak and a second tidbit to advisers 2, 3, 4 and 5 the next day with the same outcome. But his third tidbit, told to advisers 1, 2, 4 and 5, reaches the papers. Which triplets are suspect? Only two of the four that could be formed from the third quartet: 1-2-5 and 1-4-5. If either of the other two triplets comprised the leakers, one of the first two tidbits would have been leaked. Because the director knows he has only three leakers, he needs to test just one of the remaining two suspect triplets.

The director might be able to find the precise triplet using far fewer tidbits if he sometimes spreads tidbits to more than four people and is willing to tolerate more than two leaks. What do you think?

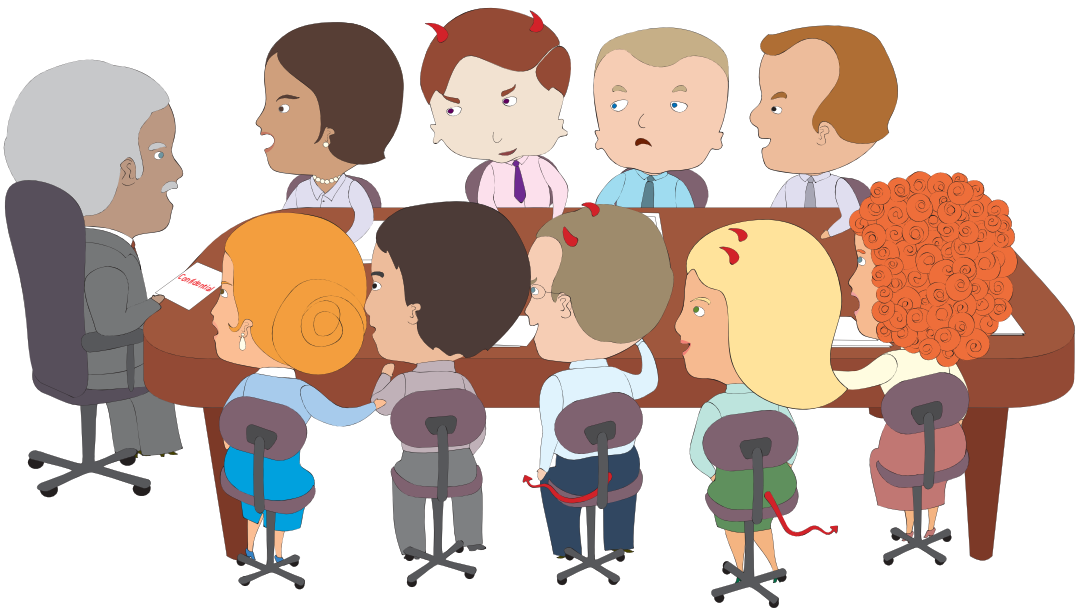
Dennis E. Shasha's latest puzzle book is Dr. Ecco's Cyberpuzzles, *published by W. W. Norton (2002).*

Answer to Last Month's Puzzle

You can make the shot by hitting the ball east by northeast (a slope of $\frac{1}{2}$). The ball will bank against positions $(3, \frac{1}{2})$ and $(2, 1)$ before gliding into the pocket. This is best seen by looking at the figures on the Web site.

Web Solution

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



SARA CHEN

Members Only

A LOOK AT SOME RECENT RESEARCH THAT COULD BE DESCRIBED AS ORGANIC **BY STEVE MIRSKY**

It happens this way sometimes. Just as Leibniz and Newton independently invented the calculus, certain scientific advances just seem to be in the air. Throw in the fact that most scientists are male, and perhaps it begins to explain why you couldn't swing Schrödinger's cat in September without hitting breaking news about penises.

First came a report in the *Journal of Urology* that scientists at Harvard Medical School had successfully grown rabbit penis parts in petri plates (which Peter Piper particularly appreciated), a first step toward growing whole penises. My initial reaction was, "Do we really need the ratio of rabbit penises to male rabbits to be greater than 1?"

The researchers removed sections of rabbits' penises, took some of the harvested cells and grew lots of new ones from them, then implanted the freshly grown tissue back in the donor rabbits. The restored rabbits appeared to function fine, although they probably took to walking gingerly rather than hopping down the bunny trail. Of course, the aim of this work is to eventually be able to create human tissue for men in need of reconstructive surgery because of disease or injury. But the technology could also someday benefit otherwise healthy guys who decided *not* to spend the money on the Lamborghini.

Next came the news from a meeting of the British Association for the Advancement of Science of the discovery of the world's oldest fossilized penis. The member belonged to a crustacean from Brazil (where the nuts come from) that frolicked some 100 million years ago. Now, it wasn't a big piece of machinery, as the entire organism was only about a millimeter long. But the penis took up about one third of the little guy's body length and volume. Extinction, perhaps, was inevitable.

Then came a Reuters report that Levi Strauss & Co. was coming out with a new kind of Dockers pants that, like some other pants, includes a special pocket for your cell phone. Only the pocket of the so-called Icon S-Fit (emphasis on the "con") includes a "radiation-reducing" lining, presumably to protect a man's private parts from the signals sent and received by cell phones. "We're not implying in any way that cell phones are dangerous," said a Levi spokesman whose name really is Cedric Jungpeter or I wouldn't be able to say it was.

Jungpeter also said, "Our intention is not to cash in on consumer fears but provide the consumers with what they want." And if the company happens to cash in on consumer fears despite that not being their intention, well, hey. By the way, I have a question: If the pocket successfully blocks radiation, how can calls get through? And if calls can't get through anyway, why not just shut the phone off before putting it in your pocket?

A shoe story came on the heels of the pants story (which has to be the most confused metaphor in this issue). New research, in the *British Journal of Urology International*, established the relation between shoe size and … sock size. In fact, the study dispelled the commonly held belief that shoe size is an indicator of penis size. Two London urologists enlisted 104 men for the study. The urologists write, "The linear distance from the symphysis pubis to the tip of the glans along the dorsal aspect, under maximal extension of the phallus, was recorded using a measuring tape," which translates to "we somehow got 104 guys to agree to drop their pants next to a tape rule."

They then compared the numbers with shoe size data and found no correlation. One of the urologists, clearly frustrated by the nonfinding, was quoted by Reuters Health news service as saying, "There must be some part of the body that is predictive of penile length.… The search continues." In the future, of course, penis size will be highly correlated with petri dish size. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

ASK THE EXPERTS

How does the Venus flytrap digest flies?

—F. Alikham, Daly City, Calif.

Lissa M. Leege, a plant ecologist and assistant professor of biology at Georgia Southern University, explains:

Before we talk about how the Venus flytrap (*Dionaea muscipula*) digests its prey, it is important to know why it does so. It can make its own food through photosynthesis, so the insect-eating plant does not use prey for the traditional animal objectives of harvesting energy and carbon. Rather it mines its food primarily for essential nutrients (nitrogen and phosphorus in particular) that are in short supply in its boggy, acidic habitat.

The Venus flytrap occurs in a restricted range of sandy shrub bogs in coastal North Carolina and South Carolina, where it is an endangered species. Frequent fires there clear out competing plants and volatilize nitrogen in the soil. Hence, Venus flytraps' unique adaptation enables them to access nitrogen when other plants can't get it from the soil.

How does this plant manage to attract, kill, digest and absorb its prey? First it lures its victim with sweet-smelling nectar, secreted on its steel-trap-shaped leaves. Unsuspecting insects land in search of a reward, trip the bristly trigger hairs and are imprisoned behind the interlocking teeth of the leaf edges. There are three to six trigger hairs on the surface of each leaf. If the same hair is touched twice or if two hairs are touched within a 20-second interval, the cells on the outer surface of the leaf fill with watery fluid to expand rapidly, and the trap shuts. If insect secretions, such as uric acid, stimulate the trap, it will clamp down further and form an airtight seal. Once the trap closes, digestive glands that line the interior edge of the leaf secrete enzymes that dissolve the soft parts, kill bacteria and fungi, and break down the insect into the necessary nutrients. These are then absorbed into the leaf. Five to 12 days after capture, the trap reopens to release the leftover exoskeleton. (If tripped by a curious spectator or a falling twig, the trap will reopen within a day or so.)

After three to five meals, the trap will no longer capture prey but will spend another two to three months simply photosynthesizing before it drops off the plant, only to be replaced by a new one. Plant owners should beware of overstimulating a Venus flytrap: after approximately 10 unsuccessful trap closures, the leaf will cease to respond to touch and will serve only as a photosynthetic organ.

How do rewritable CDs work?

—R. Raiszadeh, Kerman, Iran

Gordon Rudd, president of Clover Systems in Laguna Hills, Calif., offers this answer:

All CDs—and DVDs—work by virtue of marks on the disc that appear darker than the background. These are detected by shining a laser on them and measuring the reflected light.

In the case of molded CDs or DVDs, such as those bought in music or video stores, these marks are physical "pits" imprinted into the surface of the disc. In CD-Recordable (CD-R) discs, a computer's writing laser creates permanent marks in a layer of dye polymer in the disc.

CD-Rewritable (CD-RW) discs are produced in a similar fashion, except that the change to the recording surface is reversible. The key is a layer of phase-change material, an alloy composed of silver, indium, antimony and tellurium. Unlike most solids, this alloy can exist in either of two solid states: crystalline (with atoms closely packed in a rigid and organized array) or amorphous (with atoms in random positions). The amorphous state reflects less light than the crystalline one does.

When heated with a laser to about 700 degrees Celsius, the alloy switches from the original crystalline phase to the amorphous state, which then appears as a dark spot when the disc is played back. These spots can be erased using the same laser (at a lower power) to heat the material to a temperature of 200 degrees C or so; this process returns the alloy to its crystalline state. Most CD-RW makers suggest that one disc can be overwritten up to 1,000 times and will last about 30 years. SA

For a complete text of these and other answers from scientists in diverse fields, visit www.sciam.com/askexpert_directory.cfm

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