PREHISTORIC KILLER KANGAROOS

SCIENTIFIC AMERICAN

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TSUNAMI

Predicting Destruction by Monster Waves

BLACK HOLES

Direct Proof at Last

NEW BRAIN CELLS

Growth Hints at Neural Repair

21st-CENTURY WEB

How XML Beats HTML

Tribal Extinction • Magnetic RAM • and more

SCIENTIFIC AMERICAN

May 1999 Volume 280 Number 5

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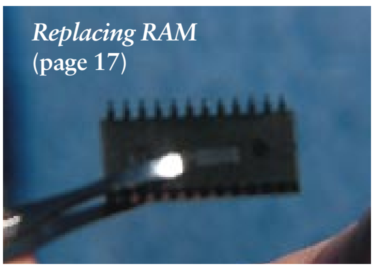
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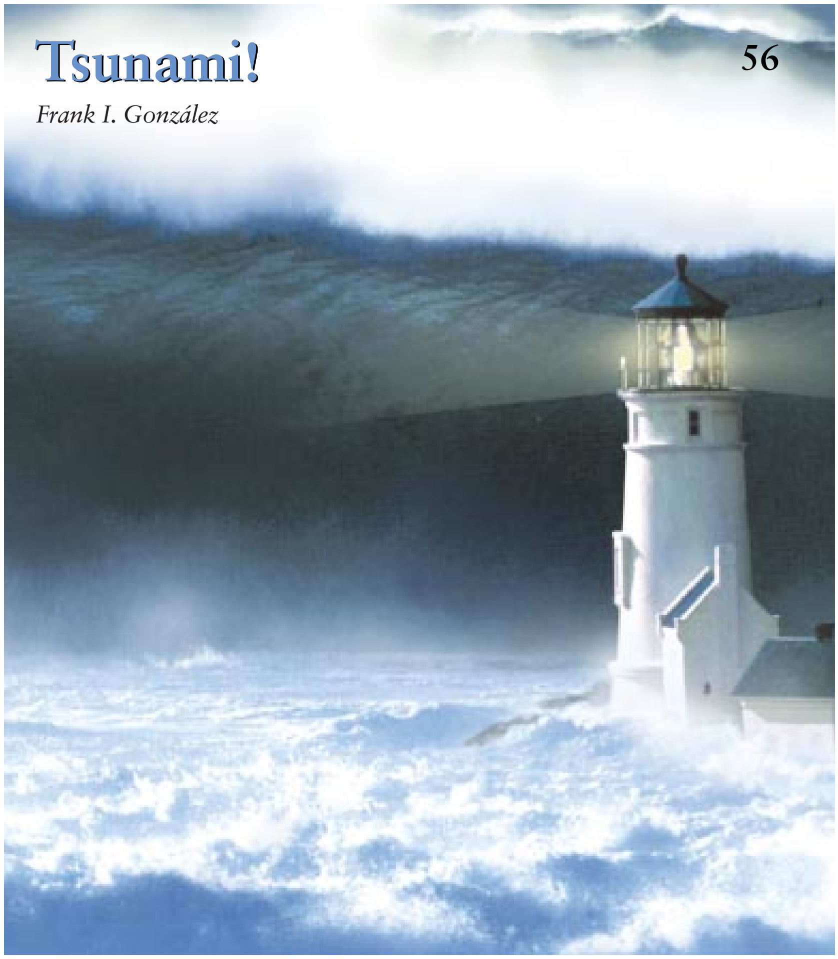
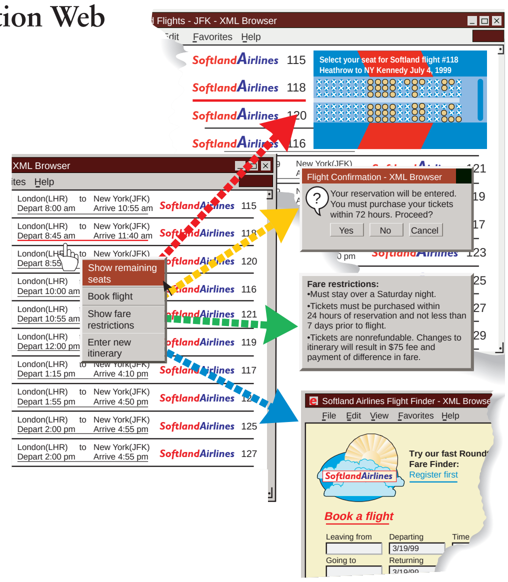

Tsunami! 56
Frank I. González

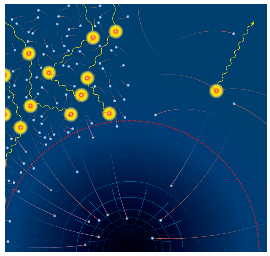
Far out at sea, it can begin as an almost unnoticeable swell moving hundreds of miles per hour. On shore, it can become a monstrous wave more than 100 feet high. Tsunamis have killed thousands in the past decade, but new methods of detecting and tracking them should reduce the toll.

89 **XML and the Second-Generation Web**
Jon Bosak and Tim Bray



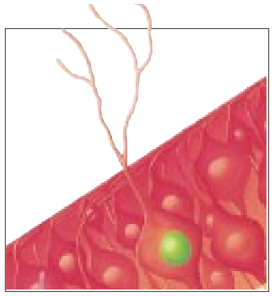
Extensible Markup Language (XML), a tool for writing World Wide Web pages, promises another on-line revolution. Pages written in XML can deliver needed information more quickly and efficiently than HTML pages can. They can also automatically reformat themselves for convenient access by computer, telephone, handheld organizer or other devices.

40 **Unmasking Black Holes**
Jean-Pierre Lasota



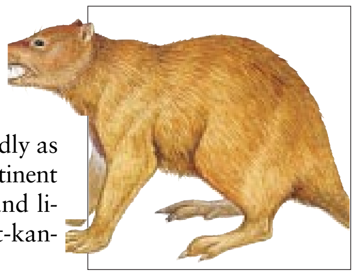
Evidence for black holes was until recently all circumstantial. Distinguishing them at a distance from other highly compact, gravitationally massive bodies such as neutron stars is inherently problematic. Now astronomers may have direct proof: energy is vanishing from volumes of space without a trace.

48 **New Nerve Cells for the Adult Brain**
Gerd Kempermann and Fred H. Gage



Last year Gage and his associates showed that, contrary to belief, the adult human brain does sometimes grow new nerve cells. This discovery could help with developing treatments for currently irreversible brain disorders such as Parkinson's disease, Alzheimer's disease and stroke.

68 **Killer Kangaroos and Other Murderous Marsupials**
Stephen Wroe



Australian mammals weren't always as cuddly as koalas. For tens of millions of years, the continent was home to ferocious marsupial wolves and lions, a pouched tiger and muscle-bound rat-kangaroos that terrorized smaller prey.

76 **Ada and the First Computer**
Eugene Eric Kim and Betty Alexandra Toole

Augusta Ada King was countess of Lovelace and daughter to the poet Lord Byron. More important, as a mathematician, she extended Charles Babbage's work on his proposed Analytical Engine and published the first in-depth paper on programming a computer.

82 **The Andaman Islanders**
Sita Venkateswar

Once erroneously feared as "dog-headed" cannibals, this ethnically distinct group of hunter-gatherers has inhabited the Andaman Islands in the Bay of Bengal for at least 2,000 years. Their unique way of life has suffered under both British and Indian rule, however, and its survival is much in question.

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Digital painting by Heidi Noland.

FROM THE EDITORS

Survivors and a Winner

Kangaroos come across as steroid-enhanced rabbits. Koalas are obviously a species of renegade plush toy. The only modern marsupial whose mention gives pause is the Tasmanian Devil, blessed with a tough-guy name and a ferocious likeness in Warner Bros. cartoons. (In reality, the devil is mostly a threat to carrion.)

Ah, but we should have seen them in the old days. Prehistoric pouched predators terrorized what is now Australia during the Miocene. Big, robust, with sharp teeth and bad dispositions, they fended off the nasty competition, including one another, for millions of years. What happened to them? As Stephen Wroe notes in his survey beginning on page 68, shifts in the climate may have overwhelmed most. Then came new enemies in the form of humans and dingoes. The Tasmanian Tiger, last of the big hunting marsupials, probably went extinct early this century.

That outcome doesn't point to an implicit inferiority in marsupials, because they had a strong run. Rather it retells the old evolutionary story about how those who deal well with change survive and those who can't, don't. All well and good when we're talking about other species—but the lesson gets uglier when applied to people.

NORMAN O. TOMALIN *Bruce Coleman Inc.*

TASMANIAN DEVIL: runt of the litter

The Tasmanians descended from those first humans in Australia, and they prospered in isolation for 10,000 years or so. Their downfall was the arrival of the Europeans, who brought territorial ambitions, violent conflict and new germs. Massacred, confined and decimated by disease, the native population declined from several thousand to a mere 44 by 1847. Truganini, a woman regarded as Tasmania's last full-blooded Aborigine, died in 1876—about half a century before the Tasmanian Tiger.

Andaman Islanders in the Bay of Bengal face a sadly similar threat (see page 82). Their numbers, too, are declining, and their traditional way of life is eroding even faster. Beyond colonialism's bad effects, the bind for the Andamanese is that their distinctiveness arose in part from their historical insistence that outsiders leave them alone. Now that option is gone forever. Dealing with this change will challenge the resilience of their culture and whatever is still sympathetic in ours.

Dennis Flanagan is the editor who, during 37 years in this chair, made Scientific American a great magazine, but saying that doesn't give him half enough credit. So let me restate the proposition: his influence as an exponent of clear, elegant science writing has been so great that every science journalist working in English should call him mentor. The American Society of Magazine Editors inducted Dennis Flanagan into its Magazine Editors' Hall of Fame in April. Three cheers for a deserved honor.

JOHN RENNIE, *Editor in Chief*
editors@sciam.com

LETTERS TO THE EDITORS

Readers responded in large numbers to the January special report, "Revolution in Cosmology." Many took particular interest in the cosmic origin of one of the authors, Nicholas B. Suntzeff, who was described as being "made of elements formed in supernovae over five billion years ago." Milton N. Adams of Virginia Beach, Va., writes, "Perhaps Suntzeff would be willing to forgo his usual work and submit himself for study. Surely such people must be extremely rare, whether they be cosmologists or of some other stripe." Of course, we are all made of such elements, but we passed this suggestion along to Suntzeff for comment anyway. He was flattered to have his body discussed in such a public way, although, he muses, "it would have been more complimentary had it been in the pages of *GQ, Details* or *Cosmopolitan.*" As for donating his body to science, Suntzeff recalls that he did this "sometime while I was taking quantum mechanics as a sophomore at Stanford, when I had to give up sleeping and normal body hygiene in order to get the problem sets done. My hygiene has gotten a lot better, but my wife regularly notices the absence of the body." Additional reader responses are included below.

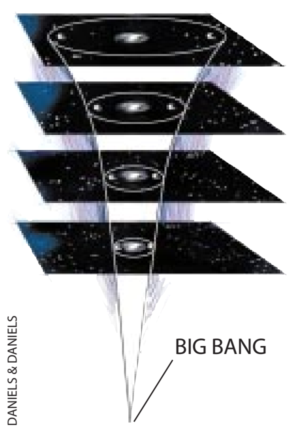
COSMIC INFLATION

In "Inflation in a Low-Density Universe," by Martin A. Bucher and David N. Spergel [January], the authors state that the big bang theory cannot explain why two galaxies on opposite sides of the universe look so similar. Now, my instinct tells me that they look similar because they originated from the same place. In fact, why should the two galaxies be different at all?

BOB PARKER
Birmingham, England

Thank you for the update on cosmology that presented alternate views on the expansion of the universe. No one has explained, however, why it is assumed that photons can travel from the microwave background for billions of years unadulterated. What if, once every billion years or so, a photon of starlight scatters or decays, emitting a low-energy photon? Might this explain the microwave background without requiring the big bang?

FRANCISCO J. OYARZUN
La Mesa, Calif.



EARLY ACCELERATED EXPANSION *might explain the present uniformity of the universe.*

Bucher replies:

In the big bang theory without inflation, everything in the universe indeed originated from the same point—the singularity at time $t = 0$. But the known laws of physics cannot describe what happened at that instant or determine whether there really was a singularity. Thus, it is not possible to rely on conditions at $t = 0$ to ensure that galaxies will look similar, as Parker suggests. The question instead is whether subsequent processes could have smoothed out any initial unevenness in the cosmos. In a universe without inflation, such smoothing necessitates something traveling faster than light, which would contradict relativity. With inflation, ordinary processes can even out the universe, and the paradox is resolved.

Modern cosmology depends on the prevailing interpretation of the microwave background—namely, that the microwave photons emerged when the universe was less than 1,000th its present size and traveled in a straight line for some 15 billion years. The strongest evidence for this is the nearly perfect thermal, blackbody spectrum of the microwaves. This spectrum is easily explained if the radiation is primordial: it is thermal because the photons were in thermal equilibrium at that early time. In contrast, an alternative explanation—such as the "tired light" theory that Oyarzun describes—would require a grand conspiracy to obtain a thermal spectrum.

IMPUGNABLE ETHICS?

Madhusree Mukerjee's article, "Out of Africa, into Asia," on Andaman Islander genetics [News and Analysis, January] contains some incorrect information and raises important issues concerning the ethics of scientific publishing. The report describes research conducted by Erika Hagelberg and Carlos Lalueza Fox on DNA extracted from hairs belonging to the Duckworth Collection at the University of Cambridge. Mukerjee cites "an unfortunate dispute regarding the hair" as the reason why the researchers have not yet published their results in a scientific journal. The article states that according to Hagelberg, I knew about her study for at least a year before voicing an objection. In fact, when I first heard that this material had been studied without my knowledge, I immediately objected. It is a very serious matter when irreplaceable material is removed from a collection without authorization and sampled destructively. I am truly disappointed that important results should be lost to science, but the pursuit of scientific knowledge is not above other standards of behavior.

ROBERT FOLEY
Director, Duckworth Collection
University of Cambridge

Mukerjee replies:

No matter the details of the dispute, surely some resolution exists that will include publication of these extremely important results. If they are buried, it will be a loss not only to science but also to efforts to save the Andamanese.

THE STING OF Y2K

Peter de Jager has provided a refreshingly lucid and concise article in "Y2K: So Many Bugs...So Little Time" [January]. Although computer programmers are reaping most of the blame, my-

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opic management contributed considerably to the origins of the Y2K bug. In 1978, while I was employed by a major corporation as a programmer, the threat of Y2K dawned on me. After changing the program I was working on to avoid the problem, I prepared a detailed report outlining the consequences of Y2K and what we might do to avert disaster—namely, institute a four-digit date standard for all new software and an orderly process for upgrading existing code. With 20 years still ahead of us, the cost and effort would have been negligible. On reading my report, management warned me against wasting my time on such frivolous speculation. This same company has recently spent several hundred million dollars wrestling with Y2K, and it is by no means certain that they will be ready when the event so long ago foretold is upon them.

GARTH KLATT
Softek Research
Calgary, Canada

RENAISSANCE REFLECTIONS

Marguerite Holloway's profile of James Flynn ["Flynn's Effect," News and Analysis, January] was quite thought provoking. Flynn asks, "Why aren't we undergoing a renaissance unparalleled in human history?" But if this is not a renaissance, what is? In the past 30 years, we have walked on the moon, solved Fermat's last theorem and built machines that can defeat the world's greatest chess grand masters. Almost all households in developed countries have hot and cold running water, refrigerators, microwave ovens and televisions. History's greatest philosophers are alive today, and although their musings may not be recognized by the intellectual mainstream, later generations will learn to respect these works. There is, of course, much room for improvement, but the same was true for the Athenians and the Italians. Nevertheless, to live in a golden age is a wonderful privilege that we must not take for granted.

PAUL E. MCKENNEY
Beaverton, Ore.

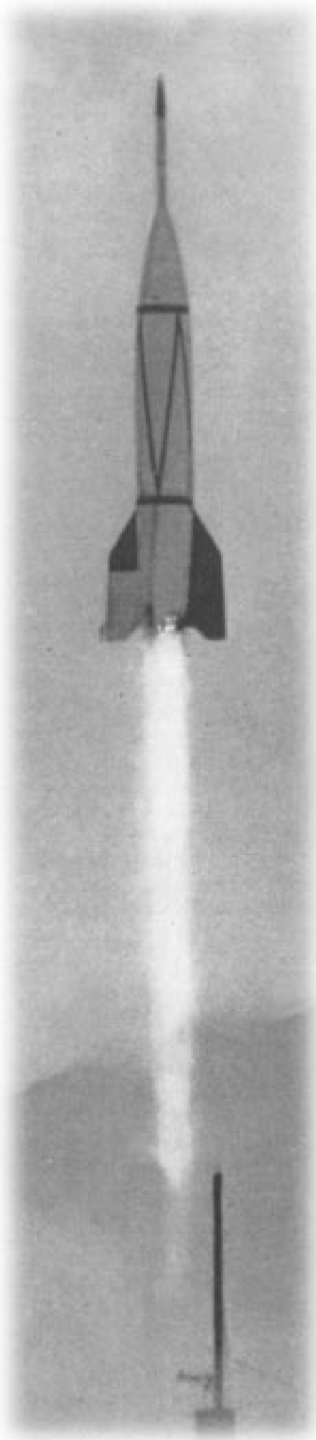
Letters to the editors should be sent by e-mail to editors@sciam.com or by post to Scientific American, 415 Madison Ave., New York, NY 10017. Letters may be edited for length and clarity.

50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

MAY 1949

ROCKET DESIGN SUCCESS—"On February 24, 1949, man made his first really substantial step into outer space. An ex-German V-2 rocket took off from the White Sands Proving Ground in New Mexico [*see illustration*]. In its nose it carried an American-made rocket, the Wac Corporal, filled with telemetered instruments. The Wac Corporal began to burn its own fuel at an altitude of 20 miles and coasted upward to an altitude of 250 miles. While definitions of the limit of the atmosphere differ, it is fair to say that at the peak of its ascent the Wac Corporal was in interplanetary space. The largest promise in that shot was in the use of the step [now called stage] principle. If the principle can be extended to three steps, we may get a 'satellite rocket' that will circle the earth."



Two-stage rocket soars to record heights

THE NATURE OF DREAMS—"When we dream we speak a language which is also employed in the most significant documents of culture: in myths, in fairy tales and art, recently in novels like Franz Kafka's. This language is the only universal language common to all races and all times. It is the same language in the oldest myths as in the dreams every one of us has today. Moreover, it is a language which often expresses inner experiences, wishes, fears, judgments and insights with much greater precision and fullness than our ordinary language is capable of.—Erich Fromm"

DEGREES C—"Scientists at the International Conference on Weights and Measures in Paris have voted to discard the traditional 'degrees Centigrade' for metric temperature readings and to use 'degrees Celsius' instead. The renaming is in honor of the 18th-century Swedish astronomer Anders Celsius."

MAY 1899

FUTURE OF COAL—"At some period in the future a successful substitute for coal may be discovered, but we must bear in mind the extreme cheapness of coal and the possibility of further economizing its consumption. If during the next half century the nation [Britain] is spared international difficulties, such as a great war, we may expect to enjoy a most prosperous period in our manufacturing industries. Eventually, as coal becomes dearer in this country, manufacturing operations that supply the world will gradually be transferred to countries where the cheapest coal is produced."

THE DEADLY FLOWER—"Large and sumptuous, the flower of the poppy seems made only for its fine appearance. It contains, nevertheless, a deadly poison—opium. After once using opium a person quickly becomes a slave to this tyrannical habit. Opium is smoked in China especially, where its success was formidable in this country of misery. Benares, Patna, and Malona are the three great Hindoo centers from which sixteen or eighteen hundred 158-pound cases of opium are exported monthly to the great commercial advantage of the English."

EARLY AIDS TO NAVIGATION—"Prof. Marconi has invented an instrument for ascertaining a ship's position in a fog, when it is within range of one of the telegraph stations. It consists of a receiver which can be revolved and which, when pointed toward the transmitting station, sets off an electric bell, thus establishing the bearings as accurately as a compass can. The instrument is to be tried on the Channel steamers."

MAY 1849

LATEST ON GRAVITY—"Science has developed the grand truth, that it is by the exercise of an all-pervading influence, gravity, that the earth is retained in its orbit. Throughout the universe the balance of gravitating force is unerringly sustained. If the most remote of those gems of light, which flicker at midnight in the dark distance of the starry vault, was, by any power, removed from its place, the disturbance of these delicately balanced mysteries would be felt throughout all the created systems of worlds."

A SCIENTIFIC PRINCE OF SIAM—"From Bangkok, Siam, we hear that his Royal Highness, Prince T. N. Chau-Fa-Rhromakhun Isaret Rangsan, has constructed a small steam-engine, and the Siamese can now boast of having running on the river Menam, a steamboat, every portion of which has been manufactured by native artificers. She is 26 ½ feet long, the engine being 2 horse power. This little phenomenon has made several trips up and down the river, his Royal Highness the Prince acting as steersman himself in full view of thousands of astonished and admiring spectators." [*Editors' note: The dedication to science of another royal Thai, King Mongkut (who ruled 1851–1868), was one of the few historically accurate themes in the musical* The King and I.]

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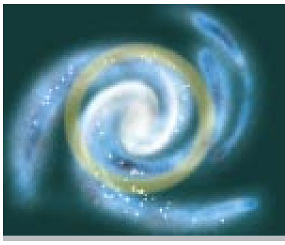
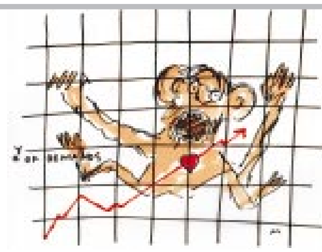
SCIENCE AND THE CITIZEN





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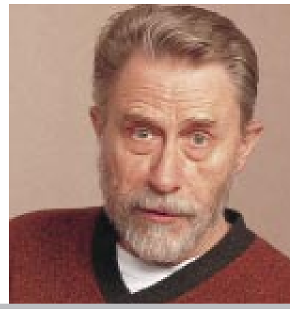

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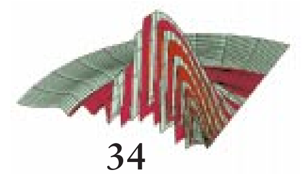

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TECHNOLOGY AND BUSINESS

IN FOCUS

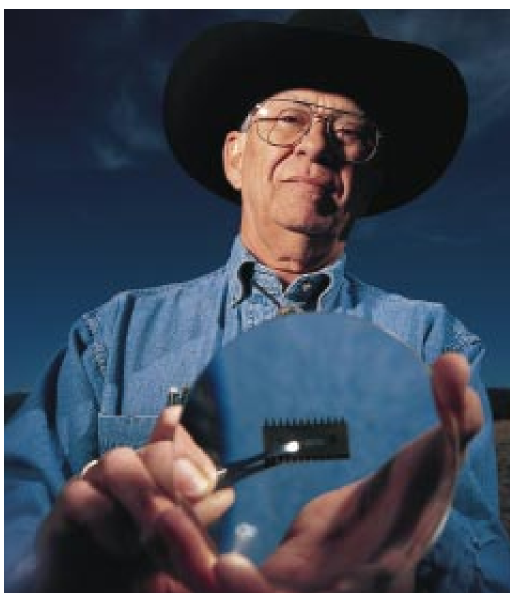
THE MAGNETIC ATTRACTION

A long race to create faster memory chips that never lose data yields prototypes at last

Laurence P. Sadwick was skeptical two years ago when a mild-mannered inventor from Pecos, N.M., brought him a novel design for a computer memory chip. The inventor, Richard M. Lienau, and the start-up firm that he had found to back him, named Pageant Technologies, made remarkable claims. These new chips, they said, could hold data even when the power went out—for many years, if need be. They would work five to 10 times faster than the so-called dynamic random-access memory (or DRAM) chips used in computers today. Yet the new chips should cost no more to make: only minor changes to existing production lines were needed. The secret ingredient that made all this possible, Lienau said, was an array of minuscule magnets.

"I gave them a hard time. I didn't trust them," recalls Sadwick, an electrical engineer at the University of Utah. After all, academic groups had tried since the mid-1980s to replace the capacitors that record information in DRAM with micron-size bits of ferromagnetic metals such as alloys of iron, nickel and cobalt. Capacitors lose their charge—and their data—unless they are refreshed every few milliseconds. Magnetic films, on the other hand, don't suffer such amnesia, which is why hard disks are coated with them. But it is one thing to measure tiny magnetic fields as they pass beneath a single moving head, as disk drives do. Building a sensor right next to each one of millions of magnetic bits is much harder.

In recent years, major manufacturers, including IBM and Motorola, had joined the search (and in February, Hewlett Packard announced it would, too). But the only company ever to produce commercial magnetic RAM chips was Honeywell, and in 1997 its best devices were still 10 times slower, 256 times less dense and far more expensive than DRAMs. Nobody else even had prototypes.



ERIC O'CONNELL

CONVENTIONAL SEMICONDUCTOR memory chips cannot retain data without power, but Richard M. Lienau thinks he has a magnetic way to fix that.

Yet after a careful analysis of Lienau's idea, Sadwick decided that it might just work, and he set about building experimental versions. His timing was right on: Pageant is now a contestant—albeit a dark horse—in what has become a heated race to introduce a magnetic memory fit enough to challenge DRAM and perhaps eventually to replace it. In the past few months, at least five competing research teams have produced working prototypes of single-bit magnetic memory cells.

All are aiming for the same three goals. First is to make cells at the micron scale that are compatible with existing production lines so that the devices can be as cheap as DRAM. Second, the new chips should require as little power as possible, because the greatest need for permanent memories is in battery-powered gadgets such as portable phones and smart cards. The last goal is speed: today's DRAMs can fetch or store data in 60 nanoseconds. Magnetic RAM should ultimately do better.

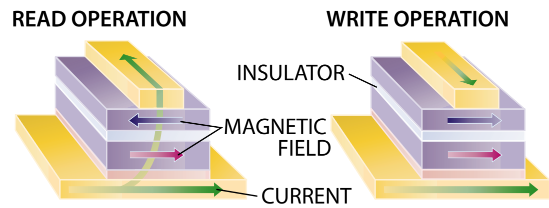
In the near term, "we would just be happy to get a toehold in the market," comments Mark B. Johnson, a physicist at the Naval Research Laboratory. "That could probably happen within two years," he says, if magnetic memories can shoulder out Flash RAM and so-called EEPROMs, the two leading forms of permanent semiconductor memory. "They are vulnerable because they are really slow: writing data can take tens of microseconds, and erasures take up to a second," Johnson observes. Both kinds of chips require high power and wear out after less than a million write operations. "Even so, that is a $5-billion-a-year market," he adds.

Magnetic memories will also compete with ferroelectric devices, in which a 0 or 1 is recorded by changing the position of atoms in a crystal. Ramtron in Colorado Springs recently produced 64-kilobit versions that the firm claims are nearly as fast as DRAM and last for years. But it has apparently failed to convince many customers, because sales fell in 1998 and the company continues to lose money.

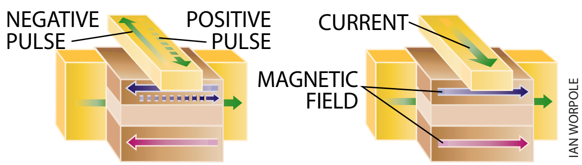
The magnetic RAM teams have divided along scientific lines to pursue three distinct approaches. Of these, the most mature and thoroughly studied is based on a principle discovered only 10 years ago: a phenomenon called giant magnetoresistance (or GMR), in which a magnetic field changes the electrical resistance of a thin metal film by up to 6 percent. Honeywell has exploited this effect in experimental chips that contain more than one million bits, according to James Daughton, president of Nonvolatile Electronics in Eden Prairie, Minn.

Unfortunately, GMR devices consume so much current that their transistors burn out if shrunk to the submicron sizes that market economics demand. But a group led by Saied Tehrani at Motorola's research center in Tempe, Ariz., believes it has found a way around this problem with a device called, for historical reasons, a pseudo-spin valve. The design roughly doubles the strength of the GMR effect, alleviating the need for such high power. Tehrani reported in November that his team has successfully built eight-by-eight-bit arrays on top of standard transistor circuitry, which allowed them to write and read each memory cell independently.

Two Kinds of Magnetic Memory



TUNNEL JUNCTION. The magnetic field of the lower layer is "pinned" (*purple arrow*). Data, stored in the upper layer (*blue arrow*), are retrieved by a current pulse (*green arrow*), part of which tunnels through the stack. Electrons tunnel more freely if the two fields are aligned. Two current pulses in a write operation can flip the field in the upper layer, changing its data.



PSEUDO-SPIN VALVE. The bottom layer holds the data—"1" if the magnetic field (*purple arrow*) points left, "0" if pointing right. The cell's state is read by two current pulses, positive and then negative. The pulses force the field in the upper layer (*blue arrow*) right and then left but are too weak to affect the bottom layer. Resistance to a sensing current (*not shown*) will vary from high to low if the cell stores a 1, from low to high if it holds a 0. In the write operation, strong current in both conductors will change both magnetic fields.

IBM researchers lead the assault on the second front, devices that exploit electron tunneling through a thin insulator, although Motorola is working on such chips as well. The faint tunneling current varies by as much as 30 percent, depending on whether the fields of two neighboring magnets are aligned or opposite. In March a team of IBM engineers led by William J. Gallagher and Stuart S. P. Parkin announced that it had constructed arrays of 14 bits from such tunnel junctions, as they are known. They have demonstrated bits that are as small as 200 nanometers wide and that switch in five nanoseconds or less, Gallagher reports.

Manufacturing masses of tunnel junctions may be tricky, however. The device is exquisitely sensitive to the depth of its thinnest layer, a plane of aluminum just 0.7 nanometer—about four atoms—thick. Any pinholes in that spread can short-out the memory cell. Moreover, both pseudo-spin valves and tunnel junctions develop flaws at temperatures above 300 degrees Celsius. Chip fabrication lines routinely run 100 degrees hotter.

Those uncertainties may leave an opening for a third approach that has less money behind it, but more history. Edwin Hall discovered 120 years ago that a current moving through a thin film is deflected to one side by a magnet. Lienau's "magram" device exploits this effect, as does a similar design of Johnson's called a Hall effect hybrid memory.

Theoretically, both designs should be easier to manufacture than spin valves or tunnel junctions. They tolerate heat well. And Johnson notes that his design requires only half as many etching steps as DRAMs. Moreover, "unlike all other memories, [magram] can be deposited on glass—perhaps even plastic—instead of single-crystal silicon," Sadwick claims as he shows, during a visit by Scientific American, a glass slide covered in gold wires leading to a one-millimeter-square array of Hall effect sensors. That versatility should allow the memory to be cheap even if it cannot shrink to the submicron cell sizes of its competitors, he argues. With single cells already working, Sadwick says, "I see no reason why we can't get eight-bit commercial samples this year."

Johnson, meanwhile, has turned over his design to Honeywell, which has built one-micron test devices on gallium arsenide. "They can write bits in eight nanoseconds," he reports. The next generation, he says, will be smaller, faster and made atop silicon, the industry standard for microchips.

—W. Wayt Gibbs in Salt Lake City

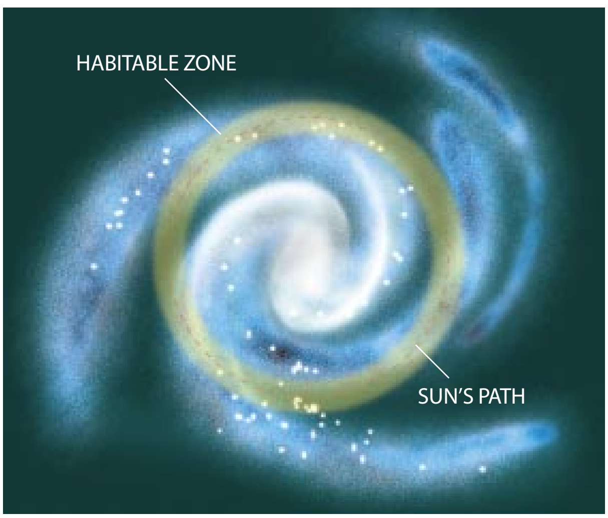
ASTRONOMY

HERE COME THE SUNS

Stars with planets seem to harbor "heavy" elements

When astronomers first discovered planets around sunlike stars three and a half years ago, many cast their discoveries in a philosophical light. Earth and the rest of the sun's family, they affirmed, were just a few faces in the planetary crowd, not special at all and certainly not the center of the universe. "What we are seeing," Robert Brown of the Space Telescope Science Institute said at the time, "is the culmination of intellectual history that began with Copernicus 500 years ago."

With some 18 worlds definitively located—roughly one per 20 sunlike stars observed—astronomers now have enough planets to test that assertion. The findings have already undermined decades of conventional wisdom about what a planetary system should look like: half the planets orbit unexpectedly close to their stars; the other half have elongated orbits unlike any in our solar system. But less widely known is another mystery—unexplained patterns in the composition of the parent stars.



***HABITABLE ZONE** might be the only region in the galaxy where planets could form and remain amenable to life.*

In 1997 Guillermo Gonzalez of the University of Washington and his colleagues discovered that the first batch of these stars contained an unusually high concentration of most elements heavier than helium, known to astronomers as "metals." Of the 12 he has data on today, 10 have an above-average metal content. Indeed, several are the most metal-rich stars in this area of the galaxy, with three times the endowment of the sun, itself enriched.

Traditionally, astrophysicists have neglected the effect a planet could have on its star. But if the metal enhancement is related to the presence of planets, they will need to revisit both planet formation and stellar evolution. In one hypothesis, unless a star and its surrounding disk of dust and gas have a critical mass of metals—roughly equal to the amount in our solar system—planets can never coalesce. Not only do these elements make up rocky planets and the rocky cores of gas giant planets, they radiate heat more efficiently and thereby provide an essential cooling mechanism for the disk.

If planets need an extra dose of metals in order to form, they would be restricted to the inner reaches of the galaxy, where enough metals have been synthesized by successive generations of stars. Gonzalez also speculates that for a planetary system to support living things, it should not have too many metals, lest the worlds be continually bombarded by debris or tossed about by mutual interactions. Therefore, the galaxy may have a narrow "habitable zone" about halfway out the galactic disk, where the frequency of supernovae and stellar close encounters is also low. Of all the stars in the solar neighborhood, the sun traces the most nearly perfect orbit through this zone.

Some astronomers, however, are doubtful. Douglas Lin of the University of California at Santa Cruz points out that the density of metals within our solar system varies a millionfold from the orbit of Mercury to that of Neptune. A slight overall metal enrichment would be lost among the internal variation that already exists.

Lin and others have focused on an alternative hypothesis—namely, that the high metal content is an effect rather than a cause of planet formation. Planets nuzzled up to their stars must have moved inward from their original positions. Might some have spiraled all the way into their stars? Although it might seem unlikely that devouring a measly planet could affect the composition of an entire star, the metals from the ex-planet would be concentrated near the surface of a sunlike star. Downing a couple of Jupiters would make a noticeable difference in the observed metal content. Comets and asteroids, too, could provide the recommended allowance—smaller morsels to be sure, but plentiful.

Imbibed bodies also bring angular momentum, which would have an especially strong effect on aged stars, causing them to spin faster and burp out gas. Mario Livio of the Space Telescope Science Institute estimates that roughly one in 20 senior stars shows signs of having digested a globe, a frequency comparable to the statistics of the planet hunters.

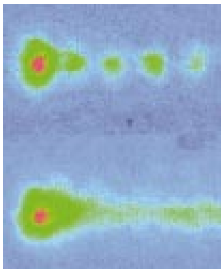
Besides the metals trend, there is a tantalizing hint of another trademark of planet-bearing stars: a dearth of lithium. In 1997, when Geoffrey W. Marcy and R. Paul Butler of San Francisco State University and William Cochran and Artie Hatzes of the University of Texas at Austin discovered a planet orbiting one of the stars in the binary system 16 Cygni, they noticed that the star had much less lithium than its planetless twin. So far a lithium trend remains unsubstantiated.

To pursue the mystery of what makes some stars fertile and leaves others barren, Cochran plans to look for planets in a sample specifically chosen to study the metals trend. Meanwhile investigators press forward on what is now their main goal: finding a full-fledged planetary system. Only such a system would quell—or vindicate—lingering doubts that these bodies really are planets, rather than very low mass brown dwarf stars (which form differently and should not be in such systems). In any event, it seems that the sun is not such a small, unregarded star at an unfashionable end of the galaxy after all. The ability to bear planets, let alone habitable ones, may not be universal. —*George Musser*

IN BRIEF

Atom Lasers and Sluggish Light

As reported in the March 12 *Science*, William D. Phillips of the National Institute of Standards and Technology and his colleagues have made a directional atom laser. They first created a Bose-Einstein condensate (BEC), a supercold collection of atoms that behave as one giant atom, and then shone two optical laser beams into it. The optical lasers, each with a slightly different frequency, imparted momentum to the atoms. The researchers "fired" the atom laser by pulsing the optical lasers, ejecting blobs of atoms or continuous streams.



NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Atoms away

In another experiment, Lene Vestergaard Hau of Harvard University and her colleagues announced in *Nature* that they used a BEC to slow light to 17 meters per second—about 38 miles an hour. The researchers shone a "coupling" laser into the opaque BEC and then fired in a second laser beam, which interacted with the coupling laser and the BEC in a process called electromagnetically induced transparency. As a result, 25 percent of the second laser's light made it through—albeit slowly. The technique should be able slow light to 37 meters per hour. *—Philip Yam*

Eyeing Protons

In a February forum at the University of Hamburg, investigators from Loma Linda University Medical Center announced promising news about proton beams to treat "wet" macular degeneration, the leading cause of legal blindness in seniors. In this condition, abnormal blood vessel growth and bleeding occurs behind the macula, the center of the retina. Sealing the leaks with lasers, the only approved therapy, unfortunately destroys the parts of the retina through which the beam passes. Protons, however, can be energized so that they pass harmlessly through a predetermined amount of tissue and stop at the target, where their energy would coagulate leaks. The method controlled the disease in 89 percent of the patients, and 65 percent reported stable or improved visual acuity. *—P.Y.*

More "In Brief" on page 24

ANTI GRAVITY

Supply and Demand

Ah, spring, and the thrill of romance is in the air. Why, the very name of this month bespeaks a time of year when potential takes center stage. May. The word is pregnant with possibility.

Also pregnant have been three chimps at the Los Angeles Zoo, which have unwittingly contributed to research illustrating what may be a vas deferens between the chimp reproductive system and our own. You see, the three male chimps that showed any interest in sex had all undergone vasectomies. A 45-year-old male named Toto, who had always seemed diffident when it came to matters of the heart and thus avoided the unkindest cut, allegedly waggled his finger at reporters and implied, "I did not have sex with those chimps."

Four adult females have been put on birth-control pills as a result of the unplanned pregnancies. Paternity tests will seek to determine if it's Toto who should tuck in the *Pan troglodytes* toddlers, or if any of the vasectomized males escaped their postoperative fate. And some veterinary student concentrating in wildlife pathology should be jumping all over a thesis ultimately to bear the title "Failure Rate of Vasectomies among Chimps."

Oddly enough, none of this business (chimps are not monkeys, so let's not go there) had anything to do with a wire story that ran just five days later under the headline "Banana War Escalates." That skirmish turned out to be nothing but a half-billion-dollar trade impasse between the U.S. and Europe, the result of tariffs hindering free-market forces.

A paper in the February 7 issue of *Proceedings of the Royal Society: Biological Sciences* also examined the effects of market forces, but not on bananas. The study looked at mate choice, a favorite subject among evolutionary biologists, in terms of the haggling associated with a free market. (And you wonder why you should have gotten a prenup.)

For zoo chimps, mate choice basically depends on cage assignment. Although that situation bears an eerie similarity to many office relationships, human mate choice tends to be more complex. The decision-making process is difficult to observe in most species, but the researchers took advantage of a valuable tool for observing courtship negotiation unique to humanity: personal ads.

Most of the researchers' conclusions were fairly straightforward. Female market value appears to be largely a function of fecundity, for which age, or more accurately youth, is an indicator. Male market value depends mostly on income and "risk of future pair-bond termination." In turn, these characteristics hugely influence the kinds of demands that men and women are willing to make of prospective partners.

Surprisingly, most men understood their place in the market. The researchers plotted the number of traits men sought in a potential mate, such as age, attractiveness and social skills, versus the males' own market values. The result is a reasonably straight line—the higher a guy's market value, the more demands he seems willing to make of his prospective mate—but only with the removal of a key demographic group: men between 45 and 49 years old. These guys had a low market value thanks to the enhanced probability of "pair-bond termination" as a result of death (their choice of "sucking in my gut" as favorite exercise regimen probably hurt, too). But they made demands more in keeping with those of men having three times the market value.

Men making the transition from being relatively young to becoming relatively old apparently sometimes do so kicking and screaming a bit. Perhaps they could learn from Toto, age 45, who never seemed to make any demands at all on his female chimp acquaintances and thereby escaped the scalpel. If this Toto suddenly found himself before any great and powerful wish-granting wizards, he could remain blissfully silent, having no need for brain, heart or any other replacement body parts. *—Steve Mirsky*

MICHAEL CRAWFORD

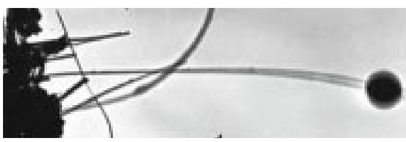
In Brief, continued from page 22

Incredible Shrinking Brain

Diabetes, high blood pressure, smoking and heavy drinking can have ominous consequences for the brain in old age, according to a report in *Stroke*. Charles DeCarli of the University of Kansas found that health risks of men in their middle years were associated with stroke and reduced brain volume when the men reached their 70s. Reduction in brain size and damage to the brain's "white matter" are natural consequences of aging, but the risk factors—especially high blood pressure—seem to have sped up the process, accounting for up to 15 percent of the detectable brain disease. —*Jessa Netting*

Nanoweight Scale

Accurately gauging the masses of viruses and other particles in the femtogram (10^{-15} gram) range may soon be possible. Walter de Heer and his colleagues at the Georgia Institute of Technology describe in the March 5 *Science* a microscopic balance made from carbon nanotubes. The



REPRINTED FROM SCIENCE

Nanotube weighs a particle

researchers can make nanotubes vibrate like a plucked guitar string by applying an oscillating voltage to them. Particles sticking to a vibrating nanotube will alter the tube's resonance, providing a means to measure the weight of the particle. With this method, the Georgia Tech workers measured a 22-femtogram graphite particle. —*P.Y.*

Olestra: All in the Mind?

The diarrhea, cramping and other symptoms attributed to olestra may have more to do with the warning labels on snack packages than on their contents, according to the February 16 *Annals of Internal Medicine*. For the six-week study, 3,181 snackers weekly selected free bags of chips labeled as olestra or regular but could only guess which they were actually eating. Those who believed they were munching olestra chips reported symptoms 50 percent more often than those who didn't, whether or not they were. The study was sponsored by Procter & Gamble, which makes olestra under the brand name Olean. —*J.N.*

More "In Brief" on page 26

AIDS EPIDEMIOLOGY

PREVENTED PREVENTION

Treating sexually transmitted diseases may not restrain the spread of HIV

Since the beginning of the AIDS epidemic, researchers have consistently noted a strong connection between HIV infection and other sexually transmitted diseases (STDs). Those infected with an STD are at least two to five times more likely to acquire HIV if exposed to the virus through sexual contact, and an individual infected with HIV and another STD is more likely to transmit the HIV virus to an uninfected person. Given this connection, the strategy has been to treat STDs to combat HIV spread. But a recent clinical trial shows that ministering to those with STDs does not decrease the incidence of HIV.

The idea of controlling the spread of AIDS by controlling STDs received strong validation from the first randomized trial to explore the connection between the two. Begun in 1991 in the rural Mwanza region of Tanzania, the community-based trial focused on delivering drug therapy and training health care personnel to treat symptomatic STDs. Results, published in August 1995, were striking: the intervention group of communities had a 38 percent lower incidence of HIV than the control group did. The program also proved to be cost-effective, comparable to other public health programs, such as childhood vaccinations.

The second trial, begun in 1994, whose results were published in *Lancet* this past February, stands in sharp contrast. Using the same community-based model, investigators looked at the Rakai district of Uganda. They offered treatment to every consenting adult in the intervention group—including those with asymptomatic infections. Despite significant reductions in curable STDs, there was no decrease in the incidence of HIV infection.

The Rakai investigators believe it is unlikely that problems in study design or follow-up account for the failure to lower HIV incidence. Enrollment of eligible adults in the study was over 80 percent, and of those participating, more than 90 percent adhered to the treatment. Researchers can only hypothesize as to the difference in study results.

One of the principal investigators of the Rakai study, Maria J. Wawer of Columbia University School of Public Health and Johns Hopkins University, notes that although HIV risk is increased by STDs at an individual level, too many other factors may have overpowered any effect of the STD treatment at the population level. "For an individual, if they or their partner has an STD, it raises the chances of seroconverting," Wawer says. "But at the population level in Rakai, a lot of the HIV occurred independently of STDs, so controlling [STDs] did not have much of an effect."

One influencing factor may be the difference in the stage of the epidemic. Among rural areas, Rakai has one of the highest documented rates of HIV in the

JOEL STETTENHEIM SABA

AIDS IN THE RAKAI DISTRICT OF UGANDA
spreads despite efforts to control other sexually transmitted diseases.

In Brief, continued from page 24

Y2Hot

Global warming has topped itself again: 1998 has set the record for the past millennium. As reported in the March 15 *Geophysical Research Letters,* Malcolm Hughes of the University of Arizona and his colleagues analyzed tree rings and ice cores to reconstruct temperature trends over the past 10 centuries. Most alarming is the past century's abrupt reversal of a 1,000-year-long cooling trend, culminating in the 1990s being the warmest decade yet. One result of the warmth: early spring activity. University of Munich researchers note in the February 25 *Nature* that spring blooms now take place six days earlier than in the 1960s and that the growing season lasts nearly 11 days longer. —*J.N.*

An Arm and a Leg

The cost of an arm and a leg may be high, but the two limbs are eerily interchangeable, as reported in the March 12 *Science.* Harvard University researchers made leg structures grow where a wing should have been. Three genes are involved in limb development, *Pitx1, Tbx4* and *Tbx5.* Moving active *Pitx1* from the leg bud to the wing bud, where the gene is normally inactive, began leg formation there. Wings did not complete their new path toward legginess, but they did become distinctly leglike: feathers were lost, muscle structure changed, and digits and claws appeared (*photograph*). —*J.N.*

REPRINTED FROM *SCIENCE*

Extra-leggy chicken

Temper, Temper

David J. Green of Pennsylvania State University and his colleagues have devised a way for tempered glass to crack without shattering. Tempering strengthens glass by compressing the molecules of the outer surface; if that surface cracks, the pent-up stress is released, exploding the rest of the glass. The researchers describe in *Science* a chemical method to make deeper layers in the glass denser by substituting sodium atoms with larger potassium atoms. Cracks could appear on the less dense outer layer but fail to reach any deeper. The method could lead to thinner glasses for scanners, photocopy machines and displays. —*P.Y.*

world and represents what is termed a mature epidemic. According to some estimates, up to one third of the women in the main trading centers are HIV-positive, and the infection rate for the general community is 16 percent. In contrast, Mwanza had a community HIV prevalence of only 4 percent and in 1992 was still experiencing a relatively early HIV epidemic. The presence of STDs may have a far greater impact on HIV transmission during the early stages of an epidemic, rather than one where the virus is already well established.

An additional factor may be Rakai's baseline rates of resistant and untreatable STDs. Of reported genital ulcers, a large percentage tested positive for herpes, which is incurable. Bacterial vaginosis, a difficult-to-treat condition that has been linked to increased risk for HIV infection, existed in 50 percent of the population at the beginning of the study. Though observed in East Africa, it was not reported in the Mwanza study.

A third factor may be the treatment approach at Rakai. Periodic mass intervention did not specifically target symptomatic STDs, as was the case in Mwanza. Wawer hypothesizes that at the population level, symptomatic STDs may have a greater effect on HIV transmission. Data from Rakai, however, suggest that a sizable portion of symptomatic cases was not associated with a treatable STD.

"The whole issue of STD control for HIV prevention is, unfortunately, a lot more complex than we hoped," Wawer says, adding that there is a great need to do more research into different populations with different STD and HIV backgrounds. There is one more community-based, randomized study currently in place in Africa, and investigators hope to present their results sometime next year. —*Roxanne Nelson*

ROXANNE NELSON, based in Seattle, described bloodless insulin monitors in the October 1998 issue.

BEHAVIOR

WINK OF AN EYE

Half-asleep ducks can control which hemisphere gets to snooze

The bird brain, though much maligned, can perform feats while sleeping of which we can only dream—namely, it can stay awake. Although it's long been known that birds can sleep with one eye open, researchers at Indiana State University have determined that ducks can carefully choreograph sleeping and waking states simultaneously in different regions of the brain.

Earlier studies had shown that birds achieve these two states of consciousness at once by splitting the tasks between the brain: one hemisphere falls asleep while the other stays awake and responsive. This half-brain, or unihemispheric, sleeping manifests itself as something like a prolonged wink; the eye connected to the wakeful half of the brain remains open, whereas that wired to the dozing half droops.

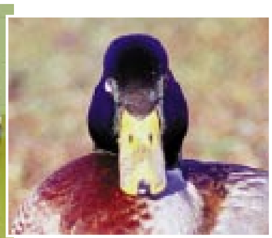
The coexistence of two states of consciousness is impressive enough, "but the kicker," Indiana State researcher Niels Rattenborg says, "is the control." Because the hemispheres of birds' brains process some information independently while awake, "it was conceivable that unihemispheric sleeping simply occurred when the hemispheres fell asleep or awakened out of phase by chance," explains Charles Amlaner, the sleep specialist of the team.

To rule out this possibility, the investigators set about finding a situation in which ducks would want control over their sleep. They knew that some aquatic mammals—the only other group besides birds that displays unihemispheric sleep—keep half of the brain awake to ensure that they keep one flipper paddling and so don't drown while sleeping at sea. Sleeping in the water is extremely specialized, however, and because almost all birds demonstrate unihemispheric sleeping, the impetus behind the evolution of this behavior had to be a more common threat—namely, predation. Much of animal behavior "is influenced by the great risk of being killed," notes team member Steven Lima.

The researchers simulated a risky sleep situation by lining up four ducks in a row. Whereas the two ducks in the central positions could presumably feel buffered by their neighbors from threats, those situated on either end were more likely to feel vulnerable to attack on their exposed sides. "Animals in general perceive more risk at the edge of a group," Rattenborg explains—a

SA

CHARLES AMLANER *Indiana State University*



JOE DICKSON

DUCKS AT THE ENDS* *sleep with one eye open* (inset; eyelid is white) *more so than the two middle ducks, which presumably feel safer.

phenomenon known as the edge effect.

The ducks on the edge spent 2.5 times longer in unihemispheric sleep than ducks in the central spots did. They also directed their open eye toward the unprotected flank during 86 percent of their unihemispheric sleeping time, whereas the central ducks indicated no preference for which eye they kept open. Some edge ducks even did this the entire time, periodically turning around to switch eyes. Half-sleeping ducks shown a video image simulating an approaching predator roused instantly, indicating that the open eye was alert. Far from being an accidental consequence of their sleepy state, the ducks' half-sleeping behavior demonstrated that they can direct the alert hemisphere and eye to stand guard.

But if unihemispheric sleeping is so valuable for detecting predators' attacks, why don't more animals do it? The answer seems to be that they lost their chance a long time ago. Christian Mathews, working in Amlaner's lab, recently found that lizards also sleep with one eye open, especially after they have seen a predator. This behavior may not technically qualify as unihemispheric sleep, because lizards' sleeping brain waves differ in general from those of birds and mammals. But the fact that lizards have a similar behavior outwardly indicates that this sleeping state may have been shared by an early common ancestor.

Early mammals probably spent much of their day sleeping safely in their burrows, Amlaner reasons. As birds refined vigilant sleeping, early mammals may have lost much of the ability, only redeveloping unihemispheric sleep under the most extreme evolutionary circumstances, such as becoming aquatic. Interestingly, Rattenborg notes, humans who have undergone a severe trauma display sleeping brain-wave patterns reminiscent of those of birds in unihemispheric sleep. Perhaps some very old part of their brain is telling them to keep an eye open for danger. *—Jessa Netting*

EXTRATERRESTRIAL INTELLIGENCE

FIELD OF DREAMS

Undeterred by failure, SETI researchers plan to build a telescope of their own

The long search for extraterrestrial intelligence has found none, but it has revealed something interesting about a certain form of terrestrial intelligence: namely, that when scientists get on to an idea they believe is truly important, something that could shake civilization to its center, failure no longer discourages—it motivates. Some 30 years of listening to deep-space radio waves is culminating with the conclusion next year of Project Phoenix, the best-funded, most ambitious search yet for signals from the 1,000 neighboring star systems most likely to harbor life. There is not a single repeatable observation of an artificial radio signal to show for all that effort. Yet the SETI community is energized, buzzing with new plans, including one to build a giant telescope array devoted to the search.

This is not the first time that the faithful have bounced back from adversity. Indeed, Project Phoenix rose from the ashes of a National Aeronautics and Space Administration program that was terminated by Congress after less than two years. Phoenix was funded by the SETI Institute in Mountain View, Calif., and backed by several computer industry tycoons, yet it had to beg time on major radio observatories. "We get 10 days a year at Arecibo in Puerto Rico; that's not much," complains William "Jack" Welch, who holds an endowed chair for SETI that the University of California at Berkeley created in June, suggesting a growing acceptance of the field among mainstream astronomers.

That and perhaps the rapidly accumulating resources of its billionaire donors have emboldened the SETI Institute to design a 10,000-square-meter radio antenna—the One Hectare Telescope, or 1HT—whose primary mission would be to search for aliens. "The idea is to build an instrument that would have as much collecting area as the new [government-owned] 100-meter dish at Green Bank, W.Va., but cost only a third of its $75-million price," Welch explains.

To save money, the 1HT would be constructed from mass-produced satellite TV dishes, 500 to 1,000 of them spread across the countryside in northern California. To amplify the signals received in a huge spectrum from 300 megahertz to perhaps 10 gigahertz, every antenna would have a custom-designed microchip, no bigger than a sugar cube and costing only a few hundred dollars, Welch says. Filtering that riot of signals to pick out a single, all-important anomalous spike will take serious computing power. Welch concedes that the processing is "an order of magnitude more challenging than what's been done before."

Although the 1HT would be used primarily for SETI surveys, Welch points out that it could also serve as a critical stepping stone for radio astronomers who hope to construct a mammoth instrument with 100 times the collecting area of the 1HT, at a cost of perhaps $600 million. The Chinese are advocating up to 30 Arecibo-like dishes erected in karst depressions in China. Australians prefer arrays of flat panels in the outback. But Welch argues that a few thousand consumer satellite dishes might perform just as well at half the price.

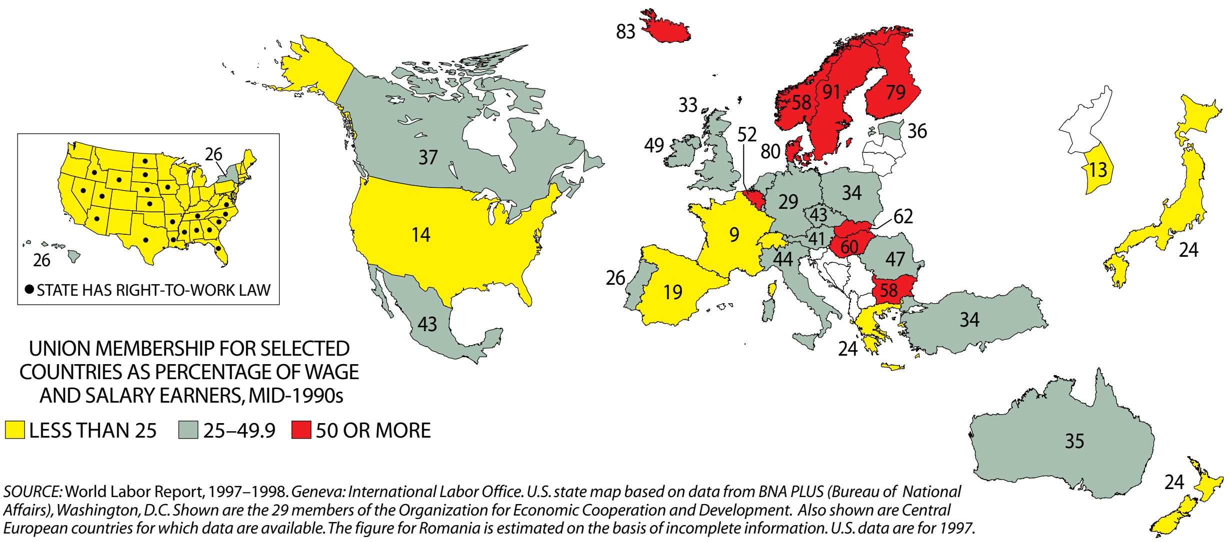
Even as the traditionalist alien hunters plan to sift once more through the radio spectrum with ever finer combs, several high-profile astronomers are beginning to look for optical beacons. In one analysis, Harvard University physicist Paul Horowitz estimated that the $1-billion Helios laser being planned at Lawrence Livermore National Laboratory could send nanosecond-long pulses that would appear 3,000 times brighter than our own sun to worlds up to 1,000 light-years away. More advanced extraterrestrials might aim such beacons at many star systems at once, including our own. Horowitz has outfitted a 1.5-meter (61-inch) telescope at Harvard to look for such pulses. Dan Werthimer of Berkeley and Geoffrey W. Marcy of San Francisco State University have also been scanning for anomalous flashes as they hunt for planets around distant stars.

There is as yet no serious money behind an optical search. But Horowitz's analysis does reflect increasing thought among SETI buffs about whether we should not only listen for aliens but also shout at them. In May a Houston outfit named Encounter 2001 plans to beam a brief radio message with mathematically encoded information about the human species and its technology from a transmitter in Ukraine to nearby stars. Of course, any recipients will already have had 50 years to ponder the meaning of television signals leaked from Earth, showing everything from Hitler at the Olympics to the O. J. Simpson trial. Is it possible that they have not yet turned the dial?

—W. Wayt Gibbs in San Francisco

BY THE NUMBERS

Labor Unions under Stress



SOURCE: World Labor Report, 1997–1998. *Geneva: International Labor Office. U.S. state map based on data from BNA PLUS (Bureau of National Affairs), Washington, D.C. Shown are the 29 members of the Organization for Economic Cooperation and Development. Also shown are Central European countries for which data are available. The figure for Romania is estimated on the basis of incomplete information. U.S. data are for 1997.*

Why have American labor unions fared so poorly, whereas those in Scandinavia have fared so well? Part of the answer lies in the political weakness of American unions. In 1947 the U.S. Congress passed the Taft-Hartley Act, which, among other things, permits states to ban union shops if they enact right-to-work laws. The Landrum-Griffin Act of 1959 banned secondary boycotts, limited the right to picket and further strengthened the power of the states to restrict organizing. Even at the peak of President Lyndon Johnson's Great Society in the mid-1960s, when liberal Democrats dominated Congress, the AFL-CIO could not get the union-shop provision of Taft-Hartley repealed. The decline of manufacturing, where unions are traditionally strong, and the shift to service industries contributed to the weakening of unions, but the most dramatic defeat came in 1981, when President Ronald Reagan broke the air-traffic controllers' strike. By 1997 unions accounted for only 14 percent of wage and salary workers, down from 33 percent in 1953.

In contrast, unions in Sweden grew from about 60 percent to more than 90 percent of wage and salary workers in the same period. According to an analysis by Bruce Western of Princeton University of 18 countries in the Organization for Economic Cooperation and Development (OECD), Swedish workers have three things American workers lack. The first is political strength: unions were involved in founding the Social Democratic Party, which has been in power for more than 57 of the past 68 years. The second is national bargaining, in which union federations negotiate nationwide agreements with employer associations. Such negotiations tend to defuse employer opposition to the legitimacy of unions and give unions more say in national economic policy. The third element is the tradition of having unions administer unemployment insurance, which creates a bond between workers and unions and makes employer recruitment of strikebreakers from the unemployed more difficult. Through these means, Swedish unions have been able to insulate themselves from market forces that increase competition among workers and thus greatly increase their power relative to employers.

The three factors—political influence, strong national bargaining and union administration of unemployment benefits—have contributed substantially to union strength in OECD member countries, especially in the four strongest—Sweden, Denmark, Finland and Norway. Of the four OECD members where labor is weakest—Japan, Switzerland, the U.S. and France—union political influence is low, national bargaining is weak or nonexistent, and governments (not unions) administer unemployment benefits.

Overall, union membership in the industrial democracies reached a high in the late 1970s but has since declined as the new industrial, low-wage countries put pressure on unions in the older industrial nations. Swedish and Finnish unions, however, substantially increased their share of wage and salary workers in recent decades, apparently because centralized bargaining and administration of unemployment benefits gave them protection against globalization of markets.

—Rodger Doyle (rdoyle2@aol.com)

RODGER DOYLE

PROFILE

A Medical Crusader for Editorial Freedom

Fired journal editor George D. Lundberg makes it a religion to serve the interests of patients

When George D. Lundberg started in 1982 as editor of the *Journal of the American Medical Association* (*JAMA*), he got hold of a list of the names of all his predecessors and the length of each of their tenures. He checked them off in turn as the duration of his own stint surpassed each one. By early this year, he had checked off all but two previous editors, who both lasted 25 years.

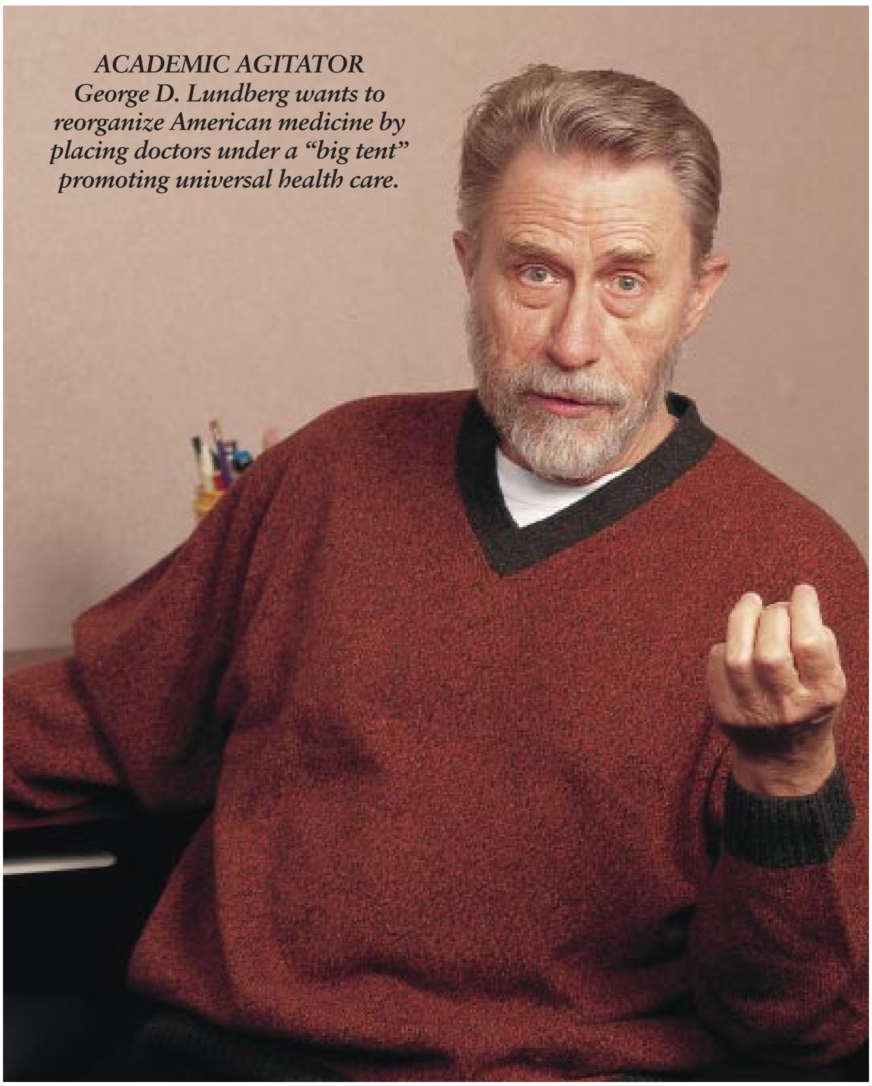
The decision of E. Ratcliffe Anderson, Jr., chief executive officer of the American Medical Association (AMA), to dismiss Lundberg on January 15 brought protests from around the world. The action was taken supposedly because Lundberg had accelerated publication of an article revealing that 59 percent of a sample of college students did not consider that oral-genital contact constituted "having sex." Anderson said that speeding up the paper amounted to "inappropriately and inexcusably interjecting *JAMA* into a major political debate"—President Bill Clinton's impeachment trial. But public opinion was never material to the charges Clinton faced, and Anderson, who has been at the association only since last summer, acknowledged that there were other reasons for the dismissal.

Neither the AMA nor Lundberg will discuss what those reasons were. Employer and former employee reached a settlement in February, whose terms have not been disclosed, and issued a joint statement that relabeled the firing as a parting of the ways. The statement bubbled with lavish praise of Lundberg's "distinguished and invaluable" career as editor and reiterated the AMA's commitment to *JAMA*'s "integrity, editorial independence and responsibility."

Critics of Anderson's action wonder, however, how believable that commitment can be. Many observers saw Lundberg's ouster as a threat to *JAMA*'s freedom to publish information that could embarrass its parent association, which spent $17 million on political lobbying in 1997. Jerome P. Kassirer, editor in chief of the *New England Journal of Medicine,* labeled the move in an editorial as an "ominous precedent," noting that his own journal routinely accelerates publication of articles that seem timely. His executive editor, Marcia Angell, describes the AMA's move to rid itself of Lundberg as "a black eye the organization really didn't need." *JAMA*'s remaining editors wrote that they strongly disagreed with Lundberg's ouster; in addition, Donald A. B. Lindberg, a member of the journal's editorial board, resigned in protest.

During his 17 years at the helm, Lundberg is universally acknowledged to have turned *JAMA* from an underappreciated AMA house organ into one of the most widely cited journals in the world, doubling its circulation and establishing numerous foreign editions. Frank Davidoff, editor of the *Annals of Internal Medicine,* published by the American College of Physicians, says Lundberg was highly creative, introducing several new features, and "took a very active role in attracting good work."

But if Lundberg ever toed the AMA party line, it was probably only by mistake. "I have not shied away from controversy in my life, and I have created rather a lot myself," he states jauntily, looking not a bit sorry. He frequently wrote editorials that did not sit comfortably with the policies or politics of his parent organization. "We received criticism from inside and outside the



ACADEMIC AGITATOR
George D. Lundberg wants to reorganize American medicine by placing doctors under a "big tent" promoting universal health care.

RALF-FINN HESTOFT *SABA*

AMA, constantly, on a host of things," he recalls, with apparent relish.

In May 1994, for instance, Lundberg ranked health care reform proposals and gave President Clinton's plan second-to-top rating. Yet none of the options had then received a blessing from the AMA, which has supported Republicans more than Democrats (but favors Clinton's "Patients' Bill of Rights"). At the time of Lundberg's departure from the journal, he was planning to "once again go big time into caring for the uninsured."

Furthermore, Lundberg was writing an editorial that was to have called for a "millennial constitutional convention" to reorganize American medicine. The structure of organized medicine has served society well for most of the 20th century, he maintains, but it does so no longer. The AMA now represents only about two fifths of U.S. physicians—down from a peak of 84 percent in 1960. Many doctors are joining more specialized societies, according to Robert J. Blendon of Harvard University, a member of *JAMA*'s editorial board, and the AMA has lost ground among academic physicians in particular. Lundberg's plan was to reestablish "a big tent" for all types of American doctors that would have as its central ethic universal access to basic medical care. He still hopes to advance the idea.

Observers sympathetic to Lundberg speculate that the real reason he was fired was his unwillingness to compromise in his conviction that the editor of a medical journal must represent the interests of patients, not the financial interests of his parent organization or its members. Unlike owners and advertisers and readers, who can express their opinions directly, patients lack an effective voice, Lundberg points out. "No matter who owns a primary source, peer-reviewed medical or scientific journal, the editor must have absolute freedom to publish what he or she chooses, or the integrity of the information within that publication is suspect and should be suspect," he asserts. "If the choice of determining whether or not to publish an article came down to: are we going to offend, perhaps seriously offend, the advertisers, the owners, the publishing staff, medical politicians, the U.S. government, the tobacco industry, the gun lobby, any of these groups," he recounts, "the questions asked were 'Is the patient going to benefit from doing this, and is it worth the risk?' " If the answers were yes, "we published!" He bangs a table for emphasis.

His zeal derives in part from his religious upbringing. The only child of Swedish immigrant parents living in Alabama, Lundberg was sent to a fundamentalist Christian college in Chicago before enrolling at the University of Alabama. At about that time, two aunts working as medical missionaries were killed in Mao Tse-tung's takeover in China, a "very emotional experience" for his family that left him with an abiding concern for international health issues. He sees editing a medical journal as a form of missionary work using information.

Lundberg wanted to be a physician from childhood and after several attempts was admitted into what was then called the Medical College of Alabama. He graduated at the top of his class in 1957, having enlisted in the army the year before. He earned board certification in pathology as well as a master's degree and by the mid-1960s was serving as chief pathologist at a general teaching hospital in El Paso, Tex. After leaving the army in 1967, he took a tenured post at the University of Southern California.

Lundberg suspects factions opposed to alternative medicine undermined him.

He was put in charge of the university medical center's large laboratory and developed a toxicology unit to do analyses on the 30 to 50 patients admitted daily with drug problems. But then Lundberg got into missionary work that earned him some criticism. He created a street-drug identification program that allowed anyone to have a drug sample analyzed; the sample's claimed and actual composition were published in the *Los Angeles Free Press* as the "Dope Scoreboard," so users could avoid the worst drugs. The program was briefly shut down by city authorities but reopened when judges, police and physicians protested.

Lundberg was recruited to *JAMA*'s editorship from the University of California at Davis, where he had been professor and chair of pathology since 1977. He had served on the journal's editorial board for eight years and was attracted by the challenge of the position even though he knew it "had a history of chewing up and spitting out many of the people who took it."

He was soon drawing attention. Over the years Lundberg has called for physician solidarity in preventing nuclear war, argued for treating violence as a public health issue and excoriated tobacco companies. Recently Lundberg made himself unpopular by calling for more autopsies. Currently fewer than 9 percent of bodies are autopsied, but studies make clear that misdiagnosis is disturbingly common. One published in *JAMA* last year showed that the causes of death identified by physicians differed from the presumably more accurate postmortem diagnoses in 44 percent of cancer cases, a finding consistent with previous assessments. But Lundberg says physicians are reluctant to press for autopsies because the results risk calling their judgment into question and possibly exposing them to legal liabilities.

The crusading editor also raised many eyebrows last November by publishing an issue of *JAMA* devoted to clinical studies of various "alternative" medical therapies. He insists that he elevated slightly the required scientific standards for papers in the issue, which found some of the therapies to be of possible value and others not. He says he thinks it likely that factions at the AMA opposed to more use of alternative medicine started working to undermine him because of the issue.

Lundberg intends to continue being a professional academic agitator. He has appointments at the Harvard School of Public Health and at Northwestern University but has made his new main home in cyberspace. Of the half a dozen or so jobs he was offered after leaving the journal, the one he took was as editor in chief of Medscape, a World Wide Web site that publishes medical information aimed primarily at physicians, some of it peer-reviewed (www.medscape.com). Lundberg, who was using computers in medicine as far back as 1963, explains that he likes the organization's reach and approves of its ethics. He intends to utilize roving teams of physician-reporters to conduct on-the-spot peer reviews of medical findings at conferences and write them up for the site.

And in time, he says, the site will aspire to publish original research. Medscape seems likely to benefit from the credibility that Lundberg should give it, and he will presumably be free to sound off on all manner of medical issues. He insists that he has been promised complete editorial independence.

—Tim Beardsley in Cambridge, Mass.

BIOENGINEERING

LEAVING A BAD TASTE

The furor in Britain raises health safety concerns about genetically modified foods

British scientist Arpad Pusztai, who was fired last year from the Rowett Research Institute in Aberdeen, Scotland, and banned from speaking to the press for a while, told a parliamentary select committee on March 8 in London he had no regrets about his comments that led to his dismissal. Humans, he had said, were being used as guinea pigs in a vast experiment with genetically modified (GM) foods.

Pusztai's testimony to the committee followed headlines in British newspapers screaming that a scientist had been gagged and his findings suppressed to keep secret that genetically modified foods threaten health. Conspiracy theories abounded—namely, that President Bill Clinton had personally pressured Prime Minister Tony Blair to give biotechnology companies, including Monsanto, a freer rein in planting GM crops. An admission on March 1 from John Prescott, secretary of state for Environment, Transport and the Regions—that the British government has indeed received representations from its U.S. counterpart about GM crops—did not help.

The furor started last August, when Pusztai released to the media results that he said indicated that rats fed potatoes genetically engineered to contain a lectin from the snowdrop plant—a naturally occurring insecticide—had suffered damaged immune systems and stunted growth of vital organs. The results stood in stark contrast to safety claims made by biotech companies and to the received wisdom of the harmlessness of transgenic crops.

Four days after his announcement Pusztai, a renowned scientist who pioneered studies on the effects of lectin, was suspended. The Rowett institute stated he had muddled his findings. Quietly, over the ensuing months, Rowett invited a group of independent scientists to audit Pusztai's work—and the audit found that his conclusions were indeed erroneous, although it absolved him of the more serious charge of scientific fraud.

GREENPEACE/COBBING

A LOAD OF CROP?
Greenpeace protests against genetically modified foods in front of 10 Downing Street in London.

Other scientists, though, came to Pusztai's defense. Two researchers forwarded his data to 21 scientists, who later issued a memorandum in February that said, "We are of the opinion ... that the consumption of the GM potatoes by rats led to significant differences in organ weights and depression of lymphocyte responsiveness compared to controls."

A study that criticized the Rowett audit and confirmed Pusztai's results also got some backing. Done by pathologist Stanley Ewen of Aberdeen University, a friend of Pusztai's, the work was examined by Thorkild Bøg-Hansen, a lectin expert from the University of Copenhagen (and one of the researchers who forwarded Pusztai's results to others). He concluded that "Dr. Ewen's results clearly showed the errors in the audit report that followed Dr. Pusztai's suspension from the Rowett Research Institute. The experiments clearly showed that ... the GM potatoes caused a major intraepithelial lymphocyte infiltration similar to inflammatory responses."

Vyvyan Howard, a toxicopathologist at the University of Liverpool and Pusztai supporter, says that the results showed the main risk of GM food to be "long-term, low-dose toxicity from subtle changes to the nature of the food chain." He describes Pusztai's findings as unexpected and not totally attributable to the lectin. In other words, the genetic modification process itself was causing unpredictable outcomes. Speculations include virus promoters (mechanisms used to switch on the inserted genes) and possible unintended switching off of beneficial genes. "It is precisely this type of finding which means that animal testing for developmental toxicological effects is essential," says Howard, who also argues that the "mixture problem" must be addressed as well. "None of us eat only a single food. The effects of mixtures to my knowledge have not been addressed," he notes, concluding that "human volunteer testing would probably be advisable."

Tom Sanders of King's College London, a nutrition expert and a member of the government's Advisory Committee on Novel Foods and Processes, is not convinced by Pusztai or his supporters. After reviewing Pusztai's experiments, he maintains that all they definitively proved was that eating raw potatoes, which are indigestible, is harmful to mammals—"something that has been known for many years," he asserts.

Sanders also says that carrying out full pharmaceutical-style testing on GM foods would be impossible, because low-level poisons ostensibly from GM products would not appear in ordinary toxicological testing. He also points out that testing for human allergenicity with animals is not possible. He suggests instead that known allergens be banned for use in GM food, along with markers used to tell which foods have been modified.

Jim Dunwell of the plant sciences department at the University of Reading has another point against Pusztai: all potatoes are not alike, and toxin levels can vary widely between different tubers before any modification is carried out. “Many assertions that are made against GM crops are not backed up by sound science,” he contends.

Both Sanders and Dunwell note the potential benefits from genetic modification—food engineered to prevent tooth decay or to deliver vaccines. Genetic engineering could cut the need for pesticides. But both also admit its risks. Sanders says that “each crop needs examination on a case-by-case basis. It is dangerous to extrapolate from one to another.” They also admit that genetic engineering could be a threat to the environment, especially if tests are not conducted locally. “The English countryside is not the American prairie,” Sanders comments.

In the next few months, the Royal Society—an independent science academy established in 1660—will complete its own review of Pusztai’s findings and of its own stance on the toxicity and allergenicity of GM foods. Only then might residents of Britain—and the rest of the world—move a step closer toward understanding the health threats, if any. But anyone after a definitive answer will be disappointed—science doesn’t deal in absolutes, and the debate will surely rage on. *—Peta Firth*

PETA FIRTH, based in London, described food scares in Britain in the January issue.

PHYSICS

QUANTUM SCULPTING

Feedback enables researchers to control an atom’s wave function

The development of quantum mechanics, the underlying laws that govern matter and energy on the scale of atoms and electrons, has not only revolutionized our understanding of the universe but also has given us such technologies as the transistor, the laser and magnetic resonance imaging. Now Philip H. Bucksbaum and his coworkers at the University of Michigan have combined several recently developed techniques with a feedback system to control the very essence of quantum particles: their wave functions. The Bucksbaum experiment “is true quantum engineering,” says physicist Michael G. Raymer of the University of Oregon. “It should open up many new possibilities, most of which we cannot even imagine now.”

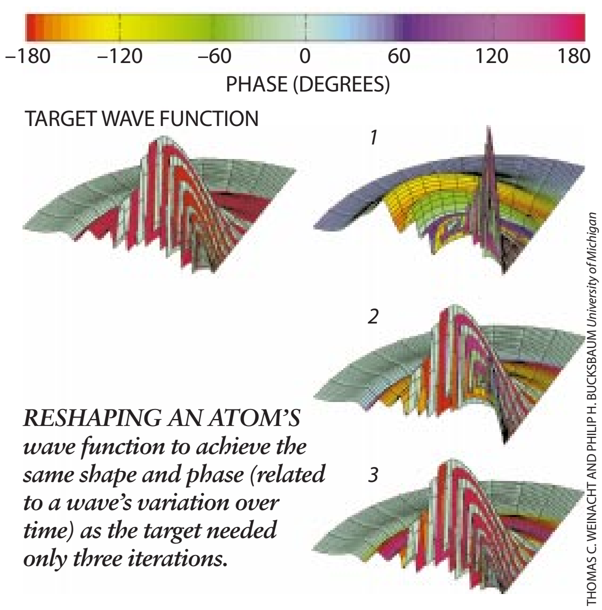
A wave function defines the physical state of a quantum object. Wave functions are slippery characters, tied to probabilities, not certainties. They obey the famous Heisenberg uncertainty principle: if one characteristic is well defined, a related feature must be highly uncertain. For instance, an electron with a very precise position must have a wide range of possible velocities. Nevertheless, during the past decade a number of research groups have assembled techniques for manipulating and analyzing complete wave functions in detail.

Bucksbaum and his graduate students Thomas C. Weinacht and Jaewook Ahn apply their technique to a type of quantum state known as a Rydberg state, which occurs when an electron in an atom is excited to such a high energy level that it barely remains bound to the atom. “Rydberg states are a great laboratory to test new ideas,” Bucksbaum explains. An electron with such high energy can occupy a very large number of quantum states. Combining those states in different proportions (that is, placing them in superposition) sculpts the shape of the electron’s wave function. In one combination, for example, the electron is smeared out in a ring around the atom; in another, it is localized and orbits the atom much like a planet orbiting the sun.

The basic tool for such wave function sculpting is a strong, ultrashort laser pulse, which excites the electron from a lower energy level. Through a design developed by Warren S. Warren of Princeton University, the researchers control the shape of the laser pulse using a so-called acousto-optic modulator—a crystal whose optical properties are governed by precisely shaped sound waves. How the laser’s intensity and phase vary over the 150-femtosecond pulse determines how the available excited states combine to produce the electron’s sculpted wave function.

But what shape of laser pulse is needed to generate a specific sculpted electron wave function? In principle, this shape can be predicted by computations, but in practice one must contend with nonideal equipment and incomplete understanding of the physical system being controlled.

Bucksbaum’s new trick, described in the January 21 issue of *Nature,* is to use feedback to modify the shaping pulse. His group works with a gas of cesium atoms in batches of about a million atoms. An approximate pulse excites the atoms, and the researchers map the shape of the resulting wave function with quantum holography, a technique they demonstrated a year ago. In optical holography, the three-dimensional shape of an object is reconstructed from its hologram, a special two-dimensional interference pattern. In quantum holography, measurements produce data loosely analogous to a hologram from which the complete wave function of the object can be reconstructed. In accordance with the uncertainty principle, however, each measurement disturbs the quantum “object,” so the “hologram” must be built up one pixel at a time over many experimental runs, with thousands of identically prepared atoms measured on each run.



RESHAPING AN ATOM’S wave function to achieve the same shape and phase (related to a wave’s variation over time) as the target needed only three iterations.

THOMAS C. WEINACHT AND PHILIP H. BUCKSBAUM *University of Michigan*

Once the physicists have mapped the resulting wave function, they look at the difference between that one and the desired one. This information is then used to adjust the detailed shape of the laser pulse used on subsequent batches of atoms. Bucksbaum found that after only two or three iterations this feedback zeroed in on the desired wave function.

Quantum control has applications in the burgeoning field of quantum computing, in which the encoding of data onto individual quantum states may allow the development of computers that function on quantum principles. Another application is control of chemical reactions. Shaped optical pulses that induce just the right excitations at specific bonds in a molecule can enhance or suppress alternate reaction pathways. Some groups have independently used feedback for this type of control, but the feedback has not been based on detailed mapping of a wave function.

Quantum physicist Carlos R. Stroud of the University of Rochester cautions that further research is needed to see if Bucksbaum's method is applicable to a wider range of quantum systems. Still, he says, "they have expanded the quantum mechanics toolbox." *—Graham P. Collins*

GRAHAM P. COLLINS, based in College Park, Md., has written articles for New Zealand Science Monthly *and* Physics Today.

SEX RESEARCH

ADAM'S RIB?

Broadening Viagra's reach may elucidate the physiology of female sexuality

No sooner had the U.S. Food and Drug Administration approved Viagra for sale last year for male erectile dysfunction than women began asking themselves and their doctors, "Will it work for me, too?"

Women are already experimenting with Viagra on their own, and reports of the drug's success are surfacing in women's magazines and on the Internet. But the question of whether the drug really alleviates female sexual dysfunction will not be answered definitively until Viagra's developer, Pfizer in New York City, completes its clinical tests of the drug in women. One thing is clear, however: Viagra has prompted women as well as men to think and talk about sexual dysfunction. Perhaps most important, Pfizer's efforts to prove that the drug works in women are beginning to add money and mainstream respectability to the field of female sexuality—an area of investigation that historically has suffered from a lack of funding as well as from thinly veiled snickers. (Men's sexuality is only marginally better understood.)

The amount of research funds currently available for studying female sexuality is difficult to assess. Although the National Institute of Child Health and Human Development estimates that it will spend roughly $163 million during the current fiscal year on contraception and reproductive research, most of it is related to contraceptive development and infertility. The majority of funding for research on the female sexual response in the past has come from a patchwork of private foundations and philanthropies. Pfizer commits roughly $2 billion a year to R&D, but spokeswoman Marianne Caprino declines to disclose how much of that goes to Viagra studies.

SAM OGDEN

NOT JUST FOR MEN?
Clinical trials of Viagra in women have begun.

Viagra works by concentrating blood flow in the genital region. One of the chief hurdles Pfizer will face in evaluating the drug for use in women is devising an objective method for measuring a woman's sexual response. To analyze erectile dysfunction in men, investigators use an apparatus called a plethysmograph to measure the firmness of a man's erection. But female sexual arousal is more complex: it involves the erection of the clitoris, which contains spaces that fill with blood just like the penis does; engorgement of the labia and vaginal walls; and vaginal lubrication. To measure female arousal, scientists use a tampon-size device called a vaginal photoplethysmograph, which uses light to assess the extent of vaginal engorgement. The technology is similar to that of blood pressure monitors that fit on the finger.

Comparatively little is known about the physiology of the female genitals. Irwin Goldstein and Jennifer R. Berman of Boston University Medical Center are now planning to map out the blood vessels and nerves that supply the vagina and clitoris. There are early indications that women are wired a bit differently from men: Cindy M. Meston of the University of Texas at Austin has found that the sympathetic nervous system, which is primarily concerned with processes involving the expenditure of energy, may be more important for female than male sexual arousal.

Meston says Pfizer's work to have Viagra approved for women has "brought a lot of attention" to the field of female sexuality research. "Viagra's been wonderful," she says. "I've gotten more research money in the last couple of months than in the last seven years combined."

The need for a treatment for female sexual dysfunction is clear. In February, Raymond C. Rosen of the University of Medicine and Dentistry of New Jersey–Robert Wood Johnson Medical School in Piscataway and his colleagues analyzed data from the National Health and Social Life Study, which surveyed 1,749 women and 1,410 men in 1992 in the first large study of sexual behavior in the U.S. since the Kinsey reports of the early 1950s. They wrote in the *Journal of the American Medical Association* that a surprising 43 percent of women and 31 percent of men say they experience some degree of sexual dysfunction, including lack of desire or pleasure in sex and an inability to climax.

Scientists expect that Viagra will only ameliorate some of these symptoms because the human sexual response depends heavily on psychological factors that the drug will not affect. Indeed, the first paper on Viagra's effectiveness in women is negative. In March, Steven Kaplan of Columbia Presbyterian Center at New York Presbyterian Hospital reported in the journal *Urology* that Viagra did not significantly improve intercourse satisfaction or sexual desire in a small sample of 33 postmenopausal women.

Pfizer is currently testing Viagra in several hundred women in Europe. Caprino says the company expects to present the results of this trial within the next several months. After that, Pfizer plans to begin large-scale clinical trials that will include women in the U.S. —*Carol Ezzell*

ACOUSTICS

MICROMICROPHONES

New sensors detect sound using light and heat

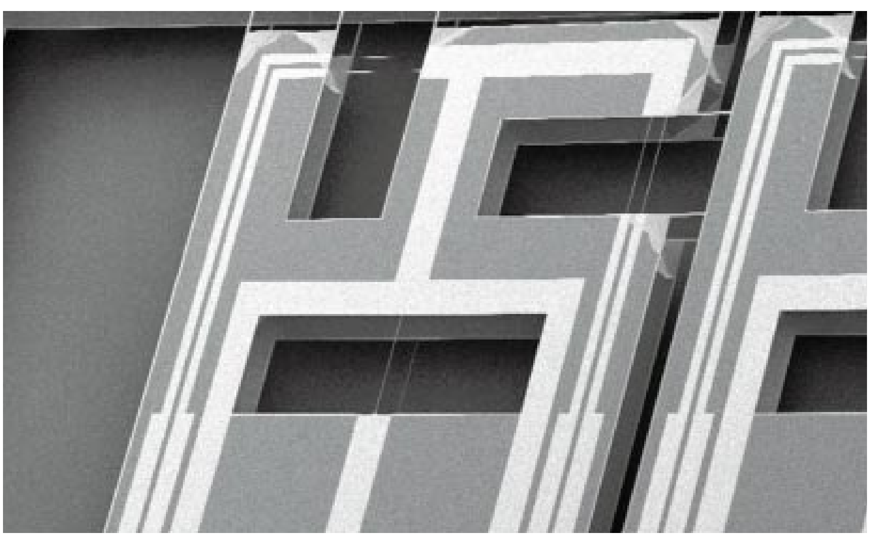
The "micro" in microphone refers to the tiny sound the instrument must pick up, not to the devices themselves, which have hardly shrunk since Alexander Graham Bell's first telephone receiver in 1876. Despite years of attempts, engineers have had little success adapting the methods of the microprocessor industry to make microphones that are as cheap and diminutive as computer chips.

That is now changing. This past March, designs for several truly microscopic acoustic sensors were unveiled at a conference in Berlin. These micromicrophones may soon find use in nearly invisible hearing aids, experimental aircraft wings, and ultrasonic cameras that let divers see through dark and murky water.

Some of the devices work just as an ordinary microphone does, only on a smaller scale. Engineers at Microtronic, a Danish firm, and Robert Bosch GmbH in Stuttgart, Germany, have created whole silicon wafers full of condenser microphones, in which the vibration of a charged membrane just 400 nanometers thick converts sound into an electrical signal. Although the device is only two millimeters square, it performs as well as conventional microphones 10 times its size.

Others presented more radical designs. Jörg Sennheiser, chairman of one of Europe's biggest microphone companies, demonstrated a "microflown" that uses no moving parts. Instead of sensing changes in pressure, the microflown detects the minuscule wind that accompanies each passing wave front.

Two narrow bridges of platinum and



COURTESY OF HANS-ELIAS DE BREE

***MICROSCOPIC MICROPHONE PINPOINTS SOUND** in three dimensions. Thin, two-lane bridges of metal—one pair for each dimension—are heated. Passing sound waves cool one span more, creating an electrical signal.*

silicon nitride, each lane only 10 microns wide, cross channels etched into a silicon wafer. Electrical current passed through the spans heats them to 300 degrees Celsius or more. As sound waves push air particles across the parallel lanes, the breeze transfers heat from the first bridge to the second. The effect is small, but it changes the resistance of the wires enough that the electrical signal rises well above the noise level.

"The device is only sensitive up to about five kilohertz, but this is high enough for receiving speech clearly," says Hans-Elias de Bree, who invented the microflown as a graduate student and has since founded a company, Microflown Technologies, to develop the sensor for market. "The performance is now close to the condenser mikes used in telephone receivers," he says, "but [the microflown] is much more directional, so it eliminates background noise." Other applications may take advantage of the sensor's ability to work where heat, dirt or vibration would damage conventional microphones.

The need to operate in extreme environments spurred other researchers to invent micromachines that translate sound reflections into light patterns. In a prototype built by Young C. Cho and his colleagues at the National Aeronautics and Space Administration Ames Research Center, red laser light passes through an optical fiber, bounces off a gold-coated silicon nitride membrane and heads back into the fiber. As the membrane vibrates—by distances less than the width of an atom—it creates variations in the intensity of the light that are easily translated into electrical signals. Cho reports that the new device is 1,000 times more sensitive than any previous fiber-optic pressure sensor and bests even commercial reference microphones. Its small size also makes it much easier to mount on airplane and spacecraft surfaces for measuring air turbulence in wind-tunnel tests.

Engineers at Boston University are developing a similar design in the hope of etching an array of 10,000 optical micromicrophones on a single silicon wafer. The U.S. Navy wants such a chip so that it can make acoustic cameras that SEALs can use to spot underwater mines at night and in turbid water. Robin Cleveland remarks that he already has single sensors working and predicts that his team will have an array ready within two years.

—*W. Wayt Gibbs in San Francisco*

CYBER VIEW

Putting the Squeeze on Music

Sex, drugs and rock 'n' roll—and rock 'n' roll is at number two, currently, as represented by the second most popular search word on the Internet these days: MP3. This extension identifies files conforming to the MPEG-3 standard of near-compact-disc-quality music and video. Tens of thousands of MP3 files are all over the Net—everything from ever popular bootleg clips from *South Park* and tunes from Hootie and the Blowfish to endangered folk songs from ex-Byrds member Roger McGuinn's Folk Den Web site.

There's another eerie similarity between sex and MP3, in that searching for MP3 files is a lot like searching for pornography, at least the way it used to be: sites are so crowded you can't get on, copyright violations abound and many links don't work, because people have been forced to take their sites down. But there the commonality ends. Whereas the Net really can't do much to change sex, it is changing everything in the music world—namely, shifting the balance of power from piracy-fearing record-label executives to small-time musicians and their fans.

Four elements are coming together to make the difference. First is MP3 itself, which squeezes about a minute of music into about one megabyte (MP4, in progress, will compress data even further). Second is Net culture, which combines the natural human instinct to share discoveries (and there is a lot of great, weird music out there) with an antiauthority instinct that hasn't forgiven the recording industry for doubling the cost of commercial music in the switch from LP vinyl to CDs. Third is hardware: despite an attempt by the Recording Industry Association of America (RIAA) to block its sale, Diamond Multimedia's palm-size Rio machine and its competitors let you carry 30 to 60 minutes of downloaded music in your pocket. Fourth, and least tangible, is frustration with mass music. Huge numbers of talented musicians can't get a recording contract but can, given the chance, attract a devoted coterie of fans. For them, MP3 provides a way to make their music available directly to fans who may be all over the world.

MP3 and its successors could completely rewrite the way the music industry does business. At least one entrepreneur is betting millions on digital distribution as the future of the music biz, by developing the Web site MP3.com. What the recording companies see at the moment, though, is a license to pirate music, and they don't like it. After the RIAA's attempt to squelch the Diamond Rio failed, it founded the Secure Digital Music Initiative (SDMI) to develop an industry standard to secure digitized music—effectively tagging it so that after downloading, it is used in predetermined ways.

The goals of this and other similar initiatives sound reasonable enough: to protect artists' ability to exploit their work while enabling consumers "to

DAVID SUTER

conveniently access music in all forms," as the SDMI puts it. What isn't clear is the form the SDMI standard might take or the consequences for small-time artists outside the large companies, which make up the SDMI forum's membership. What is clear is that SDMI isn't likely to succeed in controlling the distribution of music. Any system that can be invented to tag music can be hacked to remove the tags.

Indeed, that's already happened. On January 26, *Wired News*'s Joe Nickell reported that the Diamond Rio had been hacked so that it could not just download music but also upload it to a computer with software readily available on the Net. (This could be trouble: the Rio won in court when its manufacturer argued successfully that it didn't contravene the 1992 Audio Home Recording Act, because it was a playback device, not a recording device that could redistribute the music.)

Another Net trend will also be insidious in turning the music industry upside down: home radio stations, which are likely to become more common as people get flat-rate, permanent, high-bandwidth Internet connections over, say, ISDN or asynchronous digital subscriber lines. The ImagineRadio Web site, for example, lets you custom-design your radio station. You pick the rough type of music and fine-tune the selection that the site plays by removing songs and artists you don't like. It's not clear how such a site fits into the current scheme, whereby music industry publishing organizations ASCAP and BMI distribute fees to artists and songwriters based on calculations made from a selection of station playlists.

The fact is that the new digital world could be very good for artists and consumers, eliminating a number of middlemen and marketers and allowing more direct contact. It may even restore to artists some of the power they've typically had to sign away to get distribution; the music industry has a notorious reputation of ripping off artists. Recording companies, with their superior ability to afford high-quality recording and production and to finance tours, also have a chance to find ways of exploiting the new medium. They could sell handsomely boxed, personalized love songs for Valentine's Day, offer tune snippets for use as computer sounds or design customized greatest-hits compilations.

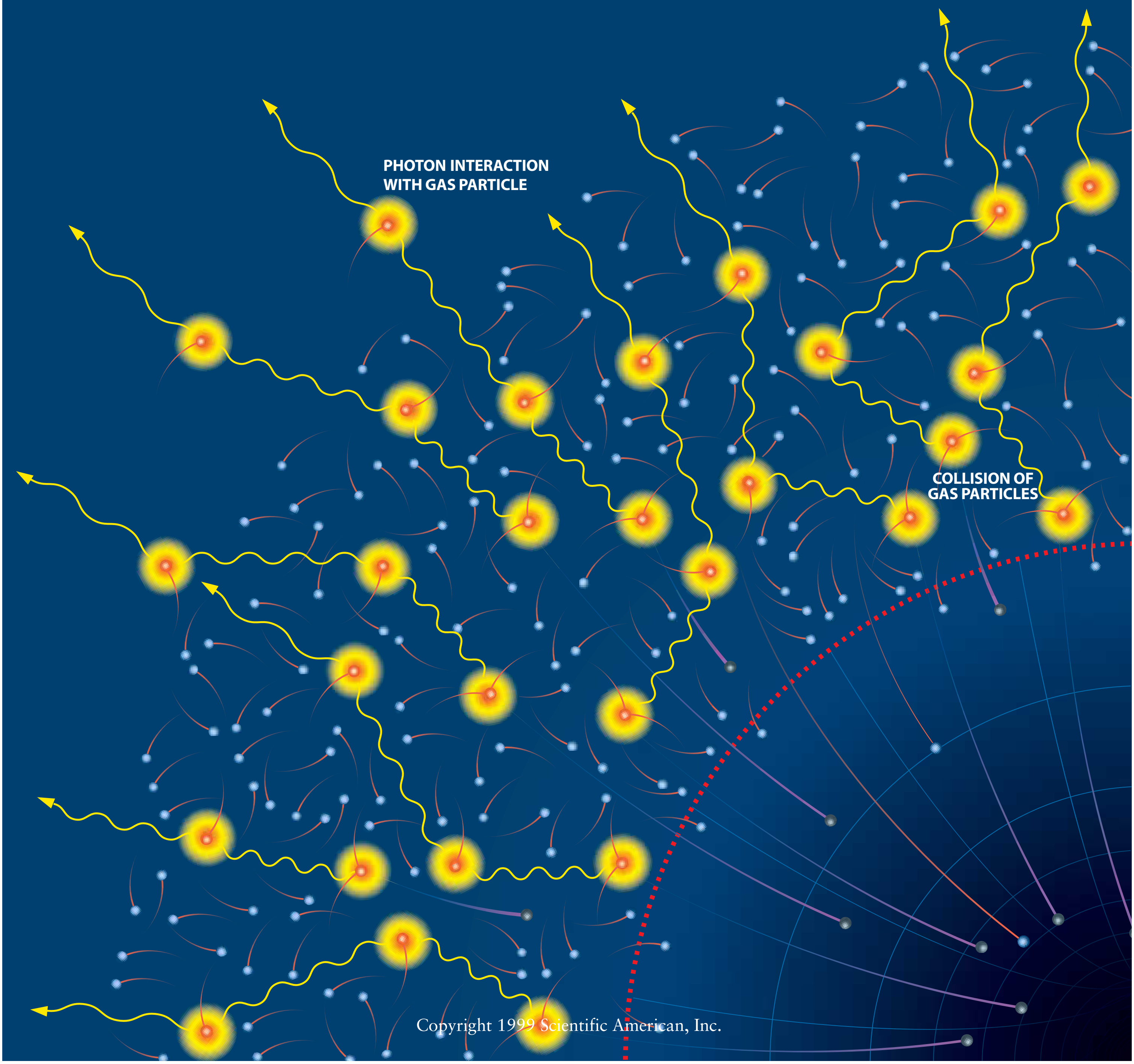
Building the infrastructure to do those kinds of things and building goodwill in the Net community would be a better way to spend millions than trying to secure a technology that has already escaped. The hard part will be not so much making money, because distribution in general will be so much cheaper. Nor will it be, as some suggest, finding the money to invest in developing artists, because most musicians make their first waves through live performances rather than through recordings. The hard part will be preserving the notion of an artist's vision: an album is, or should be, more than a collection of singles. —*Wendy M. Grossman*

WENDY M. GROSSMAN is a former internationally obscure folksinger.

Unmasking Black Holes

by Jean-Pierre Lasota

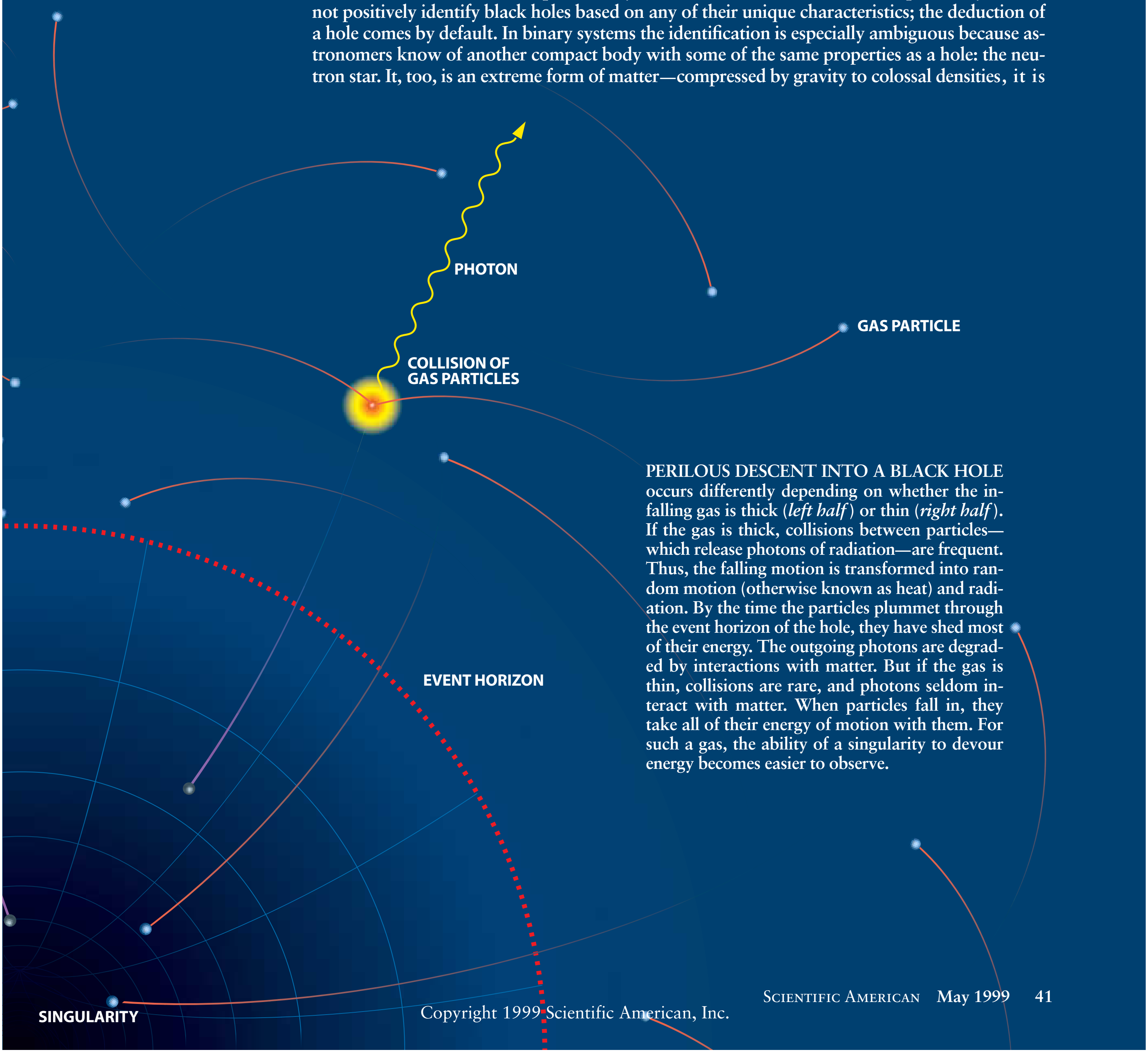
Until recently, the evidence for black holes was circumstantial. Now astronomers may have direct proof: energy is vanishing from volumes of space without a trace



Throughout the universe, astronomers sense the presence of black holes. These fascinating bodies sit at the centers of many galaxies (including our own Milky Way), pair up with normal stars in binary systems and might even ramble alone through the interstellar medium. The most compact objects in the universe, they contain the most extreme form of matter known to science—the concentration of an arbitrarily large mass in something approaching a mathematical point. And they pose correspondingly intense challenges for observers. After all, they really are black. They emit no electromagnetic radiation, at least not at levels astronomers could ever hope to detect.

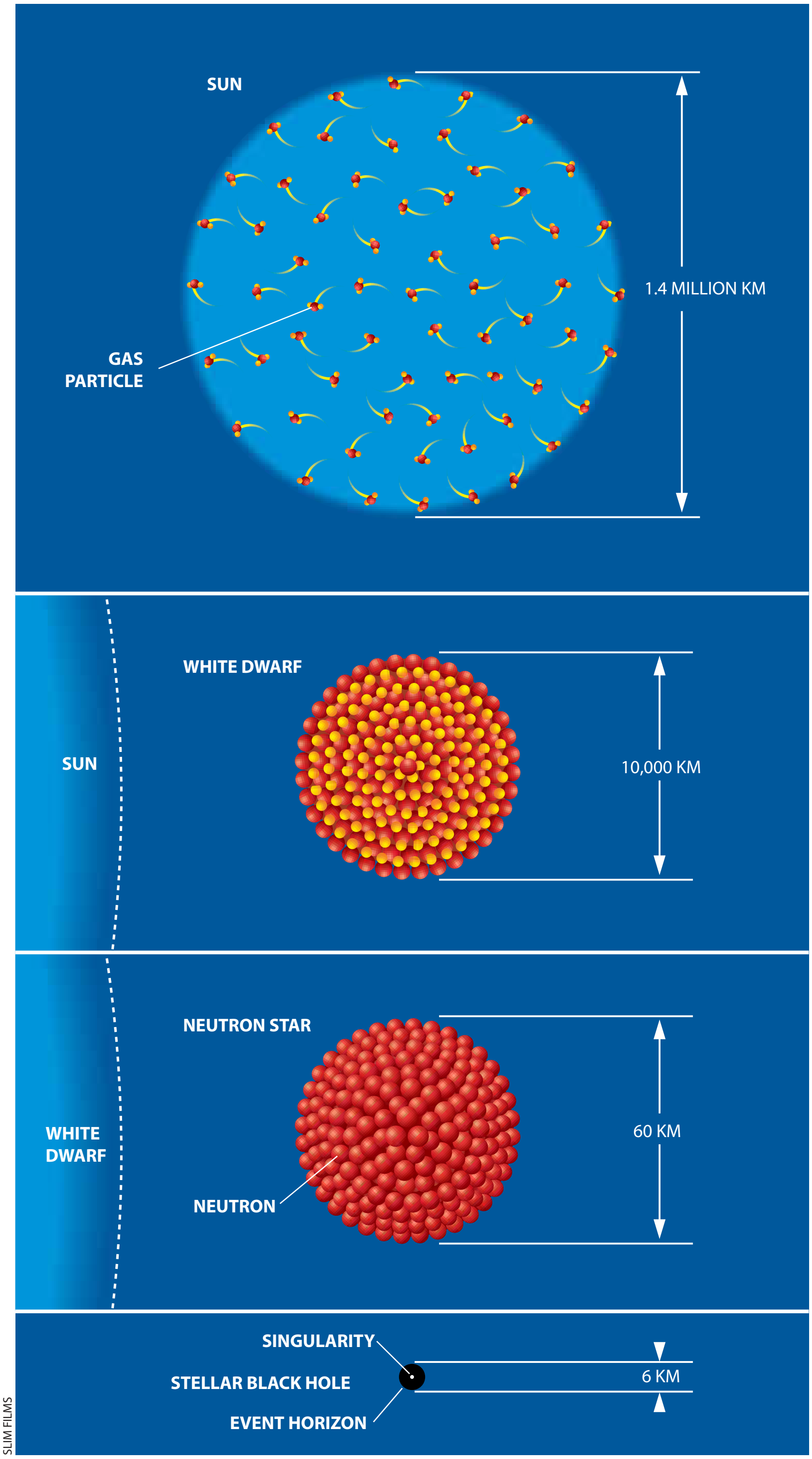
To deduce their existence, researchers have had to rely on two indirect lines of argument. Near galactic centers, stars are moving so rapidly that they would fly off unless the gravity of a huge mass—up to the equivalent of a billion suns—held them in. Whatever has this mass must be extremely dense, and theorists know of no alternative to a black hole. Second, many galactic centers and binary-star systems spew radiation and matter at gargantuan rates. They must contain an extraordinarily efficient mechanism for generating energy. In theory, the most efficient engine possible is a black hole.

All this evidence, however, proves only the existence of some kind of compact body. It does not positively identify black holes based on any of their unique characteristics; the deduction of a hole comes by default. In binary systems the identification is especially ambiguous because astronomers know of another compact body with some of the same properties as a hole: the neutron star. It, too, is an extreme form of matter—compressed by gravity to colossal densities, it is



PERILOUS DESCENT INTO A BLACK HOLE occurs differently depending on whether the infalling gas is thick (*left half*) or thin (*right half*). If the gas is thick, collisions between particles—which release photons of radiation—are frequent. Thus, the falling motion is transformed into random motion (otherwise known as heat) and radiation. By the time the particles plummet through the event horizon of the hole, they have shed most of their energy. The outgoing photons are degraded by interactions with matter. But if the gas is thin, collisions are rare, and photons seldom interact with matter. When particles fall in, they take all of their energy of motion with them. For such a gas, the ability of a singularity to devour energy becomes easier to observe.

SLIM FILMS



LIVE AND DEAD STARS are battlegrounds between gravity and some kind of outward pressure. The balance of power determines the size of the star. (The three objects shown below the sun have the same mass as the sun.) In an ordinary, living star such as the sun, the pressure is gaseous, driven ultimately by nuclear reactions at the core. In a white dwarf—the dense, glowing corpse of a sunlike star—the pressure is quantum "degeneracy," created by the close packing of electrons. In a neutron star, left over from the explosive cremation of a massive star, the atoms are crushed and their nuclei are stacked together. In a black hole, there is no outward pressure; gravity is unchecked, and the star collapses nearly to a mathematical point inside a surface of no return known as the event horizon.

in essence an atomic nucleus the size of a city—in which many massive stars end their lives. A neutron star with 1 solar mass has the same radius (about 30 kilometers) as the "event horizon" that demarcates a black hole with 10 solar masses. Observable attributes, such as the temperature of the infalling matter, cannot distinguish between the two. A central problem in the study of black holes has been to discover how to tell them from neutron stars.

Over the past few years, astronomers may have found a way. It is based on the salient difference between neutron stars and black holes: the former have hard surfaces on which matter can accumulate, whereas matter falling into the latter is swallowed and disappears forever. This distinction subtly alters the radiation emitted from the vicinity of each type of body, allowing astronomers to demonstrate that the strangest objects in the cosmos are a reality.

Through Thick and Thin

The intense gravity of black holes is what makes them such efficient engines. The event horizon is a surface from which nothing can escape even if it travels at the speed of light. Objects are pulled toward the horizon at a correspondingly high speed, and en route they may collide with other objects and shatter. The effect is to heat the material near the hole. Because the objects are moving at close to the speed of light, the kinetic energy available for transformation into heat is comparable to the energy inherent in their mass at rest ($E = mc^2$). For an object to return to its starting point far away from the hole, it would need to give up a significant fraction of its mass and convert it to pure energy. In this sense, black holes transform rest mass into thermal energy.

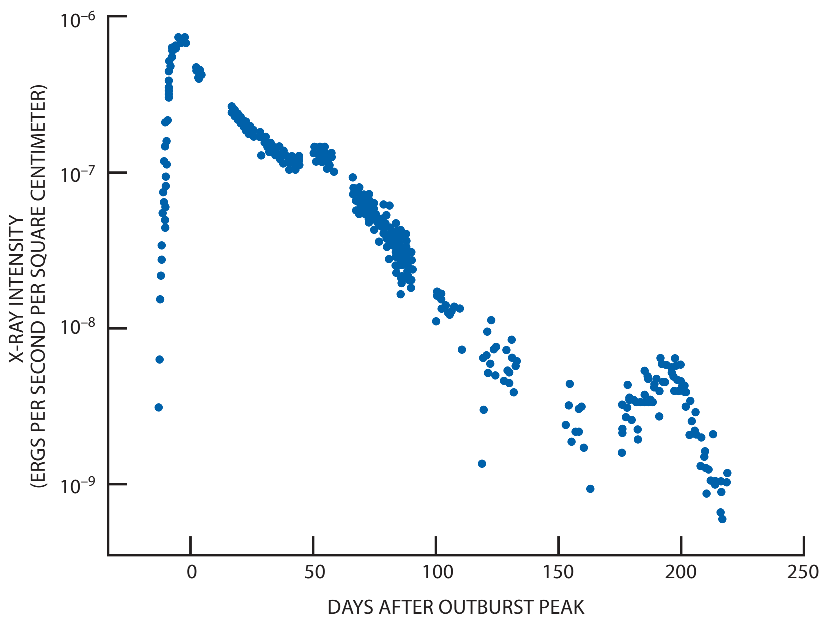
The efficiency of this conversion depends on how fast the black hole is rotating. Angular momentum is one of the few properties that matter does not lose when it becomes part of a hole; although the rotation cannot be seen directly, it twists space-time near the horizon. A black hole cannot spin at an arbitrarily fast rate, however. Above a certain maximum rate, the surface of the black hole would cease to exist. A hole spinning at close to the maximum possible rate could convert 42 percent of infalling mass into energy, whereas a static hole could manage only 6 percent. In comparison, the efficiency of thermonuclear fusion in ordinary stars is a mere 0.7 percent. For the fission of uranium, the value is only 0.1 percent.

If particles around the hole can share their energy—for example, by collisions—the infalling matter can be unimaginably hot. The typical temperature of a proton just outside the horizon corresponds to the conversion of much of its mass into pure energy, or about 10^{13} degrees. At such a temperature, the material should glimmer in gamma rays. But although protons (and ions in general) are easy to heat up, they are not very good at radiating energy. They would rather transfer their energy by collisions to better emitters, particularly electrons, which give off photons at lower energies, such as x-rays. Astronomers should therefore see an intense outpouring of x-rays from a region thick with electrons.

In fact, that is exactly what they observe in certain x-ray binary systems. The first such system was discovered in 1962, and astronomers have identified several hundred of them. The brightest sources of x-rays in the sky, they are thought to consist of an ordinary star in orbit around an unseen object. Some emit radiation continuously, whereas others, known as x-ray transients, are seen only from time to time during a few months or so, spending most of their lives in a quiescent state that emits few if any x-rays. Most of these systems have been seen only once. When in outburst, they emit 10^{30} to 10^{31} watts in the form of x-rays—up to 100,000 times the total output of the sun.

The energy distribution of this radiation has nearly the same shape as a so-called blackbody spectrum, similar to (but much more intense than) the spectrum given off by such diverse objects as the sun, a glowing coal and a human body. A blackbody spectrum is produced by an "optically thick" medium, which is so dense that photons cannot leave it without undergoing numerous collisions with electrons. The collisions scatter, destroy and create photons, obscuring the original source of the radiation and averaging out the details of each interaction. The resulting spectrum depends only on the temperature and size of the emitting surface. In an "optically thin" gas, photons have almost no interactions before escaping, and their spectrum depends on the detailed properties of the matter.

The inferred temperature for the x-ray binaries is 10^7 degrees, which is consistent with that expected for a black hole. To generate the observed emission, a hole would need to swallow, or accrete, 10^{-9} to 10^{-8} solar mass per year—which agrees with estimates of how quickly the ordinary star is losing mass to its companion. Thus, x-ray binaries could be the best proof that stellar-mass black holes exist [see "The Search for Black Holes," by Kip S. Thorne; SCIENTIFIC AMERICAN, December 1974].



LISA BURNETT; SOURCE: MARTIN ELVIS *Harvard-Smithsonian Center for Astrophysics*

OUTBURST OF X-RAYS from a transient source peaked on August 13, 1975. Over a few weeks, the intensity (*vertical axis*) increased by a factor of at least 10,000. This x-ray source, known as A0620–00 and located in the constellation Monoceros, was the brightest ever seen. Astronomers had also observed an outburst of visible light from the same region 58 years earlier, but at the time they did not have x-ray detectors.

Taking a Pulse

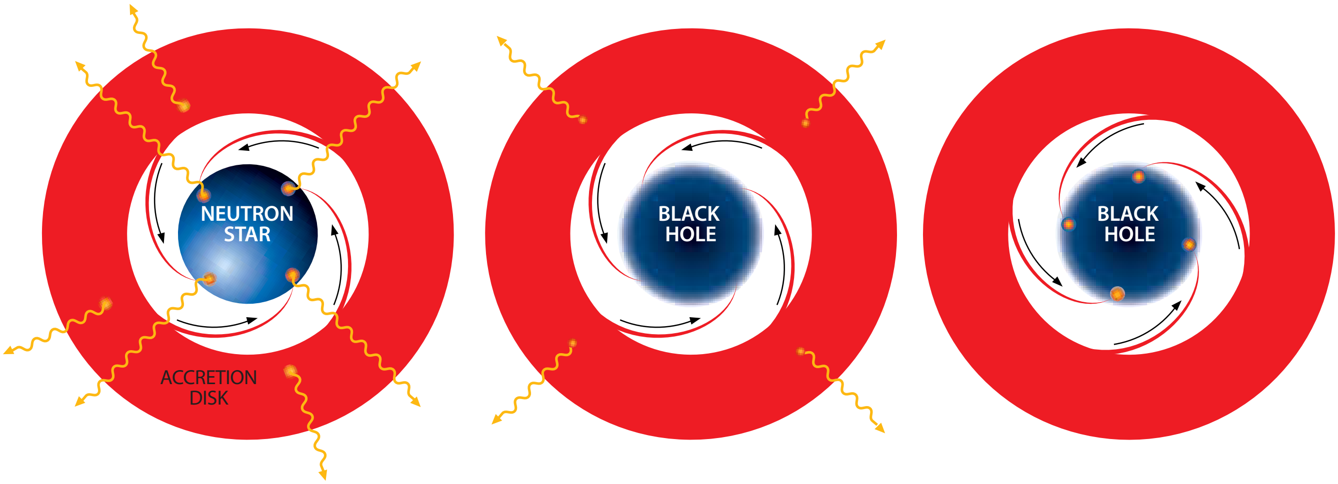
Yet the very same arguments could also apply to a neutron star. Though not quite as powerful as a hole, a neutron star is still an impressive engine. Material can impact its surface at half the speed of light, converting to energy with an efficiency of about 10 percent—not far from that of a typical hole.

Indeed, astronomers know that the compact object in many binary systems is not a black hole. Radio pulsars found in binaries are, like single pulsars, thought to be rapidly rotating, magnetized neutron stars. Astronomical black holes cannot have magnetic fields. They are nearly featureless objects and cannot generate the regular pulses observed from pulsars. Similarly, x-ray pulsars cannot be black holes. Any regular, stable pulsation rules out the presence of a hole. Even irregular x-ray bursts entail a neutron star, which provides a surface on which matter can accumulate and, from time to time, explode [see "X-ray Binaries," by Edward P. J. van den Heuvel and Jan van Paradijs; SCIENTIFIC AMERICAN, November 1993].

Unfortunately, the converse is not true: the absence of pulses or bursts does not imply a black hole. For example, a neutron star accreting matter at a very high rate is not expected to produce x-ray bursts. Because accretion rates vary over time, surprises are possible. For example, the system Circinus X-1 was suspected of harboring a black hole until the day it began to show x-ray bursts.

Black holes have two properties that can be used to ascertain their presence in binary systems: their lack of a hard surface and their unlimited mass. The mass of a hole is determined by the way it formed—in particular, by the mass of the star from which it developed—and by the amount of matter it has swallowed. No principle of physics determines how massive a black hole can be. In comparison, other compact objects, such as neutron stars, cannot have arbitrarily large masses.

The mass of any object except a black hole is limited by its ability to



THREE STYLES OF ACCRETION give off radiation in different ways. As gas spirals onto a neutron star, it releases much of its energy on impact (*left*). But gas spiraling into a black hole does not have an impact; it simply vanishes through the horizon. Either the gas releases energy before it reaches the horizon (*center*)—as it will if its density is high, so that gas atoms collide—or it carries the energy with it to the grave (*right*). Astronomers can use the style of radiation to deduce which type of object is present.

hold up under its own weight. In ordinary stars, particle thermal motions—powered by thermonuclear fusion—produce the pressure that prevents collapse. But dead stars, such as neutron stars and white dwarfs, generate no energy. Instead the pressure opposing the pull of gravity is the result of so-called degeneracy, a passive force that results from quantum-mechanical interactions at the extremes of density.

According to the Pauli exclusion principle, there is a limit to the number of fermions (one of the two classes of elementary particles, the one that includes electrons, protons and neutrons) that can be packed into a given space. In a white dwarf, electrons try to occupy the lowest possible energy levels. Because of the Pauli principle, however, they cannot all be in the lowest level. Only two electrons are allowed to be in each energy state. Electrons therefore pile up to a certain value of energy, which depends on the density. This pileup creates pressure that opposes gravity. (The same effect prevents electron levels in atoms from collapsing onto one another.) As demonstrated by Subrahmanyan Chandrasekhar in 1930, the mass of a white dwarf star must be less than 1.4 solar masses.

Resisting Gravity

In neutron stars, densities are so high that even electron degeneracy cannot resist gravity. The atoms buckle, protons and electrons compact together to form neutrons, and the atomic nuclei merge. The result is a ball of neutrons. The particles cannot all occupy the same energy level, so they pile up, generating outward pressure.

The properties of degenerate nuclear matter are poorly known, because the strong interactions among neutrons—and their constituent quarks—have to be taken into account [see "The Nuclear Equation of State," by Hans Gutbrod and Horst Stöcker; SCIENTIFIC AMERICAN, November 1991]. For this reason, researchers are not sure of the maximum mass of a neutron star, although a simple argument clarifies the absolute maximum. In a degenerate star the pull of gravity increases with mass. To resist this increased pull, matter must stiffen. Above some critical mass, it would become so stiff that sound would propagate at speeds faster than that of light—contrary to the basic principles of relativity. This critical mass is about six times that of the sun. According to a more detailed calculation performed by American, French and Japanese groups, the maximum mass is actually lower than 3 solar masses. Known neutron stars never exceed 2 solar masses.

By process of elimination, what astronomers call black holes—or, out of prudence, black hole candidates—are compact objects whose masses are larger than about 3 solar masses. In binary systems, measurements of the speeds of the stars, combined with Kepler's laws of orbital motion, can put a firm lower limit on the stellar masses. Currently astronomers know seven x-ray transient binaries in which the compact object definitely meets this criterion for a black hole. With some additional assumptions, they have estimated that the actual mass of these holes varies from 4 to 12 solar masses.

The identification of these objects as black holes would be more reliable if they showed the other characteristic that neutron stars cannot have: a black hole has no hard surface. The event horizon is simply a surface of no return. Everything that falls through it is irretrievably lost from our universe.

If a blob of hot plasma falling into a black hole does not have enough time to radiate away its thermal energy, the heat will be dragged in along with the matter. Its energy will never be seen by distant observers; it will be "advected" through the horizon and disappear. This leakage does not violate the law of conservation of mass-energy, because the heat energy is incorporated into the mass of the hole. But it does greatly reduce the apparent efficiency of the black hole engine. In contrast, when hot plasma falls onto a neutron star, all its thermal energy is ultimately radiated away, either by the plasma itself or by the surface of the neutron star.

Therefore, black holes and neutron stars should be easiest to distinguish when the accreting matter is, for whatever reason, unable to shed its heat before encountering the horizon or surface. At a workshop in Kyoto in 1995, I called such flows ADAFs (advection-dominated accretion flows), a name now commonly used. Very hot and tenuous plasmas are examples of poor ra-

A Black Hole Caught in the Act

by Jeffrey E. McClintock

For astronomers trying to observe black holes in the process of swallowing energy, there is no better place to look than x-ray transient sources. A typical one is a celestial object that, over the course of a week, brightens a millionfold in x-rays and 100-fold in visible light. It remains bright for about a year before fading back into oblivion, where it could spend a decade or century before reemerging. Other variable sources of x-rays, such as x-ray burst sources and pulsating x-ray stars, do not involve such intense, lengthy and rare increases in brightness.

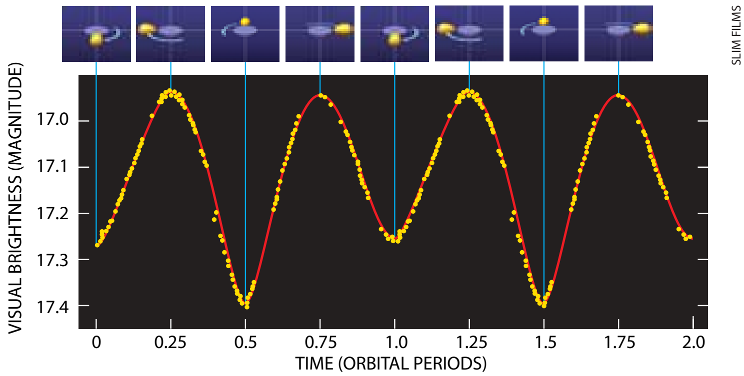
Astronomers estimate that a few thousand dormant x-ray transients lurk undiscovered in our galaxy. About two dozen such objects have been caught in the act of outburst. Each is a compact object—a black hole or a neutron star—in the process of pulling off and accreting gas from a hapless companion star.

Of these systems, none has yielded greater treasures than the black hole transient known as GRO J1655–40. It was discovered in 1994 by Shuang Nan Zhang of the National Aeronautics and Space Administration Marshall Space Flight Center and his collaborators using the Gamma Ray Observatory satellite. Since then, astronomers have seen variations in the orbital velocity of its companion star (which enable a precise measurement of the mass of the compact object); telltale signs that the black hole is spinning rapidly; a suggestive oscillation from near the hole; and jets of material squirting out at close to the speed of light.

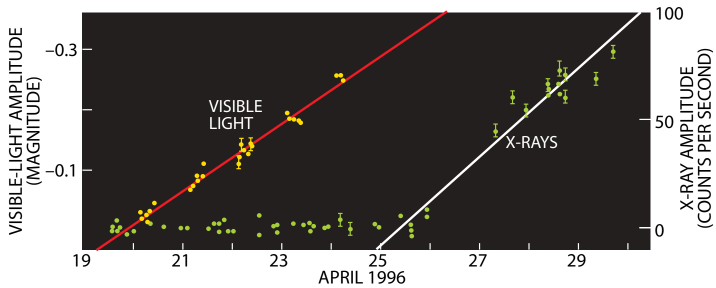
The velocity of the companion allowed astronomers to deduce the lowest mass the compact object could have: 3.2 times that of the sun. A better mass estimate was tricky to come by because it depended on the values of two additional quantities: the mass of the star and the tilt of the orbit to our line of sight. These were determined from changes in the light intensity of the star as it orbited the black hole (*center right*). The maximum intensity corresponded to viewing the star—which had been elongated by the gravity of the hole—broadside. The minimum followed a quarter of an orbit later when the star was viewed from one of its ends. By a stroke of luck, it turned out that the orbital plane and the accretion disk were nearly edge-on to our line of sight. Moreover, the surface of the companion star was free of blemishes, such as star spots. The result was the most precise mass measurement ever made for a black hole candidate: 7.0 solar masses.

In unprecedented behavior for an x-ray transient, GRO J1655–40 had a pair of closely spaced outbursts in 1994 and in 1996. The steady brightening in visible light began about six days before the start of the x-ray outburst on April 25, 1996 (*bottom right*). Theorists believe this delay occurred because it took time for the material to diffuse inward and thicken the gas near the hole. The shape of the x-ray spectrum suggested that the black hole spun at close to 90 percent of its maximum allowable rate.

Four months later Ronald A. Remillard of the Massachusetts Institute of Technology and his collaborators, using the Rossi X-ray Timing Explorer satellite, detected occasional oscillations in the x-rays. Occurring nearly 300 times a second, these vibrations were the fastest ever seen in a black hole system. According to theory, the frequency of vibration depends on the radius of the black hole's event horizon, which in turn depends on the mass and rotation rate of the hole. Using the measured mass for this system, astronomers are now trying to make the first firm determination of the rotation rate of a black hole.



OSCILLATING BRIGHTNESS of the companion star has allowed astronomers to weigh the black hole in the binary system GRO J1655–40. Typically a star would not brighten and darken in this way. But this star has been deformed by the gravity of the hole. Like a pear, it is larger when viewed from the side and therefore seems to give off more light (*inset*). The orbital period reflects the mass of the hole.

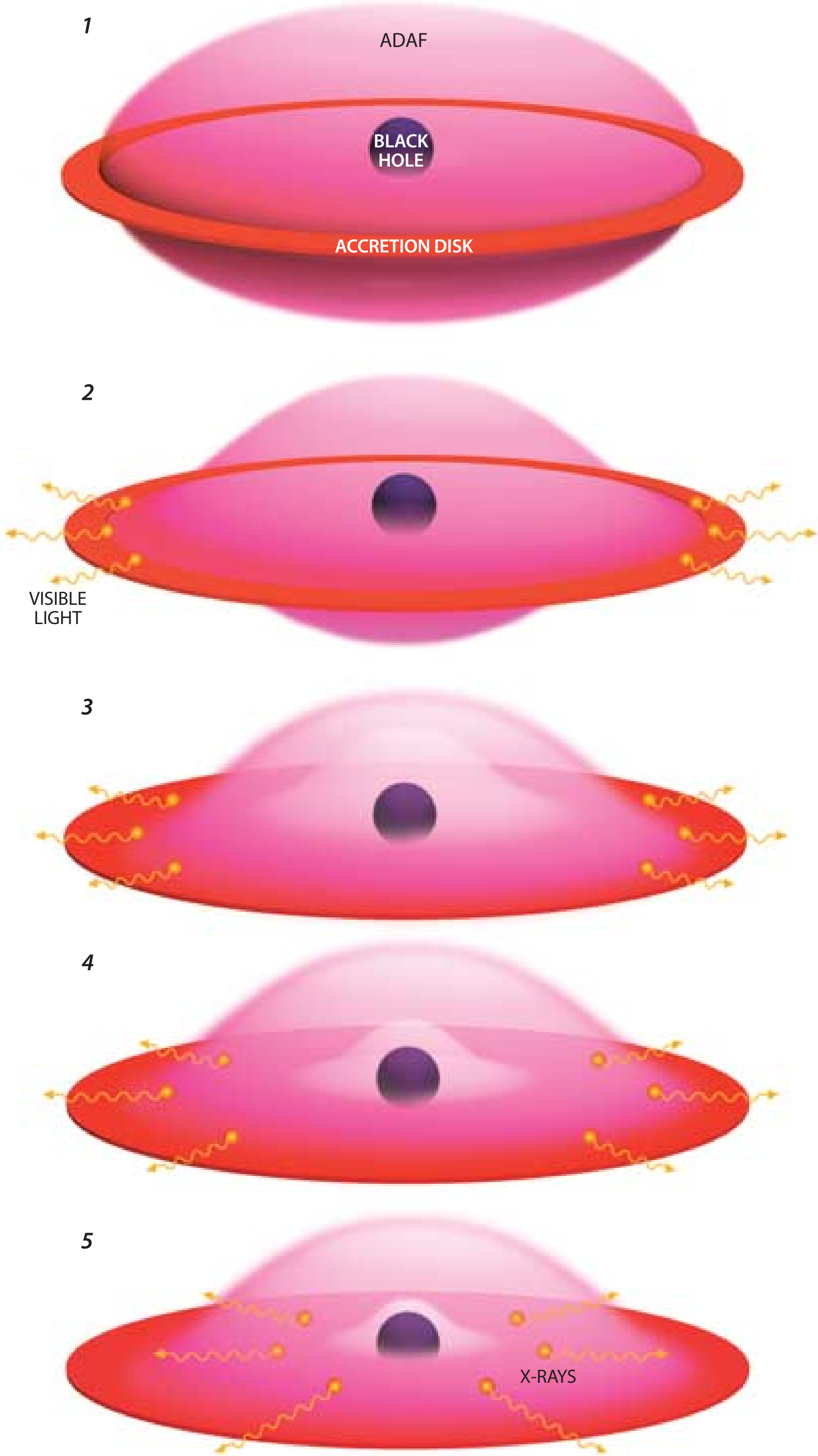


SIX DAYS after the binary system GRO J1655–40 began to brighten in visible light (*left*), it also started to pour out x-rays (*right*).

For several months after the outburst, two jets of material, one on each side of the source, were ejected from the system at 92 percent of the speed of light. The acceleration of this material probably took place at the inner edge of the accretion disk, where gas perforce orbits the hole at nearly the speed of light.

The system has by now returned to its quiescent state. Rather than spiraling inward while pouring out x-rays, the gas around the hole is plunging straight in with no time to radiate before being swallowed up. In the process, the gas atoms and some 99.9 percent of their heat energy drain out of our universe, never to be seen again.

JEFFREY E. MCCLINTOCK is a senior astrophysicist at the Harvard-Smithsonian Center for Astrophysics. He and his collaborators discovered the first black hole in an x-ray transient in 1986.



SLIM FILMS; SOURCE: JEFFREY E. McCLINTOCK

ACCRETION FLOW in an x-ray transient system consists of a hot, thin, spheroidal gas (*pink*) surrounded by a cool, dense, flat accretion disk (*red*). In its usual, quiescent state (*1*), the hot gas drops into the black hole while emitting only a small amount of radiation—a condition astronomers call an advection-dominated accretion flow (ADAF). But during an outburst, the unstable disk heats up and starts to glow in visible light (*2*). The inner edge of the disk begins to advance toward the hole (*3, 4, 5*), replacing the ADAF until it begins to give off x-rays. This model explains the six-day delay between the visible and x-ray outbursts that astronomers saw in GRO J1655–40.

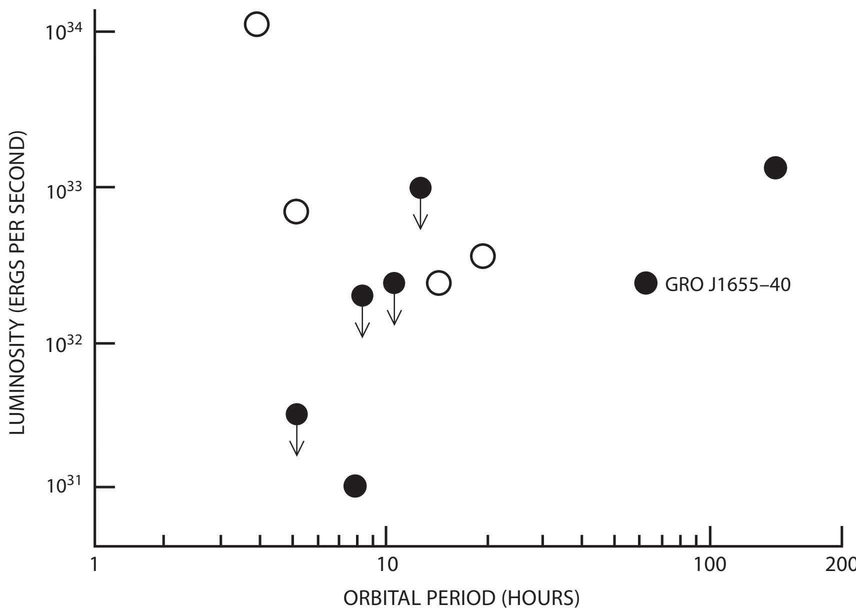
diators. Accordingly, astronomers have looked for x- and gamma-ray sources that appear dimmer than they should be if their radiative efficiency were 10 percent or so.

Down the Drain

Material plummeting toward a compact object does not fall straight in. Because of the conservation of angular momentum, it settles into roughly circular orbits. From there it can drop farther down only if there is friction, which removes angular momentum. The friction also heats up the accreting gas. If the gas can cool efficiently, it loses orbital energy and forms a flat, thin structure—an accretion disk. Such disks have been observed in many binary systems [see "Accretion Disks in Interacting Binary Stars," by John K. Cannizzo and Ronald H. Kaitchuck; Scientific American, January 1992]. But if cooling is inefficient, as it is with ADAFs, the matter will take on an almost spherical shape.

As long ago as 1977, Setsuo Ichimaru of Tokyo University used this concept to explain some properties of the massive binary Cygnus X-1, which contains the first recognized black hole candidate. But for some reason, his work went unnoticed. The recent lively interest in ADAFs started in 1994 with simple theoretical models of optically thin ADAFs by Ramesh Narayan and Insu Yi of Harvard University and by Marek Abramowicz and Ximing Chen of Gothenburg University, Shoji Kato of Kyoto University, Oded Regev of Technion University in Haifa and me. In the hands of these researchers and of others such as Ann Esin, Rohan Mahadevan and Jeffrey E. McClintock of the Harvard-Smithsonian Center for Astrophysics and Fumio Honma of Kyoto, ADAF models have gone from success to success. For example, an ADAF explains the spectrum of our galactic center, vindicating a suggestion made by Martin J. Rees of the University of Cambridge at a conference in 1982.

One type of binary system, known as a quiescent x-ray transient, appears to involve a two-component accretion flow. The inner part is an ADAF; the outer part forms a flat accretion disk. These systems spend most of their time in a quiescent state, during which most of the feeble observed radiation is emitted by the ADAF. Occasionally they give off an intense burst of radiation.



LISA BURNETT; SOURCE: KRISTIN MENOU *Harvard-Smithsonian Center for Astrophysics*

PROOF OF BLACK HOLES has come from a comparison of the brightness (*vertical axis*) of objects heavier than 3 solar masses (*black circles*) and lighter than 3 solar masses (*white circles*). The heavier bodies are fainter than the lighter ones even if they have the same orbital period (*horizontal axis*). Yet two objects with the same orbital period accrete matter at the same rate and should therefore emit roughly the same amount of radiation. The discrepancy can be explained if matter and energy are disappearing from our universe—as only a hole could accomplish. (The arrows indicate upper limits on a measurement.)

Because ADAFs are inherently stable, these outbursts must be triggered in the outer disk.

On April 20, 1996, a team of astronomers—McClintock, Ronald Remillard of the Massachusetts Institute of Technology, Jerome Orosz of Pennsylvania State University and Charles Bailyn of Yale University—was observing the x-ray transient GRO J1655–40. It looked as if something was badly wrong with the observations. But it soon became apparent that, by a stroke of luck, the team had caught a very rare event: an outburst. Over the next five days the system brightened in visible light but remained undetected in x-rays.

On the sixth day it began to blaze in x-rays. As shown by Jean-Marie Hameury of Strasbourg Observatory, McClintock, Narayan and me, the delay was exactly what is expected for two-component accretion flows. The outer disk, far from the black hole, emits light but not x-rays. Thus, when an outburst starts, it is seen only at visible wavelengths. Subsequently, matter diffuses toward the black hole more rapidly, and the tenuous ADAF region fills up until it starts to give off x-rays. The observations were a beautiful and unexpected confirmation of this theory [*see box on page 45*].

Using quiescent x-ray transients, Narayan, McClintock and Michael Garcia of the Center for Astrophysics were the first to advance a quantitative criterion to distinguish objects with hard surfaces (neutron stars) from those without (black holes). Later, I suggested a different criterion based on the fact that quiescent neutron-star transients should be brighter than black holes that accrete at the same rate. Although the accretion rate cannot be measured directly, the orbital period can serve as a proxy, because two objects with the same period should gobble up matter at roughly the same rate. Putting it all together, researchers expect black hole systems to be dimmer than neutron star systems with the same orbital period. Because periods are known only for a handful of such systems, the expected difference is not yet well established. Even so, for any given orbital period, confirmed black holes are indeed dimmer than neutron stars [*see illustration above*].

Although recent work has cast doubt on the simple ADAF model because it does not take outflows into account, more general models still require the presence of a black hole to reproduce observations. The modeling of flows into black holes remains a very active field of research. In any case, bodies too massive to be neutron stars can now be moved from the category of black hole candidate to confirmed black hole. Only an object with an event horizon can cause energy to disappear in the manner that astronomers infer for these systems. Upcoming observations by the orbiting x-ray observatories such as Chandra and XMM should add to the list. Black holes may still be black, but they can no longer hide in disguise. We are learning how to unmask them. SA

The Author

JEAN-PIERRE LASOTA used to think astronomy was boring. His true interests were literature and history. But under Communist rule in Poland, where he grew up, scholarship in the humanities was stifled by Marxist ideology. So his father—who had known Albert Einstein personally—convinced him to study physics instead. A decade after he started his career in black hole theory, he was introduced to the observational side of astronomy and found it wasn't so dull after all. Now he is a research director at the French National Center for Scientific Research. From 1987 to 1998 Lasota directed the relativistic astrophysics and cosmology department of Paris Observatory. Recently he joined the Institute of Astrophysics in Paris.

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New Nerve Cells for the Adult Brain

Contrary to dogma, the human brain does produce new nerve cells in adulthood. Can our newfound capacity lead to better treatments for neurological diseases?

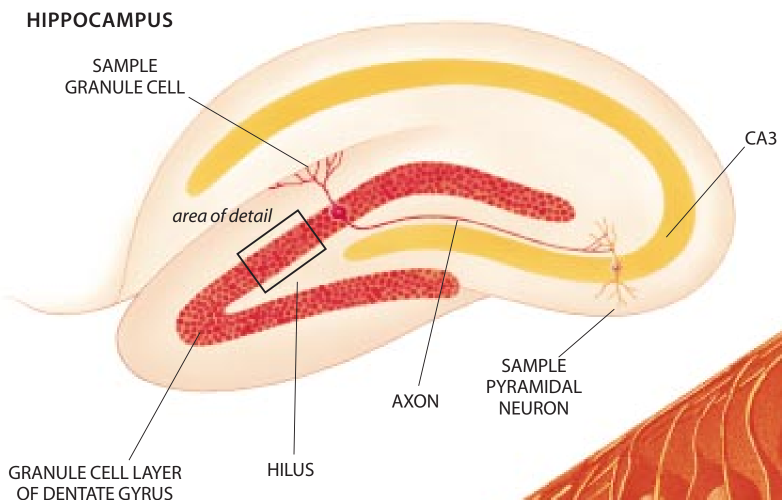
by Gerd Kempermann and Fred H. Gage

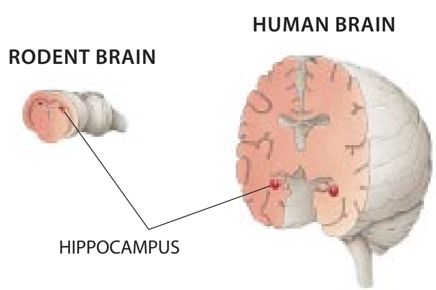
Cut your skin, and the wound closes within days. Break a leg, and the fracture will usually mend if the bone is set correctly. Indeed, almost all human tissues can repair themselves to some extent throughout life. Remarkable "stem" cells account for much of this activity. These versatile cells resemble those of a developing embryo in their ability to multiply almost endlessly and to generate not only carbon copies of themselves but also many different kinds of cells. The versions in bone marrow offer a dramatic example. They can give rise to all the cells in the blood: red ones, platelets and a panoply of white types. Other stem cells yield the various constituents of the skin, the liver or the intestinal lining.

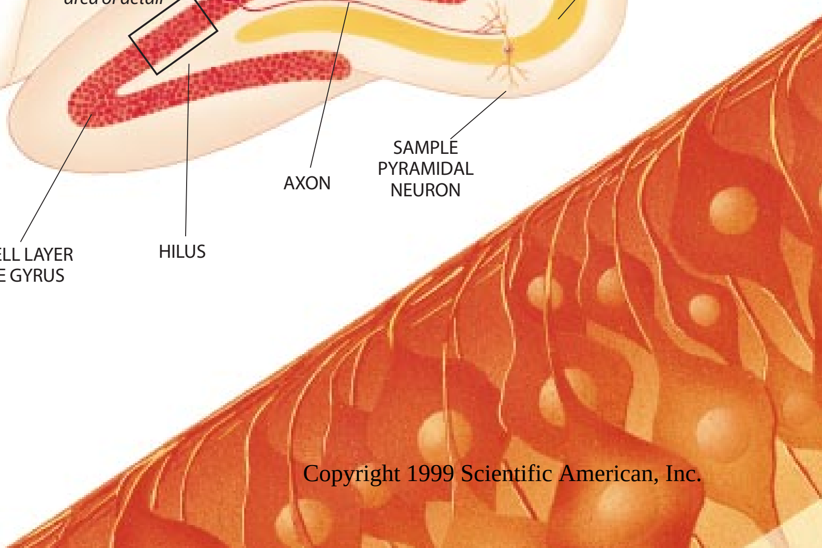
The brain of the adult human can sometimes compensate for damage quite well, by making new connections among surviving nerve cells (neurons). But it cannot repair itself, because it lacks the stem cells that would allow for neuronal regeneration. That, anyway, is what most neurobiologists firmly believed until quite recently.

This past November, Peter S. Eriksson of the Sahlgrenska University Hospital in Göteborg, Sweden, one of us (Gage) at the Salk Institute for Biological Studies in La Jolla, Calif., and several colleagues published the startling news that the mature human brain does spawn neurons routinely in at least one site—the hippocampus, an area important to memory and learning. (The hippocampus is not where memories are stored, but it helps to form them after receiving input from other brain regions. People with hippocampal damage have difficulty acquiring knowledge yet can recall information learned before their injury.)

The absolute number of new cells is low relative to the total number in the brain. Nevertheless, considered with recent findings in animals, the November discovery raises some tantalizing prospects for medicine. Current data suggest that stem cells probably make new neurons in another part of the human brain and also reside, albeit dormantly, in additional locations. Hence, the adult brain, which repairs itself so poorly, might actually harbor great potential for neuronal regeneration. If investigators can learn how to induce existing stem cells to produce useful numbers of functional nerve cells in chosen parts of the brain, that advance could make it possible to ease any number of disorders involving neuronal damage and death—among them Alzheimer's disease, Parkinson's disease and disabilities that accompany stroke and trauma.







Although the finding that the mature human brain can generate neurons was surprising, hints had actually appeared for years in studies of other adult mammals. As long ago as 1965, for instance, Joseph Altman and Gopal D. Das of the Massachusetts Institute of Technology had described neuronal production (neurogenesis) in the hippocampus of adult rats—in the precise hippocampal area, known as the dentate gyrus, where it has now been found in human beings.

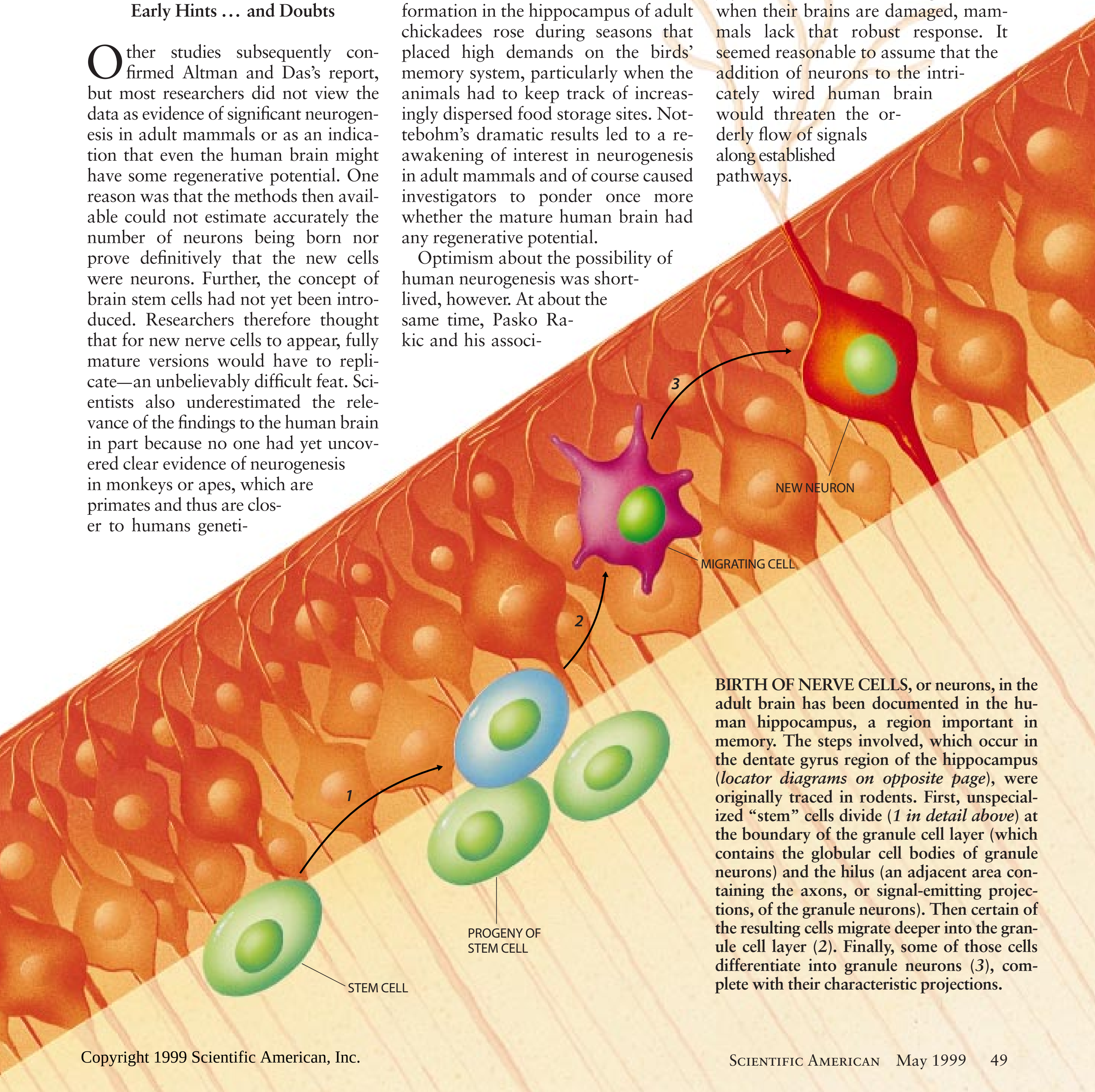
Early Hints ... and Doubts

Other studies subsequently confirmed Altman and Das's report, but most researchers did not view the data as evidence of significant neurogenesis in adult mammals or as an indication that even the human brain might have some regenerative potential. One reason was that the methods then available could not estimate accurately the number of neurons being born nor prove definitively that the new cells were neurons. Further, the concept of brain stem cells had not yet been introduced. Researchers therefore thought that for new nerve cells to appear, fully mature versions would have to replicate—an unbelievably difficult feat. Scientists also underestimated the relevance of the findings to the human brain in part because no one had yet uncovered clear evidence of neurogenesis in monkeys or apes, which are primates and thus are closer to humans genetically and physiologically than are other mammals.

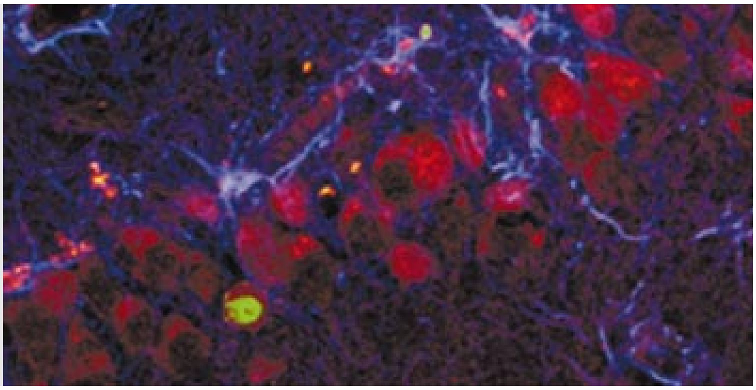
There matters stood until the mid-1980s, when Fernando Nottebohm of the Rockefeller University jarred the field with astonishing results in adult canaries. He discovered that neurogenesis occurred in brain centers responsible for song learning and, moreover, that the process accelerated during the seasons in which the adult birds acquired their songs. Nottebohm and his co-workers also showed that neuron formation in the hippocampus of adult chickadees rose during seasons that placed high demands on the birds' memory system, particularly when the animals had to keep track of increasingly dispersed food storage sites. Nottebohm's dramatic results led to a reawakening of interest in neurogenesis in adult mammals and of course caused investigators to ponder once more whether the mature human brain had any regenerative potential.

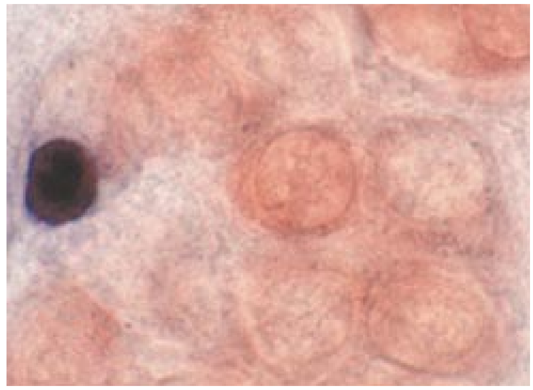
Optimism about the possibility of human neurogenesis was short-lived, however. At about the same time, Pasko Rakic and his associates at Yale University pioneered the study of neurogenesis in adult primates. That work, which was well done for its time, failed to find new brain neurons in grown rhesus monkeys.

Logic, too, continued to argue against neuronal birth in the adult human brain. Biologists knew that the extent of neurogenesis had become increasingly restricted throughout evolution, as the brain became more complex. Whereas lizards and other lower animals enjoy massive neuronal regeneration when their brains are damaged, mammals lack that robust response. It seemed reasonable to assume that the addition of neurons to the intricately wired human brain would threaten the orderly flow of signals along established pathways.



BIRTH OF NERVE CELLS, or neurons, in the adult brain has been documented in the human hippocampus, a region important in memory. The steps involved, which occur in the dentate gyrus region of the hippocampus (*locator diagrams on opposite page*), were originally traced in rodents. First, unspecialized "stem" cells divide (*1 in detail above*) at the boundary of the granule cell layer (which contains the globular cell bodies of granule neurons) and the hilus (an adjacent area containing the axons, or signal-emitting projections, of the granule neurons). Then certain of the resulting cells migrate deeper into the granule cell layer (*2*). Finally, some of those cells differentiate into granule neurons (*3*), complete with their characteristic projections.





PHOTOGRAPHS BY LINDA KITABAYASHI *Salk Institute*

PROOF OF NEURON FORMATION in the mature human brain includes these micrographs of hippocampal tissue from adults who died of cancer. The images, derived through different methods, mark neurons in red. The green in a neuron in the left image and the dark shading of a neuron in the right image reveal that the cells' chromosomes harbor a substance—bromodeoxyuridine (BrdU)—that was injected into the patients to assess tumor growth. BrdU becomes integrated into the DNA of dividing cells (such as stem cells) but is not retained by already established neurons. Its presence therefore signals that the marked cells differentiated into neurons only after the BrdU was delivered, late in the patients' lives.

Signs that this reasoning might be flawed emerged only a few years ago. First, a team headed by Elizabeth Gould and Bruce S. McEwen of Rockefeller and Eberhard Fuchs of the German Primate Center in Göttingen revealed in 1997 that some neurogenesis occurs in the hippocampus of the primatelike tree shrew. Then, in March 1998, they found the same phenomenon in the marmoset. Marmoset monkeys are evolutionarily more distant from humans than rhesus monkeys are, but they are nonetheless primates.

Cancer Patients Showed the Way

Clearly, the question of whether humans possess a capacity for neurogenesis in adulthood could be resolved only by studying people directly. Yet such studies seemed impossible, because the methods applied to demonstrate new neuron formation in animals did not appear to be transferable to people.

Those techniques vary but usually take advantage of the fact that before cells divide, they duplicate their chromosomes, which enables each daughter cell to receive a full set. In the animal experiments, investigators typically inject subjects with a traceable material (a "marker") that will become integrated only into the DNA of cells preparing to divide. That marker becomes a part of the DNA in the resulting daughter cells and is then inherited by the daughters' daughters and by future descendants of the original dividing cells.

After a while, some of the marked cells differentiate—that is, they specialize, becoming specific kinds of neurons or glia (the other main class of cells in the brain). Having allowed time for differentiation to occur, workers remove the brain and cut it into thin sections. The sections are stained for the presence of neurons and glia and are viewed under a microscope. Cells that retain the marker (a sign of their derivation from the original dividing cells) and also have the anatomic and chemical characteristics of neurons can be assumed to have differentiated into nerve cells after the marker was introduced into the body. Fully differentiated neurons do not divide and cannot integrate the marker; they therefore show no signs of it.

Living humans obviously cannot be examined in this way. That obstacle seemed insurmountable until Eriksson hit on a solution soon after completing a sabbatical with our group at Salk. A clinician, he one day found himself on call with a cancer specialist. As the two chatted, Eriksson learned that the substance we had been using as our marker for dividing cells in animals—bromodeoxyuridine (BrdU)—was coincidentally being given to some terminally ill patients with cancer of the tongue or larynx. These patients were part of a study that injected the compound to monitor tumor growth.

Eriksson realized that if he could obtain the hippocampus of study participants who eventually died, analyses conducted at Salk could identify the neurons and see whether any of them displayed the DNA marker. The presence of BrdU would mean the affected neurons had formed after that substance was delivered. In other words, the study could prove that neurogenesis had occurred, presumably through stem cell proliferation and differentiation, during the patients' adulthood.

Eriksson obtained the patients' consent to investigate their brains after death. Between early 1996 and February 1998, he raced to the hospital and was given brain tissue from five such patients, who had passed away between the ages of 57 and 72. As hoped, all five brains displayed new neurons—specifically those known as granule cells—in the dentate gyrus. These patients donated their brains to this cause, and we owe this proof of adult human neurogenesis to their generosity. (Coincidentally, at about the time this study was published, Gould's and Rakic's groups both reported that nerve cell production does take place in the hippocampus of adult rhesus monkeys.)

Do the New Neurons Work?

Of course, the mere demonstration of human neurogenesis is not enough. If the ultimate goal is to stimulate controlled neuronal regeneration in ailing human brains, scientists will want to determine the locations of stem cells capable of evolving into neurons. They will also need to be sure that neurons derived from such cells will be functional and able to send and receive messages appropriately. Fortunately, the discovery that neurogenesis in the rodent hippocampus does, after all, mirror activity in the human brain means that investigators can return to studies in rats and mice to seek clues.

Past work in rodents has revealed that some neurogenesis occurs throughout life not only in the hippocampus but in the brain's olfactory system. Stem cells also reside in such brain regions as the septum (involved in emotion and learning) and the striatum (involved in fine-tuning motor activity) and in the spinal cord. The cells outside the hippocampus and olfactory system do not appear to produce new neurons under normal conditions, though.

If the front part of the animal's brain were transparent, the dentate gyrus portion of the hippocampus would be seen partly as a thin, dark layer, roughly the shape of a sideways V. This V consists of the cell bodies of granule neurons—the globular parts that contain the nucleus. An adjacent layer inside the V is called the hilus. It is composed primarily of the axons, or long signal-carrying projections, through which granule cells relay signals to a hippocampal relay station known as CA3.

The stem cells that give rise to newly born granule cells sit at the boundary of the dentate gyrus and the hilus. These cells divide continuously. Many of the progeny are exactly like their parents, and a good number apparently die soon after being produced. But some migrate deeper into the granule cell layer and assume the appearance of the surrounding granule cells, complete with multiple projections for receiving and sending signals. They also extend their axons along the same tracts used by their already established neighbors.

The stem cells that yield new neurons in the olfactory system line the walls of fluid-filled brain cavities known as lateral ventricles. Arturo Alvarez-Buylla of Rockefeller and his co-workers have demonstrated that certain descendants of these stem cells migrate a good distance into the olfactory bulb, where they take on the characteristic features of neurons in that area.

Given that the new neurons in both brain regions look like their earlier-born counterparts, chances are good that they behave like those neurons. But how might this surmise be proved? Studies analyzing the effects of environment on brain anatomy and learning have been instructive.

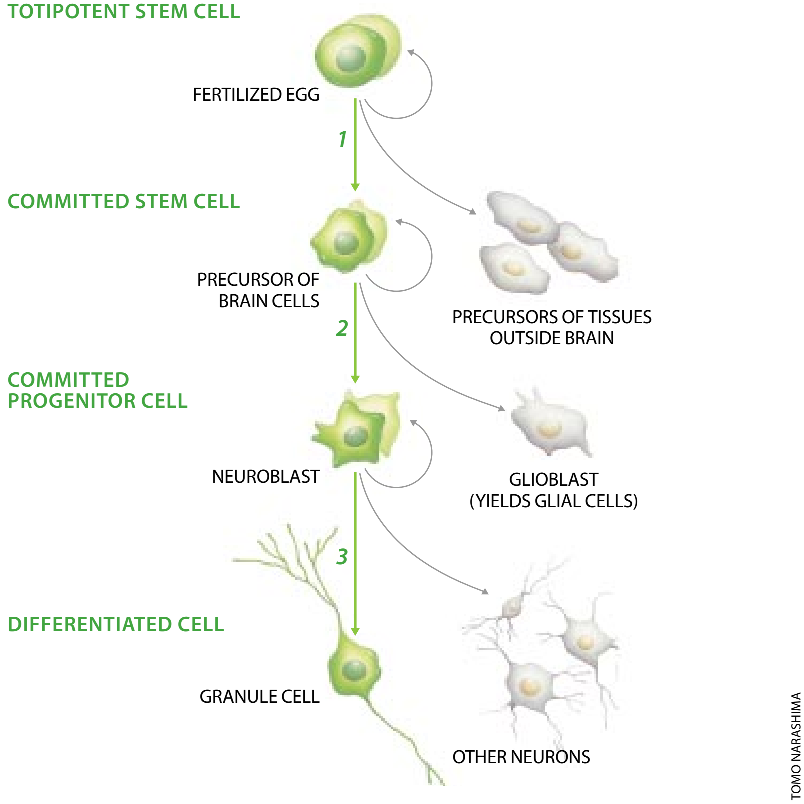
In the early 1960s Mark R. Rosenzweig and his colleagues at the University of California at Berkeley removed rodents from their standard, rather spartan laboratory conditions and put them into an enriched environment, where they luxuriated in very large cages and shared the company of many other rodents. They could also explore their surroundings (which were continually changed by the caretakers), take spins in running wheels and play with a variety of toys.

Rosenzweig's group and later that of William T. Greenough of the University of Illinois described amazing consequences of living under such improved conditions. Relative to animals kept in standard cages, those enjoying the high life ended up with slightly heavier brains, greater thickness in certain brain structures, differences in the levels of some neurotransmitters (the molecules that carry stimulatory or inhibitory messages from one neuron to another), more connections between nerve cells and increased branching of neuronal projections. Moreover, they performed better on learning tests; for instance, they were more successful at learning to navigate mazes.

Together the various results implied that the environmental changes had led to improved brain function. Since then, neurobiologists have become convinced that enriching the environment of mature rodents influences brain wiring in ways that enhance brainpower. For years, however, they dismissed the notion that the production of new nerve cells in the adult brain could contribute to such improvements, even though Altman suggested as early as 1964 that such a process should be considered.

New findings have now confirmed that environmental manipulations do affect adult neurogenesis. Applying technology not available in the 1960s, our group demonstrated in 1997 that adult mice given enriched living conditions grew 60 percent more new granule cells in the dentate gyrus than did genetically identical control animals. They also did better on a learning task that involved finding their way out of a pool of water. Enrichment even enhanced neurogenesis and learning performance in very old mice, which have a base rate of neuronal production much lower than that in younger adults.

We do not claim that the new neurons



GRANULE CELL DEVELOPMENT in an embryo is thought to occur through the steps shown in green. A totipotent stem cell, able to give rise to any cell in the body, produces early descendants that include still unspecialized stem cells committed to producing cells of the brain (*1*). These committed cells later yield "progenitor" cells destined to make only neurons (*2*) or only glial cells (which promote neuronal survival). Ultimately, neuronal progenitors spawn granule cells in the hippocampus (*3*) or other kinds of neurons elsewhere in the brain. Steps 2 and 3 now appear to recur throughout life in the human hippocampus.

are solely responsible for the behavioral improvements, because changes in wiring configurations and in the chemical microenvironment in the involved brain areas surely play an important part. On the other hand, it would be very surprising if such a dramatic jump in neuron formation, as well as the preservation of adult neurogenesis throughout evolution, served no function.

Hunt for Controls

If, as we suspect, the neurons born routinely in the brain of the adult human are functional, then an understanding of the controls on their formation could eventually teach neurobiologists how to prompt such neuronal generation where it is needed. Aside from environmental enrichment, various other factors that influence neurogenesis have been identified in animal studies over the past several years.

PHOTOGRAPHS BY JAMES ARONOVSKY

These results will make the most sense if readers recall that neurogenesis has many steps—from stem cell proliferation, to selected survival of some progeny, to migration and differentiation. It turns out that factors influencing one step along the way may not affect others. An increase in stem cell proliferation can yield a net rise in new neurons if the rates of daughter cell survival and differentiation remain constant, but the neuronal number may not rise if the survival and differentiation rates change in opposite directions. Similarly, neurons will be added if proliferation stays constant but survival and differentiation increase.

Among the regulatory influences that have been uncovered are some that usually seem to discourage neurogenesis. In the past few years, for example, Gould and McEwen have reported that certain everyday inputs into the dentate gyrus may actually keep a lid on nerve cell production. Specifically, neurotransmitters that stimulate granule cells to fire will also inhibit stem cell proliferation in the hippocampus. High levels of glucocorticoid hormones in the blood inhibit adult neurogenesis as well.

Given these findings, it is perhaps no surprise that the team has shown stress to reduce stem cell proliferation in the same region. Stress leads to the release of excitatory neurotransmitters in the brain and to the secretion of glucocorticoid hormones from the adrenals. Understanding inhibition is important for learning how to overcome it. But that aspect of the picture is still far from clear. For instance, the discovery that extreme levels of excitatory transmitters and of certain hormones can constrain neurogenesis does not necessarily mean that lower levels are detrimental; in fact, they may be helpful.

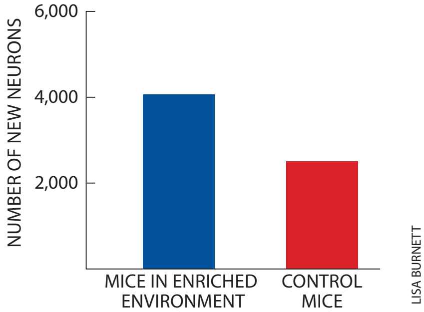
As for factors that promote hippocampal neurogenesis, we and others have been trying to identify which features of an enriched environment have the strongest effect. With her associates, Gould, now at Princeton University, has shown recently that participation in a learning task, even in the absence of enriched living, enhances the survival of the cells generated by stem cell division, resulting in a net elevation in the number of new neurons.

Meanwhile our group compared neurogenesis in two groups of mice kept in standard cages, one with a running wheel and one without. The mice having unlimited access to the wheels made heavy use of the opportunity and ended up with twice as many new nerve cells as their sedentary counterparts did, a figure comparable to that found in mice placed in an enriched environment. In the runners, a higher rate of stem cell division was involved in the final effect, whereas it played no role in the gains of the enriched-living group. In the latter case (as in Gould's study), stimulating conditions apparently promoted survival of stem cell progeny, so that more of those cells lived to become neurons. This finding highlights once again that the processes regulating neurogenesis in adults are complex and occur on several levels.

Certain molecules are known to influence neurogenesis. We and our co-workers have evaluated epidermal growth factor and fibroblast growth factor, which despite their names have been shown to affect nerve cell development in cell cultures. With H. Georg Kuhn of Salk and Jürgen Winkler of the University of California at San Diego, we delivered these compounds into the lateral ventricles of adult rats, where they evoked striking proliferation by the resident stem cells. Epidermal growth factor favored differentiation of the resulting cells into glia in the olfactory bulb, but fibroblast growth factor promoted neuronal production.

Interestingly, the induction of certain pathological conditions, such as epileptic seizures or stroke, in adult animals can evoke dramatic stem cell division and even neurogenesis. Whether the brain can make use of this response to replace needed neurons is not known. In the case of the seizures, aberrant connections formed by newborn neurons may be part of the problem. The stem cell division and neurogenesis are more evidence that the brain harbors potential for self-repair. The question is, why does that potential usually go unused?

In the experiments discussed so far, we and others examined regulatory events by holding genes constant: we observed the neurological responses of genetically identical (inbred) animals to different inputs. Another way to uncover controls on neurogenesis is to hold the environment constant and compare genes in strains of animals that differ innately in their rates of neuron production. Pre-



ENRICHED LIVING ENVIRONMENT (*opposite page*) **is far superior to standard laboratory conditions** (*above*) **for stimulating neurogenesis in the dentate gyrus of the mouse hippocampus** (*graph*). **Scientists are trying to determine which aspects of the richer environment exert the strongest effect. New findings comparing animals living in standard cages with and without a running wheel suggest that increased running could have an important role.**

sumably, the genes that vary include those affecting the development of new nerve cells. In a similar approach, researchers can compare the genes active in brain regions that display neurogenesis and in brain regions that do not. Genetic studies are under way.

Genes serve as the blueprints for proteins, which in turn carry out the bulk of cellular activities, such as inducing cell division, migration or differentiation. Therefore, if the genes participating in neuronal generation can be identified, investigators should be able to discover their protein products and to tease out the precise contributions of the genes and their proteins to neurogenesis.

Repairing the Brain

With continued diligence, scientists may eventually be able to trace the molecular cascades that lead from a specific stimulus, be it an environmental cue or some internal event, to particular alterations in genetic activity and, in turn, to rises or falls in neurogenesis. Then they will have much of the information needed to induce neuronal regeneration at will. Such a therapeutic approach could involve administration of key regulatory molecules or other pharmacological agents, delivery of gene therapy to supply helpful molecules, transplantation of stem cells, modulation of environmental or cognitive stimuli, alterations in physical activity, or some combination of these factors.

Compilation of such techniques could take decades. Once collected, though, they might be applied in several ways. They might provide some level of repair, both in brain areas known to manifest some neurogenesis and in sites where stem cells exist but are normally quiescent. Doctors might also be able to stimulate stem cells to migrate into areas where they usually do not go and to mature into the specific kinds of nerve cells required by a given patient. Although the new cells would not regrow whole brain parts or restore lost memories, they could, for example, manufacture valuable amounts of dopamine (the neurotransmitter whose depletion is responsible for the symptoms of Parkinson's disease) or other substances.

Research in related areas of science will contribute to the search for these advanced therapeutic approaches. For instance, several laboratories have learned to culture what are called human embryonic stem cells—highly versatile cells, derived from early embryos, that are capable of giving rise to virtually any cell type in the human body. One day it might be possible to prod these embryonic stem cells into generating offspring that are committed to becoming a selected type of neuron. Such cells might then be transplanted into damaged sites to replenish lost nerve cells [see "Embryonic Stem Cells for Medicine," by Roger A. Pedersen; Scientific American, April].

Transplants, of course, may be rejected by a recipient's immune system. Scientists are exploring many ways around that problem. One solution could be to harvest stem cells from the brains of the affected patients themselves and to manipulate that material instead of stem cells from a donor. Researchers have already devised relatively noninvasive means of extracting such brain cells from patients.

These medical applications are admittedly goals and are nowhere close to reality at the moment. Indeed, the challenges ahead are huge. Notably, at one point or another analyses of the controls on neurogenesis and of proposed therapies for brain disorders will have to move from rodents to people. To study humans without interfering with their health, researchers will have to make use of extremely clever protocols, such as ones involving the noninvasive imaging techniques known as functional magnetic resonance imaging or positron emission tomography. Further, we will have to develop safeguards ensuring that neurons stimulated to form in the human brain (or transplanted into it) will do just what we want them to do and will not interfere with normal brain function. Nevertheless, the expected benefits of unlocking the brain's regenerative potential justify all the effort that will be required. SA

The Authors

GERD KEMPERMANN and FRED H. GAGE have worked together since 1995, when Kempermann began a three-year term as a postdoctoral fellow in Gage's laboratory at the Salk Institute for Biological Studies in La Jolla, Calif. Kempermann, who holds a medical degree from the University of Freiburg in Germany, is now a neurology resident at the University of Regensburg. Gage has been a professor in the Laboratory of Genetics at Salk since 1995 and a professor in the department of neurosciences at the University of California, San Diego, since 1988. He earned his doctorate in neurobiology from Johns Hopkins University in 1976 and was an associate professor of histology at Lund University in Sweden before moving to California.

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TSUNAMI!

Its awesome fury cannot be diminished, but lessons learned from a rash of disasters this decade—and a new way to track these killer waves—will help save lives

by Frank I. González

The sun had set 12 minutes earlier, and twilight was waning on the northern coast of Papua New Guinea. It was July 17, 1998, and another tranquil Friday evening was drawing to a close for the men, women and children of Sissano, Arop, Warapu and other small villages on the peaceful sand spit between Sissano Lagoon and the Bismarck Sea. But deep in the earth, far beneath the wooden huts of the unsuspecting villagers, tremendous forces had strained the underlying rock for years. Now, in the space of minutes, this pent-up energy violently released as a magnitude 7.1 earthquake. At 6:49 P.M., the main shock rocked 30 kilometers (nearly 19 miles) of coastline centered on the lagoon and suddenly deformed the offshore ocean bottom. The normally flat sea surface lurched upward in response, giving birth to a fearsome tsunami.

Retired Colonel John Sanawe, who lived near the southeast end of the sandbar at Arop, survived the tsunami and later told his story to Hugh Davies of the University of Papua New Guinea. Just after the main shock struck only 20 kilometers offshore, Sanawe saw the sea rise above the horizon and then spray vertically perhaps 30 meters. Unexpected sounds—first like distant thunder, then like a nearby helicopter—gradually faded as he watched the sea slowly recede below the normal low-water mark. After four or five minutes of silence, he heard a rumble like that of a low-flying jet plane. Sanawe spotted the

HISTORY'S MOST TERRIFYING TSUNAMIS could have dwarfed a lighthouse, as in this artist's conception. At heights of 30 meters and speeds of 15 meters per second (35 miles per hour), waves already this close to shore would be impossible to outrun.

PHOTOILLUSTRATION BY JANA BRENNING; PHOTOGRAPHS BY ROBERT BECK AND KATHLEEN NORRIS COOK

Larger Wave than Expected

Papua New Guinea

July 17, 1998
Maximum wave height: 15 meters
Fatalities: More than 2,200

Sissano area four days after the tsunami. Bare spots mark locations of structures swept away.

Swept clean by three monstrous waves, this now barren sandbar along Papua New Guinea's north coast once was crowded with houses and villages. Surprisingly, a relatively small earthquake (magnitude 7.1) spawned waves usually limited to much larger quakes. This apparent discrepancy between earthquake strength and tsunami intensity has prompted speculation among scientists that the seismic vibrations may have triggered other seafloor disturbances, such as an underwater landslide or an explosion of gas hydrates, that helped to create a much larger tsunami.

Unexpectedly high tsunami waves have caused other disasters, such as that in Nicaragua in 1992, but intensive surveys of the seafloor to investigate the mystery have never been conducted until now. Two expeditions explored the seafloor off the ravaged coast of Papua New Guinea for signs of an undersea landslide earlier this year. The survey teams, jointly led by Takeshi Matsumoto of the Japan Marine Science and Technology Center and David Tappin of the South Pacific Applied Geoscience Commission, identified a small depression that could be a candidate landslide site. The next question is whether this feature is fresh or was created by another earthquake long ago. *—F.G.*

first tsunami wave, perhaps three or four meters high. He tried to run home, but the wave overtook him. A second, larger wave flattened the village and swept him a kilometer into a mangrove forest on the inland shore of the lagoon.

Other villagers were not so fortunate as Sanawe. Some were swept across the lagoon and impaled on the broken mangrove branches. Many more were viciously battered by debris. At least 30 survivors would lose injured limbs to gangrene. Saltwater crocodiles and wild dogs preyed on the dead before help could arrive, making it more difficult to arrive at an exact death toll. It now appears that the tsunami killed more than 2,200 villagers, including more than 230 children. Waves up to 15 meters high, which struck within 15 minutes of the main shock, had caught many coastal inhabitants unawares. Of the few villagers who knew of the tsunami hazard, those trapped on the sandbar simply had no safe place to flee.

Tsunamis such as those that pounded Papua New Guinea are the world's most powerful waves. Historical patterns of their occurrence are revealed in large databases developed by James F. Lander, Patricia A. Lockridge and their colleagues at the National Geophysical Data Center in Boulder, Colo., and Viacheslav K. Gusiakov and his associates at the Tsunami Laboratory in Novosibirsk, Russia. Most tsunamis afflict the Pacific Ocean, and 86 percent of those are the products of undersea earthquakes around the Pacific Rim, where powerful collisions of tectonic plates form highly seismic subduction zones.

Since 1990, 10 tsunamis have taken more than 4,000 lives. In all, 82 were reported worldwide—a rate much higher than the historical average of 57 a decade. The increase in tsunamis reported is due to improved global communications; the high death tolls are partly due to increases in coastal populations. My colleagues and I at the National Oceanic and Atmospheric Administration Pacific Marine Environmental Laboratory in Seattle set up an electronic-mail network as a way for researchers in distant parts of the world to help one another make faster and more accurate tsunami surveys. This Tsunami Bulletin Board, now managed by the International Tsunami Information Center, has facilitated communication among tsunami scientists since shortly after the 1992 Nicaragua tsunami [*see box on page 60*].

Disasters similar to those in Nicaragua

and Papua New Guinea have wreaked havoc in Hawaii and Alaska in the past, but most tsunami researchers had long believed that the U.S. West Coast was relatively safe from the most devastating events. New evidence now suggests that earthquakes may give birth to large tsunamis every 300 to 700 years along the Cascadia subduction zone, an area off the Pacific Northwest coast where a crustal plate carrying part of the Pacific Ocean is diving under North America. A clear reminder of this particular threat occurred in April 1992, when a magnitude 7.1 earthquake at the southern end of the subduction zone generated a small tsunami near Cape Mendocino, Calif. This event served as the wake-up call that has driven the development of the first systematic national effort to prepare for dangerous tsunamis before they strike. The Pacific Marine Environmental Laboratory is playing a key research and management role in this endeavor.

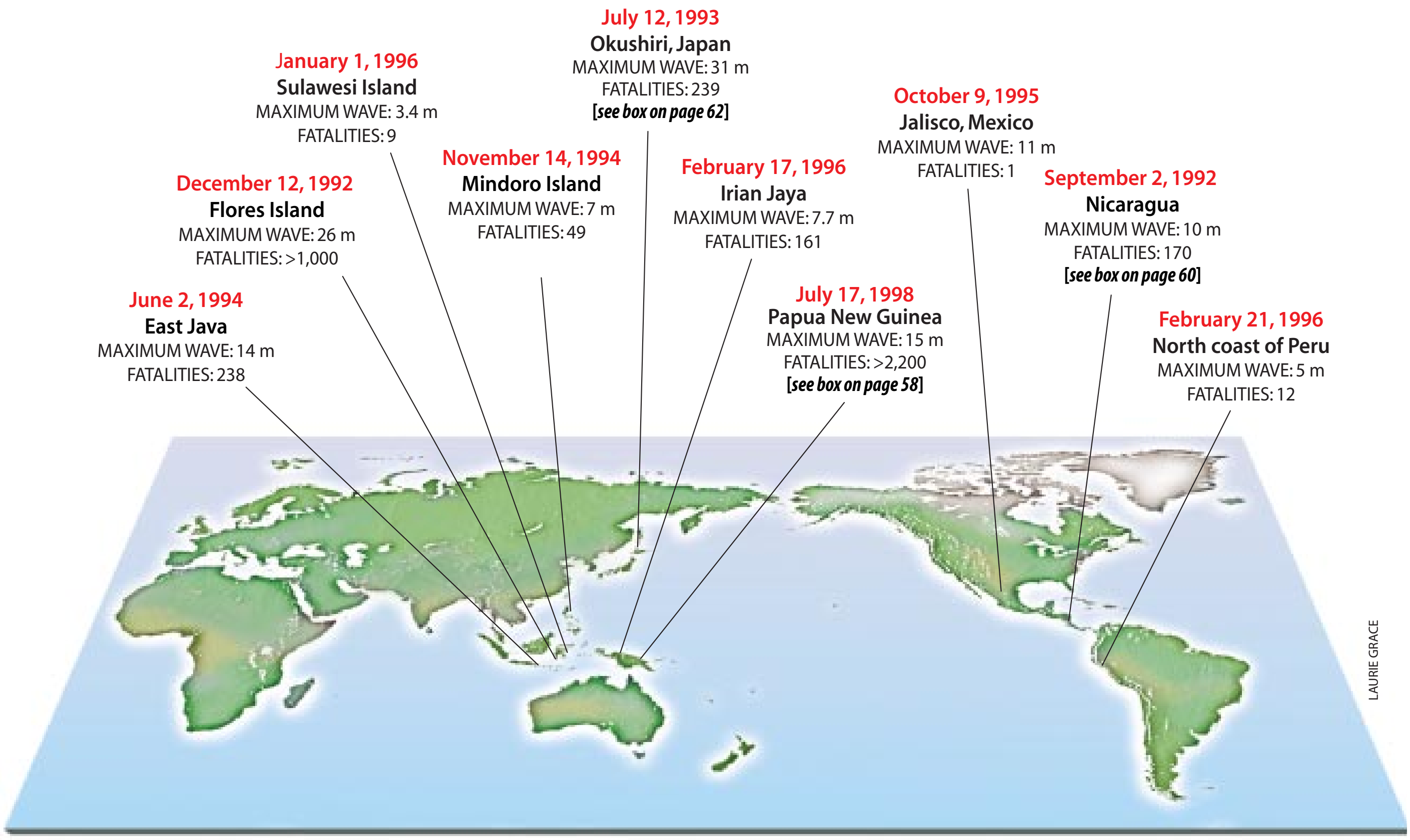
The Physics of Tsunamis

To understand tsunamis, it is first helpful to distinguish them from wind-generated waves or tides. Breezes blowing across the ocean crinkle the surface into relatively short waves that create currents restricted to a shallow layer; a scuba diver, for example, might easily swim deep enough to find calm water. Strong gales are able to whip up waves 30 meters or higher in the open ocean, but even these do not move deep water.

Tides, which sweep around the globe twice a day, do produce currents that reach the ocean bottom—just as tsunamis do. Unlike true tidal waves, however, tsunamis are not generated by the gravitational pull of the moon or sun. A tsunami is produced impulsively by an undersea earthquake or, much less frequently, by volcanic eruptions, meteorite impacts or underwater landslides. With speeds that can exceed 700 kilometers per hour in the deep ocean, a tsunami wave could easily keep pace with a Boeing 747. Despite its high speed, a tsunami is not dangerous in deep water. A single wave is less than a few meters high, and its length can extend more than 750 kilometers in the open ocean. This creates a sea-surface slope so gentle that the wave usually passes unnoticed in deep water. In fact, the Japanese word *tsu-nami* translates literally as "harbor wave," perhaps because a tsunami can speed silently and undetected across the ocean, then unexpectedly arise as destructively high waves in shallow coastal waters.

A powerful tsunami also has a very long reach: it can transport destructive energy from its source to coastlines thousands of kilometers away. Hawaii, because of its midocean location, is especially vulnerable to such Pacific-wide tsunamis. Twelve damaging tsunamis have struck Hawaii since 1895. In the most destructive, 159 people died there in 1946 from killer waves generated almost 3,700 kilometers away in Alaska's Aleutian Islands [*see box on page 64*]. Such remote-source tsunamis can strike unexpectedly, but local-source tsunamis—as in the case of last year's Papua New Guinea disaster—can be especially devastating. Lander has estimated that more than 90 percent of all fatalities occur within about 200 kilometers of the source. As an extreme example, it is believed that a tsunami killed more than 30,000 people within 120 kilometers of the catastrophic eruption of Krakatoa volcano in the Sunda Straits of Indonesia in 1883. That explosion generated waves as high as a 12-story building.

Regardless of their origin, tsunamis



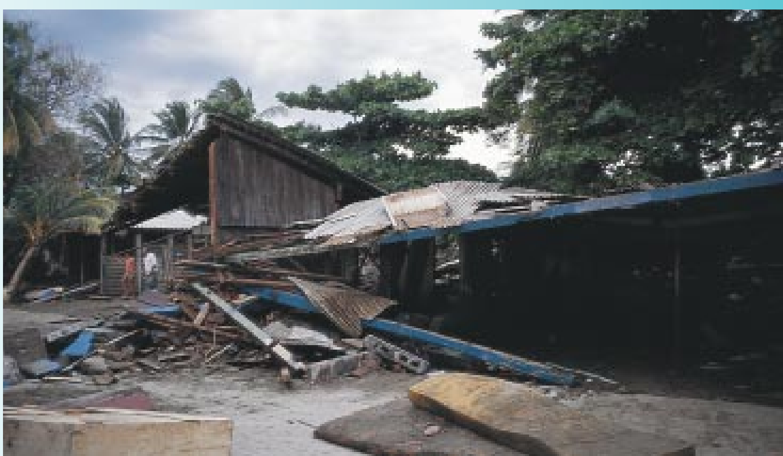
TEN DESTRUCTIVE TSUNAMIS have claimed more than 4,000 lives since 1990. Last year's Papua New Guinea disaster is the most recent in this string of killer waves generated by earthquakes along colliding tectonic plates of the Pacific Rim.

Slow, Silent, Deadly Quake

Nicaragua

September 2, 1992
Maximum wave height: 10 meters
Fatalities: 170

Survivors line up for emergency food supplies



PHOTOGRAPHS BY PAOLO BOSIO *Gamma Liaison*

Coastal village the day after the tsunami

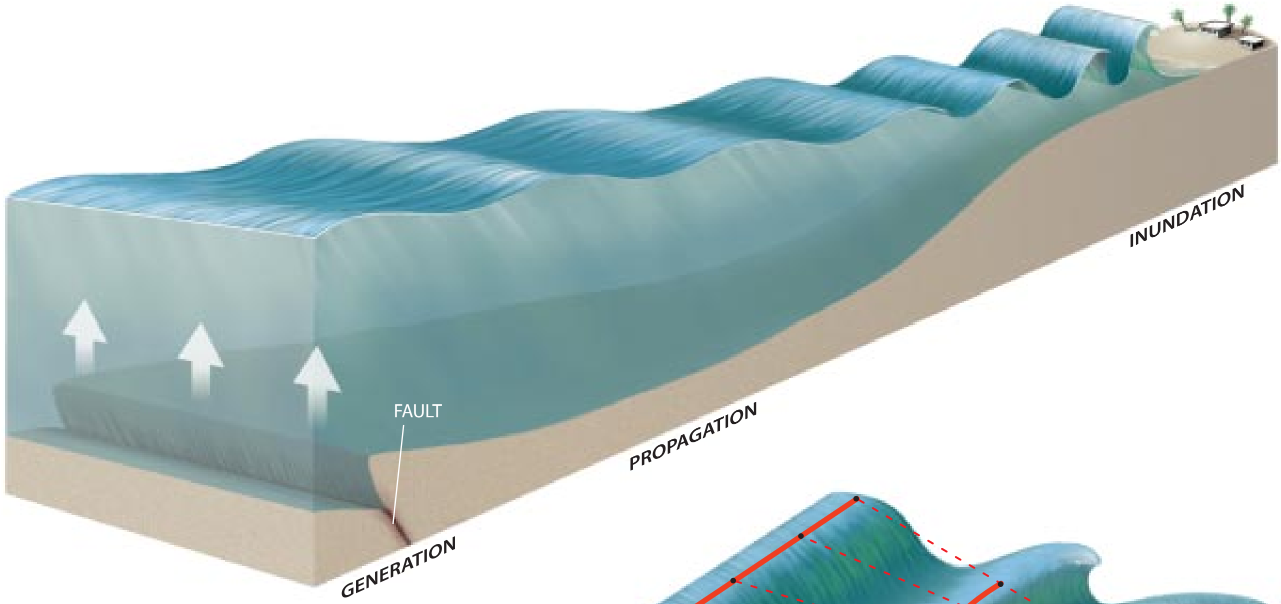
Coastal inhabitants can be educated to run to higher ground when they feel the land shake from an earthquake. But in certain tragic cases, such as the 1992 Nicaragua tsunami that killed 170 people and left 13,000 homeless, residents feel only a minor tremor, or even none at all, and assume there is no danger. An estimated 5 to 10 percent of tsunami-causing earthquakes are of this particularly hazardous breed—so-called silent earthquakes, first described by Hiroo Kanamori of the California Institute of Technology.

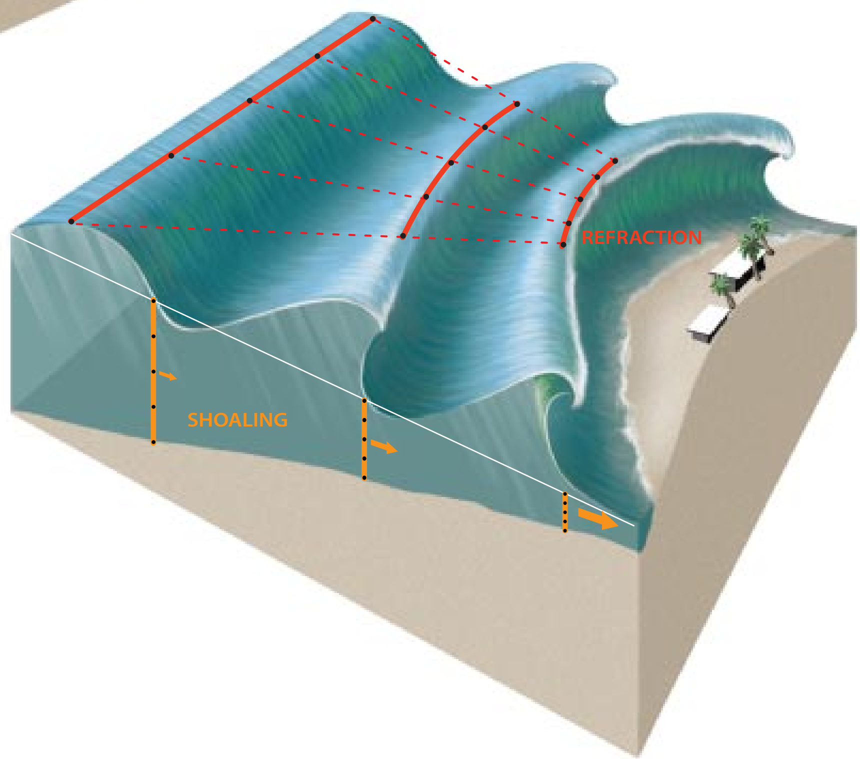
In the latest Nicaragua event, the short waves that produce the characteristic rumbling of an earthquake—and that die out quickly as they spread out from the epicenter—never made it from the quake's offshore origin to the mainland. Longer waves did reach the coast, but they hardly shook the ground. What is more, standard seismometers, which record only seismic waves with periods less than 20 seconds, missed most of these longer waves. Kanamori argued that the Nicaragua quake was actually five times greater than its assigned magnitude of 7.0 because these low-frequency waves had been ignored. The Nicaragua event made it abundantly clear that broadband seismometers sensitive to low-frequency waves must be linked to warning systems to forecast the true potential tsunami danger. *—F.G.*

evolve through three overlapping but quite distinct physical processes: generation by any force that disturbs the water column, propagation from deeper water near the source to shallow coastal areas and, finally, inundation of dry land. Of these, the propagation phase is best understood, whereas generation and inundation are more difficult to model with computer simulations. Accurate simulations are important in predicting where future remote-source tsunamis will strike and in guiding disaster surveys and rescue efforts, which must concentrate their resources on regions believed to be hardest hit.

Generation is the process by which a seafloor disturbance, such as movement along a fault, reshapes the sea surface into a tsunami. Modelers assume that this sea-surface displacement is identical to that of the ocean bottom, but direct measurements of seafloor motion have never been available (and may never be). Instead researchers use an idealized model of the quake: they assume that the crustal plates slip past one another along a simple, rectangular plane inside the earth. Even then, predicting the tsunami's initial height requires at least 10 descriptive parameters, including the amount of slip on each side of the imaginary plane and its length and width. As modelers scramble to guide tsunami survey teams immediately after an earthquake, only the orientation of the assumed fault plane and the quake's location, magnitude and depth can be interpreted from the seismic data alone. All other parameters must be estimated. As a consequence, this first simulation frequently underestimates inundation, sometimes by factors of 5 or 10.

Low inundation estimates can signify that the initial tsunami height was also understated because the single-plane fault model distributes seismic energy over too large an area. Analyses of seismic data cannot resolve energy distribution patterns any shorter than the seismic waves themselves, which extend for several hundred kilometers. But long after the tsunami strikes land, modelers can work backward from records of run-up and additional earthquake data to refine the tsunami's initial height. For example, months of aftershocks eventually reveal patterns of seismic energy that are concentrated in regions much smaller than the original, single-plane fault model assumed. When seismic energy is focused in a smaller area, the vertical motion of the seafloor—and therefore





JENNIFER C. CHRISTIANSEN

TSUNAMIS EVOLVE through three stages: generation, propagation and inundation (*above*). A seafloor disturbance, such as motion along a fault, pushes up the overlying water. The wave propagates across the deep ocean at jetliner speeds; however, with a length up to 600 times its height, the wave's slope is often too gentle to notice. The wave slows down to highway speeds as it enters shallow water, and it sometimes runs ashore as a tidelike flood. Other times, refraction and shoaling funnel the wave's energy into a dangerously high wall of water (*right*). Wave energy is squeezed into a smaller volume (*dots*) as it moves into shallower water, slows down and is overtaken by the wave behind, or wraps around a headland. This increased energy density then increases both the wave height and the currents.

the initial tsunami height—is greater. Satisfactory simulations are achieved only after months of labor-intensive work, but every simulation that matches the real disaster improves scientists' ability to make better predictions.

Propagation of the tsunami transports seismic energy away from the earthquake site through undulations of the water, just as shaking moves the energy through the earth. At this point, the wave height is so small compared with both the wavelength and the water depth that researchers apply linear wave theory, which assumes that the height itself does not affect the wave's behavior. The theory predicts that the deeper the water and the longer the wave, the faster the tsunami. This dependence of wave speed on water depth means that refraction by bumps and grooves on the seafloor can shift the wave's direction, especially as it travels into shallow water. In particular, wave fronts tend to align parallel to the shoreline so that they wrap around a protruding headland before smashing into it with greatly focused incident energy. At the same time, each individual wave must also slow down because of the decreasing water depth, so they begin to overtake one another, decreasing the distance between them in a process called shoaling. Refraction and shoaling squeeze the same amount of energy into a smaller volume of water, creating higher waves and faster currents.

The last stage of evolution, inundation and run-up, in which a tsunami may run ashore as a breaking wave, a wall of water or a tidelike flood, is perhaps the most difficult to model. The wave height is now so large that linear theory fails to describe the complicated interaction between the water and the shoreline. Vertical run-up can reach tens of meters, but it typically takes only two to three meters to cause damage. Horizontal inundation, if unimpeded by coastal cliffs or other steep topography, can penetrate hundreds of meters inland. Both kinds of flooding are aided and abetted by the typical crustal displacement of a subduction zone earthquake, which lifts the offshore ocean bottom and lowers the land along the coast. This type of displacement propagates waves seaward with a leading crest and landward with a leading trough (the reason a receding sea sometimes precedes a tsunami). Not only does the near-shore subsidence facilitate tsunami penetration inland but, according to recent studies by Raissa Mazova of the Nizhny Novgorod State Technical

Education Saves Lives

Okushiri, Japan

July 12, 1993
Maximum wave height: 31 meters
Fatalities: 239

Fires burned across the ravaged shores of Aonae, a small fishing village on Okushiri's southern peninsula, in the wake of the 1993 tsunami. Waves ranging from 5 to 10 meters had crashed ashore less than five minutes after the magnitude 7.8 earthquake struck perhaps 15 to 30 kilometers offshore in the Sea of Japan. The waves washed over seawalls erected after past tsunami disasters. High currents swept up buildings, vehicles, docked vessels and heavy material at coastal storage areas, transforming them into waterborne battering rams that obliterated all in their path. Collisions sparked electrical and propane gas fires, but access by fire engines was blocked by debris.

The loss of lives in this event was a great tragedy, but it is clear that both warning technology and community education greatly reduced the number of casualties. The Japan Meteorological Agency issued timely and accurate warnings, and many residents saved themselves by fleeing to high ground immediately after the main shock—even before the warning. Okushiri clearly demonstrated that the impact of tsunamis can be reduced. This event has also become the best-documented tsunami disaster in history. Detailed damage assessments of transportation and telecommunications networks, interviews with survivors and local officials, run-up and inundation measurements, and extensive aerial photography produced a database especially valuable to the U.S.: this urban township is a better analogue of U.S. coastal communities than the other, less developed areas destroyed by tsunamis this decade. *—F.G.*

KYOTO NEWS SERVICE

Fires and denuded peninsula in wake of the tsunami

NOAA

Damaged fire truck amid the debris

University in Russia and by Costas Synolakis of the University of Southern California, both theoretical predictions and field surveys indicate that coastal run-up and inundation will be greater if the trough of the leading wave precedes the crest.

Tsunami Threats

Predicting where a tsunami may strike helps to save lives and property only if coastal inhabitants recognize the threat and respond appropriately. More than a quarter of all reliably reported Pacific tsunamis since 1895 originated near Japan. This is not surprising, because Japan is precariously situated near the colliding margins of four tectonic plates. Recognizing the recurring threat, the Japanese have invested heavily over the years in tsunami hazard mitigation, including comprehensive educational and public outreach programs, an effective warning system, shoreline barrier forests, seawalls and other coastal fortifications.

On the night of July 12, 1993, their preparations faced a brutal test. A magnitude 7.8 earthquake in the Sea of Japan generated a tsunami that struck various parts of the small island of Okushiri [*see box above*]. Five minutes after the main shock the Japan Meteorological Agency issued a warning over television and radio that a major tsunami was on its way. By then, 10- to 20-meter waves had struck the coastline nearest the source, claiming a number of victims before they could flee. In Aonae, a small fishing village on the island's southern peninsula, many of the 1,600 townspeople fled to high ground as soon as they felt the main shock. A few minutes later tsunami waves five to 10 meters high ravaged hundreds of their homes and businesses and swept them out to sea. More than 200 lives were lost in this disaster, but quick response saved many more.

Over the past century in Japan, approximately 15 percent of 150 tsunamis were damaging or fatal. That track record is much better than the tally in countries with few or no community education programs in place. For example, more than half of the 34 tsunamis that struck Indonesia in the past 100 years were damaging or fatal. Interviews conducted after the 1992 Flores Island tsunami that killed more than 1,000 people indicated that most coastal residents did not recognize the earthquake as the natural warning of a possible tsunami and did not flee inland. Similarly, Papua New Guinea residents were tragically uninformed, sending the number of casualties from last year's disaster higher than expected for a tsunami of that size. A large quake in 1907 evidently lowered the area that is now Sissano Lagoon, but any resulting tsunami was too small and too long ago to imprint a community memory. When the earthquake struck last year, some people actually walked to the coast to investigate the disturbance, thus sealing their fate.

Scientists have learned a great deal from recent tsunamis, but centuries-old waves continue to yield valuable insights. Lander and his colleagues have described more than 200 tsunamis known to have affected the U.S. since the time of the first written records in Alaska and the Caribbean during the early 1700s and in Hawaii and along the West Coast later that century. Total damage is estimated at half a billion dollars and 470 casualties, primarily in Alaska and Hawaii. An immediate threat to those states and the West Coast is the Alaska-Aleutian subduction zone. Included in this region's history of large, tsunami-generating earthquakes are two disasters that drove the establishment of the country's only two tsunami warning centers. The probability of a magnitude 7.4 or greater earthquake occurring somewhere in this zone before 2008 is estimated to be 84 percent.

Another major threat, unrevealed by the written records, lurks off the coasts of Washington State, Oregon and northern California—the Cascadia subduction zone. Brian F. Atwater of the U.S. Geological Survey has identified sand and gravel deposits that he hypothesized were carried inland from the Washington coast by tsunamis born of Cascadia quakes. Recent events support this theory. The Nicaragua tsunami was notable for the amount of sand it transported inland, and researchers have documented similar deposits at inundation sites in Flores, Okushiri, Papua New Guinea and elsewhere.

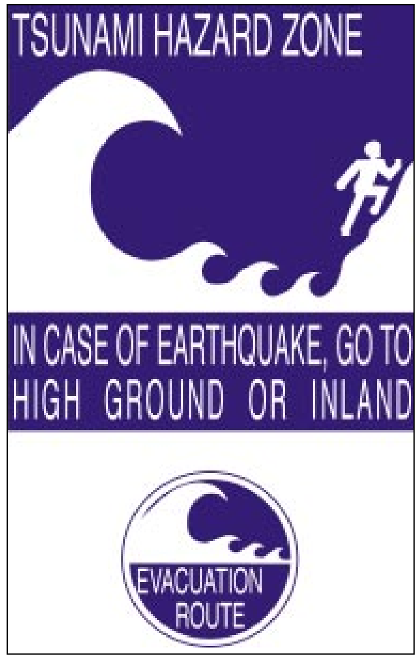
At least one segment of the Cascadia subduction zone may be approaching the end of a seismic cycle that culminates in an earthquake and destructive tsunami [see "Giant Earthquakes of the Pacific Northwest," by Roy D. Hyndman; SCIENTIFIC AMERICAN, December 1995]. The earthquake danger is believed to be comparable to that in southern California—about a 35 percent probability of occurrence before 2045. Finally, the 1992 Cape Mendocino earthquake and tsunami was a clear reminder that the Cascadia subduction zone can unleash local tsunamis that strike the coast within minutes.

Getting Ready in the U.S.

Hard on the heels of the surprising Cape Mendocino tsunami, the Federal Emergency Management Agency (FEMA) and NOAA funded an earthquake scenario study of northern California and the production of tsunami inundation maps for Eureka and Crescent City in that state. The resulting "all hazards" map was the first of its kind for the U.S. It delineates areas susceptible to tsunami flooding, earthquake-shaking intensity, liquefaction and landslides. Researchers then tackled the possible effects of a great Cascadia subduction zone earthquake and tsunami. About 300,000 people live or work in nearby coastal regions, and at least as many tourists travel through these areas every year. Local tsunami waves could strike communities within minutes of a big quake, leaving little or no time to issue formal warnings. What is more, a Cascadia-born tsunami disaster could cost the region between $1.25 billion and $6.25 billion, a conservative estimate considering the 1993 Okushiri disaster.

Clarification of the threat from the Cascadia subduction zone and the many well-reported tsunami disasters of this decade have stimulated a systematic effort to examine the tsunami hazard in the U.S. In 1997 Congress provided $2.3 million to establish the National Tsunami Hazard Mitigation Program. Alaska, California, Hawaii, Oregon and Washington formed a partnership with NOAA, FEMA and the USGS to tackle the threat of both local- and remote-source tsunamis. The partnership focuses on three interlocking activities: assessing the threat to specific coastal areas; improving early detection of tsunamis and their potential danger; and educating communities to ensure an appropriate response when a tsunami strikes.

The threat to specific coastal areas can be assessed by means of tsunami inundation maps such as those designed for Eureka and Crescent City using state-of-the-art computer modeling. These maps provide critical guidance to local emergency planners charged with identifying evacuation routes. Only Hawaii has systematically developed such maps



OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

COMMUNITY EDUCATION is crucial to the recent U.S. push to avoid future tsunami disasters. Signs, standardized for all Pacific states, now alert coastal dwellers and visitors to tsunami-prone areas.

over the years. To date, three Oregon communities have received maps, six additional maps are in progress in Oregon, Washington and California, and three maps are planned for Alaska.

Rapid, reliable confirmation of the existence of a potentially dangerous tsunami is essential to officials responsible for sounding alarms. Coastal tide gauges have been specially modified to measure tsunamis, and a major upgrade of the seismic network will soon provide more rapid and more complete reports on the nature of the earthquake. These instruments are essential to the warning system, but seismometers measure earthquakes, not tsunamis. And although tide gauges spot tsunamis close to shore, they cannot measure tsunami energy propagating toward a distant coastline. As a consequence, an unacceptable 75 percent false-alarm rate has prevailed since the 1950s. These incidents are expensive, undermine the credibility of the warning system, and place citizens at risk during the evacuation. A false alarm that triggered the evacuation of Honolulu on May 7, 1986, cost Hawaii more than $30 million in lost salaries and business revenues.

NOAA is therefore developing a network of six deep-ocean reporting stations that can track tsunamis and report them in real time, a project known as

Not the First, Not the Last

East Aleutian Islands

April 1, 1946
Maximum wave height: 35 meters
Fatalities: 165

A rash of tsunamis has struck the Pacific Rim this decade, but destructive waves have made their mark long before now. Earthquakes along a seismic subduction zone off Alaska's Aleutian Islands have stirred up the worst tsunamis in U.S. recorded history. On April 1, 1946, a magnitude 7.8 earthquake generated a tsunami that wiped out the Scotch Cap Lighthouse in Alaska and killed five Coast Guard employees. The same tsunami also made a surprise attack five hours later on residents of Hilo, Hawaii. There debris-laden waves up to eight meters high caught a number of schoolchildren before classes began and wiped out a hospital. Altogether the killer waves took the lives of 165 people, 159 of them in Hawaii, and caused more than $26 million in damage.

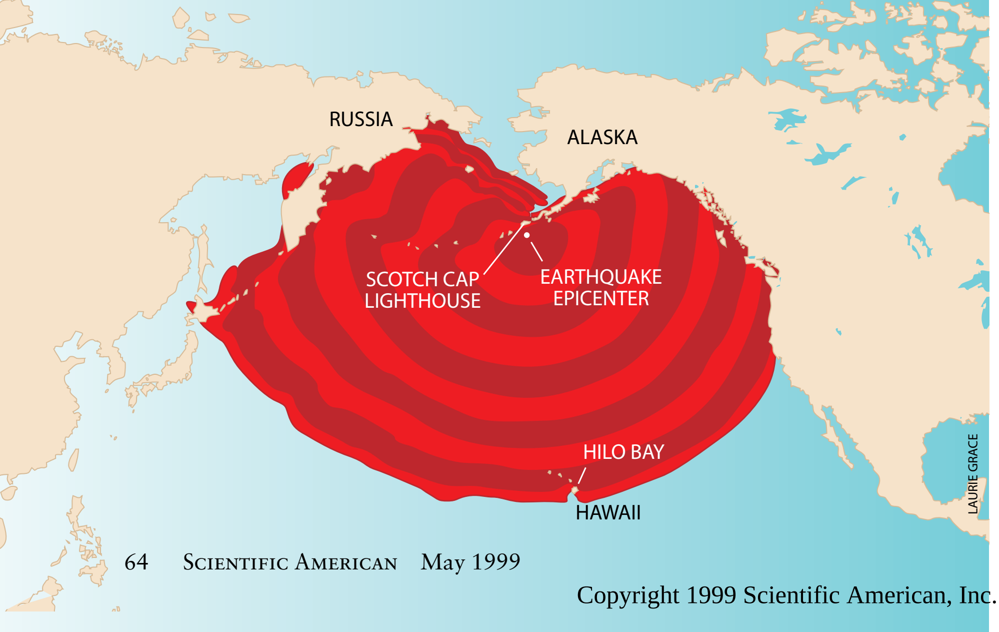
The U.S. reacted to this disaster by setting up the Pacific Tsunami Warning Center in Hawaii in 1948. Similarly, three years after the March 28, 1964, Alaskan tsunami that took more than 100 lives, the Alaska Regional Tsunami Warning System (now the West Coast and Alaska Tsunami Warning Center) was established. Today a newly recognized threat from a seismic zone off the West Coast has driven the U.S. to take action against a tsunami disaster *before* it occurs. This endeavor by state and federal partners features a systematic tsunami inundation mapping program, a state-of-the-art, deep-ocean tsunami detection network and educational campaigns to prepare coastal communities for a potential disaster. —*F.G.*

PHOTOGRAPHS BY CORBIS

Flattened parking meters in Hilo, Hawaii

Scotch Cap Lighthouse before tsunami

Scotch Cap Lighthouse after tsunami



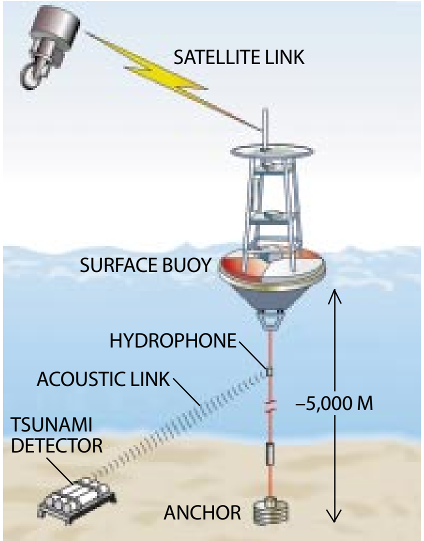
LAURIE GRACE

Deep-Ocean Assessment and Reporting of Tsunamis (DART). Scientists have completed testing of prototype systems and expect the network to be operating reliably in two years. The rationale for this type of warning system is simple: if an earthquake strikes off the coast of Alaska while you're lying on a Hawaiian beach, what you really want to have between you and the quake's epicenter is a DART system. Here's why:

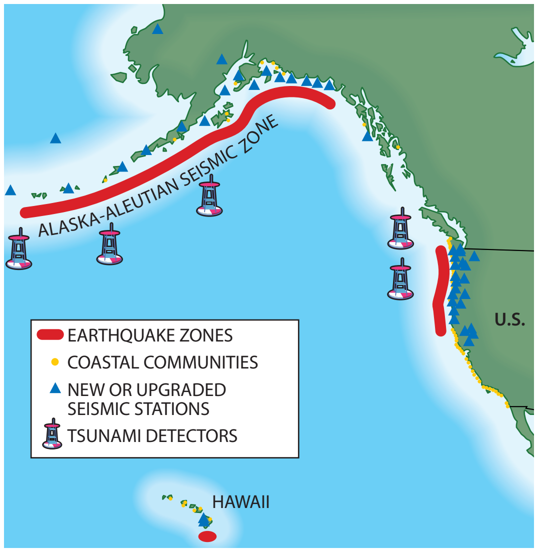
Seismometers staked out around the Pacific Rim can almost instantly pinpoint a big Alaskan quake's location. In the next moment, complex computer programs can predict how long a triggered tsunami would take to reach Hawaii, even though there is not yet evidence a wave exists. After some minutes, tide gauges scattered along the coastlines may detect a tsunami. But the only way to be sure whether a dangerous wave is headed toward a distant coast is to place tsunami detectors in its path and track it across the open ocean.

Conceptually, the idea of such a real-time reporting network is straightforward; however, formidable technological and logistical challenges have held up implementation until now. The DART systems depend on bottom pressure recorders that Hugh B. Milburn, Alex Nakamura, Eddie N. Bernard and I have been perfecting over the past decade at the Pacific Marine Environmental Laboratory. As the crest of a tsunami wave passes by, the bottom recorder detects the increased pressure from the additional volume of overlying water. Even 6,000 meters deep, the sensitive instrument can detect a tsunami no higher than a single centimeter. Ship and storm waves are not detected, because their length is short and, as with currents, changes in pressure are not transmitted all the way to the ocean bottom. We placed the first recorders on the north Pacific seafloor in 1986 and have been using them to record tsunamis ever since. The records cannot be accessed, however, until the instruments are retrieved.

Ideally, when the bottom recorders detect a tsunami, acoustic chirps will transmit the measurements to a car-size buoy at the ocean surface, which will then relay the information to a ground station via satellite. The surface buoy systems, the satellite relay technology and the bottom recorders have proved themselves at numerous deep-ocean stations, including an array of 70 weather buoys set up along the equator to track



ILLUSTRATIONS BY ARIES GALINDO AND LAURIE GRACE



MICHELE G. BULLOCK *NOAA Corps*

DEEP-OCEAN TSUNAMI DETECTORS (*left*) and a major upgrade of existing earthquake monitoring networks (*blue triangles on map*)—both scheduled for installation within two years—lead the U.S. effort to take the surprise out of tsunami attacks. The deep-ocean detectors depend on high-tech sensors stationed on the seafloor. When one of these instruments senses a tsunami wave overhead, it will send acoustic signals to a buoy at the surface, such as the one being launched in the photograph, which will then relay the warning via satellite to the officials who are responsible for sounding an alarm.

El Niño, the oceanographic phenomenon so infamous for its effect on world climate. The biggest challenge has been developing a reliable acoustic transmission system. Over the past three years, four prototype DART systems have been deployed, worked for a time, then failed. Design improvements to a second-generation system have refined communication between the bottom recorders and the buoys.

In the next two years, our laboratory plans to establish five stations spread across the north Pacific from the west Aleutians to Oregon and a sixth sited on the equator to intercept tsunamis generated off South America. More buoys would reduce the possibility that tsunami waves might sneak between them, but the current budget limits the number that NOAA can afford. This is where detailed computer simulations become invaluable. Combined with the buoy measurements, the simulations will provide more accurate predictions to guide officials who may have only a few minutes to decide whether to sound an alarm.

Even the most reliable warning is ineffective if people do not respond appropriately. Community education is thus perhaps the most important aspect of the national mitigation program's threefold mission. Each state is identifying coordinators who will provide information and guidance to community emergency managers during tsunami disasters. Interstate coordination is also crucial to public safety because U.S. citizens are highly mobile, and procedures must be compatible from state to state. Standard tsunami signage has already been put in place along many coastlines.

Tsunami researchers and emergency response officials agree that future destructive tsunamis are inevitable and technology alone cannot save lives. Coastal inhabitants must be able to recognize the signs of a possible tsunami—such as strong, prolonged ground shaking—and know that they should seek higher ground immediately. Coastal communities need inundation maps that identify far in advance what areas are likely to be flooded so that they can lay out evacuation routes. The proactive enterprise now under way in the U.S. will surely upgrade tsunami prediction for a much larger region of the Pacific. All of these efforts are essential to the overriding goal of avoiding tragedies such as those in Papua New Guinea, Nicaragua and elsewhere. SA

The Author

FRANK I. GONZÁLEZ is Tsunami Research Program Leader and Director of the Center for Tsunami Inundation Mapping Efforts at NOAA's Pacific Marine Environmental Laboratory in Seattle. He earned his Ph.D. in physical oceanography from the University of Hawaii in 1975 and joined the laboratory two years later. In 1984 he received NOAA's highest award for outstanding scientific research—the NOAA Administrator's Award—for his work on hazardous ocean waves. He has participated in field surveys and documentation of three devastating tsunamis that recently occurred in Nicaragua, Indonesia and Japan. The author dedicates this article to the memory of his wife, Yolanda Cano González. In his words: "Yolanda was well known by many in the tsunami research community. She was a gifted, award-winning teacher who loved children, gardening, science and, wondrously, me. As she loved and nurtured her gardens, Yolanda loved and nurtured her students and their enthusiasm for science."

Further Reading

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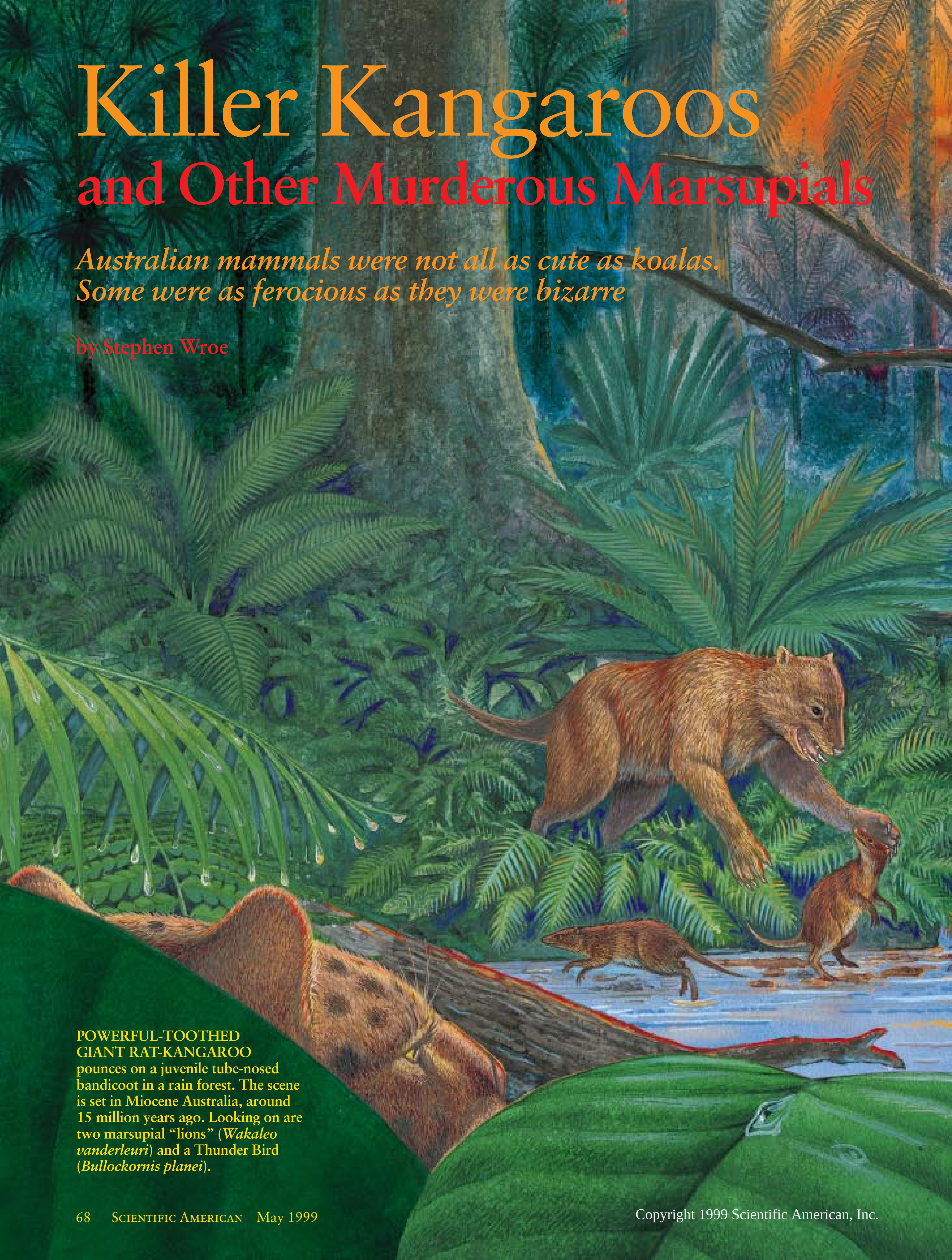
Additional information on tsunamis can be found at http://www.pmel.noaa/tsunami/ on the World Wide Web.

Killer Kangaroos
and Other Murderous Marsupials

Australian mammals were not all as cute as koalas. Some were as ferocious as they were bizarre

by Stephen Wroe



POWERFUL-TOOTHED GIANT RAT-KANGAROO pounces on a juvenile tube-nosed bandicoot in a rain forest. The scene is set in Miocene Australia, around 15 million years ago. Looking on are two marsupial "lions" (*Wakaleo vanderleuri*) and a Thunder Bird (*Bullockornis planei*).

ROBERTO OSTI

Dawn mist blankets the rain forest of Riversleigh in northeastern Australia, 15 million years ago. A bandicoot family emerges to dip snouts warily into a shallow freshwater pool. Their ears swivel, ever alert to a sudden crack or rustle in the undergrowth: drinking is always a dangerous activity. Suddenly, a dark, muscular form explodes from behind a nearby bush, colliding with a young bandicoot in one bound. The shaggy phantom impales its victim on long, daggerlike teeth, carrying the carcass to a quiet nook to be dismembered and eaten at leisure.

In nature, many animals will meet a violent death. So the sad end of one small bandicoot seems hardly worth mention. The demise of this little fellow would, however, have surprised most modern onlookers. Its killer was a kangaroo—the Powerful-Toothed Giant Rat-kangaroo (*Ekaltadeta ima*), to be exact.

In 20th-century Australia, warm-blooded predators are few and far between. Among our natives, the largest carnivores are the Spotted-Tailed Quoll (*Dasyurus maculatus*) and the Tasmanian Devil (*Sarcophilus harrisii*). (The doglike dingo, which also eats flesh, did not originate in Australia but was introduced by humans between 5,000 and 4,000 years ago.) The Spotted-Tailed Quoll is a marsupial that weighs up to seven kilograms (15 pounds); it is also known as a native "cat" because of a passing resemblance to ordinary, placental cats. The Tasmanian Devil, another marsupial, is only slightly larger and looks like a lapdog with a fierce hyena's head. It is arguably the least fussy eater in the world and will devour an entire carcass, including the teeth. This odd pair is placed in the family Dasyuridae, which includes other native cats as well as far smaller, mostly insectivorous creatures called marsupial mice.

Some scientists have suggested that Australia has never supported a healthy contingent of large warm-blooded carnivores. Most recently, Tim Flannery of Harvard University has argued that their evolution was constrained by poor soils and erratic climate for the past 20 million years or so. His rationale is that these constraints limited plant biomass, in turn restricting the size and abundance of potential prey animals. Instead, he and others have hypothesized, reptiles such as the seven-meter-long (23-foot-long) lizard *Megalania prisca,* which lived in Pleistocene times, took up the role of large terrestrial carnivores. Cold-blooded predators require less food than warm-blooded ones and so—the argument goes—were more likely to survive difficult conditions.

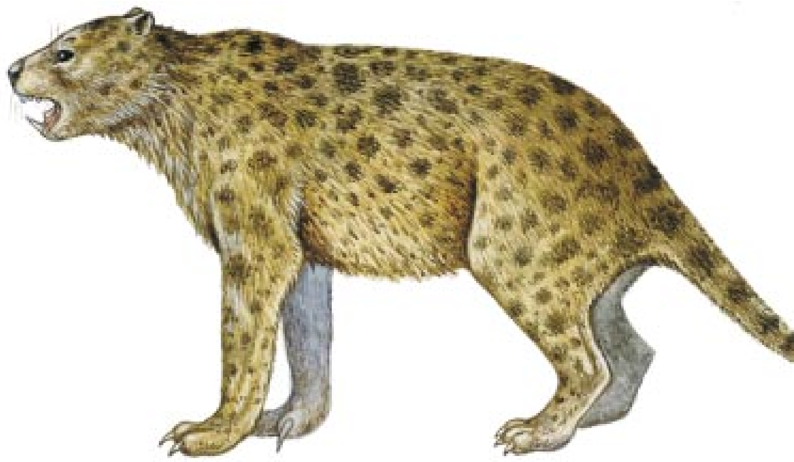
This claim is challenged by recent developments, notably spectacular fossil finds in Riversleigh, Queensland. A European naturalist, W. E. Cameron, first noted the presence of fossils at this remote site in 1900. But Cameron believed that the material he had seen was fairly young, less than two million years old. Moreover, Riversleigh's extreme inaccessibility—summer heat and monsoon rains allow excavations only in winter—persuaded paleontologists to neglect the locality for decades. In 1963, however, Richard Tedford of the American Museum of Natural History in New York City and Alan R. Lloyd of the Australian Bureau of Mineral Resources took a gamble and visited the site. They found the fossils intriguing and older than previously believed but fragmentary and hard to retrieve.

Still, their findings stimulated other expeditions to Riversleigh, and in 1983 my former supervisor Michael Archer, now director of the Australian Museum in Sydney, struck paleo pay dirt. In an idle moment at the site he looked down at his feet and saw a very large lump of rock that just happened to contain as many new species of Australian Tertiary mammals as had been described in previous centuries. Since then, new specimens, including large carnivores, have emerged at a prodigious rate. Many are exquisitely well preserved, so much so that some could be mistaken for the remains of animals that died only weeks ago.

Predator's Gallery

Formidable flesh-eaters from ancient Australia included a marsupial lion (*below*), a marsupial wolf (*near right*), a giant rat-kangaroo (*far right*) and an enormous lizard (*below, right*). The largest rat-kangaroo, *Propleopus oscillans* (which weighed 60 kilograms), the "lion" and the lizard survived until fairly recent times and may have even preyed on humans. —*S.W.*

ILLUSTRATIONS BY ROBERTO OSTI AND ANNE MUSSER

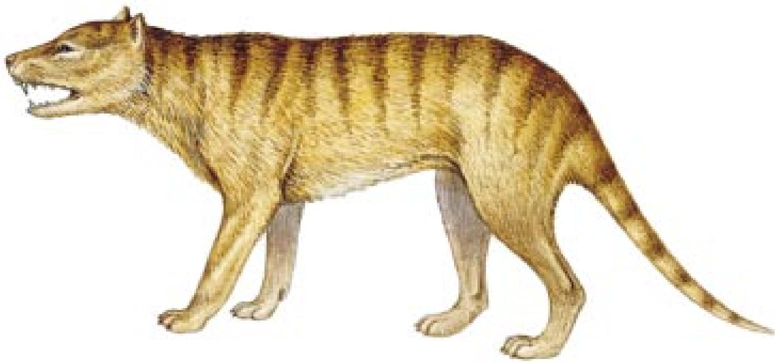


LARGEST MARSUPIAL LION
(*Thylacoleo carnifex*)
130 TO 260 KILOGRAMS

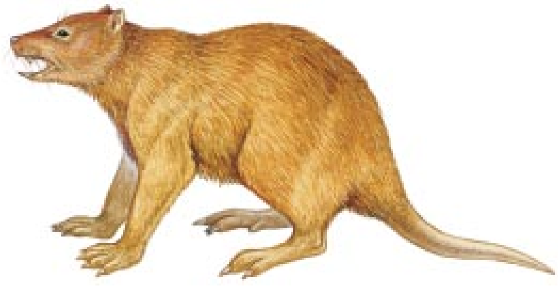
The ancient creatures appear to have been mostly trapped in limestone caves. Their bones, which were quickly and perfectly preserved by water rich in calcium carbonate, testify to a lost menagerie of beasts that were every bit as deadly as, but far stranger than, anything known today. Since 1985 nine new species from Riversleigh, each the size of the Spotted-Tailed Quoll or bigger, have more than doubled the tally of large Australian carnivores at least five million years old. This bestiary now includes two kinds of giant rat-kangaroo, nine species of marsupial "wolf," five species of marsupial "lion" and one native cat.

The giant rat-kangaroos (propleopines) are closely related to the Musky Rat-kangaroo. This tiny animal, still found in the rain forests of Queensland, weighs less than a kilogram—small enough to look like a rat. It eats a wide variety of plant stuffs and small animals, and alone among living kangaroos it cannot hop. A living fossil, it is the last and tiniest survivor of a family that included some fearsome, muscle-bound cousins. The giant rat-kangaroos ranged from around 15 to 60 kilograms in weight. Like their diminutive descendant, they probably walked on all fours.

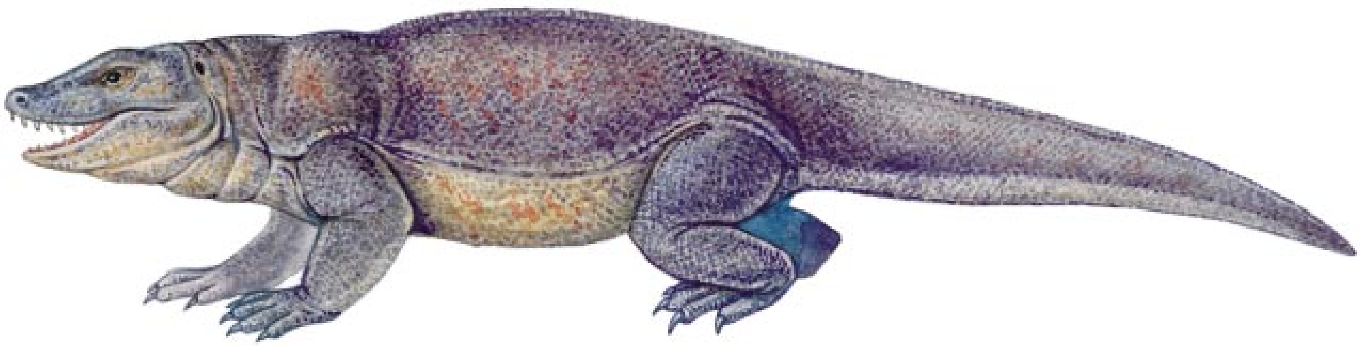
The marsupial wolves (thylacinids) and marsupial lions (thylacoleonids) are so named because of their superficial physical resemblances to canines and felines, although they were more closely related to kangaroos. The last of the marsupial wolves, perhaps confusingly called the Tasmanian Tiger because of the stripes on its rump, was exterminated early in this century because of a largely undeserved reputation for preying on sheep. Like cats, the marsupial lions had short, broad, powerful skulls, and they probably filled simi-



LARGEST MARSUPIAL WOLF
(*Thylacinus potens*)
MAXIMUM 45 KILOGRAMS



POWERFUL-TOOTHED
GIANT RAT-KANGAROO
(*Ekaltadeta ima*)
20 KILOGRAMS



GIANT MONITOR LIZARD
(*Megalania prisca*)
620 KILOGRAMS

lar ecological niches as well; their size ranged from that of a house cat to that of a lion. Although no fossils contain actual traces of a pouch, specialized features of the bones shared with living animals leave no doubt that all these creatures were marsupials.

Fearsome Forest

For much of the Miocene epoch (25 to five million years ago), Australia was carpeted in wall-to-wall green, and rain forest covered many areas that are now savanna or desert. These jungles were an evolutionary powerhouse, nurturing a far greater diversity of life than any modern Australian habitat does. A day trip through one of these forests would have been filled with surprises, many of them potentially dangerous.

One would have been the Powerful-Toothed Giant Rat-kangaroo, among the most ancient of rat-kangaroos (another five species have been described from younger deposits). *E. ima* was also the smallest, weighing only about 10 to 20 kilograms. It is well represented by two nearly complete skulls. These fossils give us our best shot yet at understanding the feeding habits of the giant rat-kangaroos.

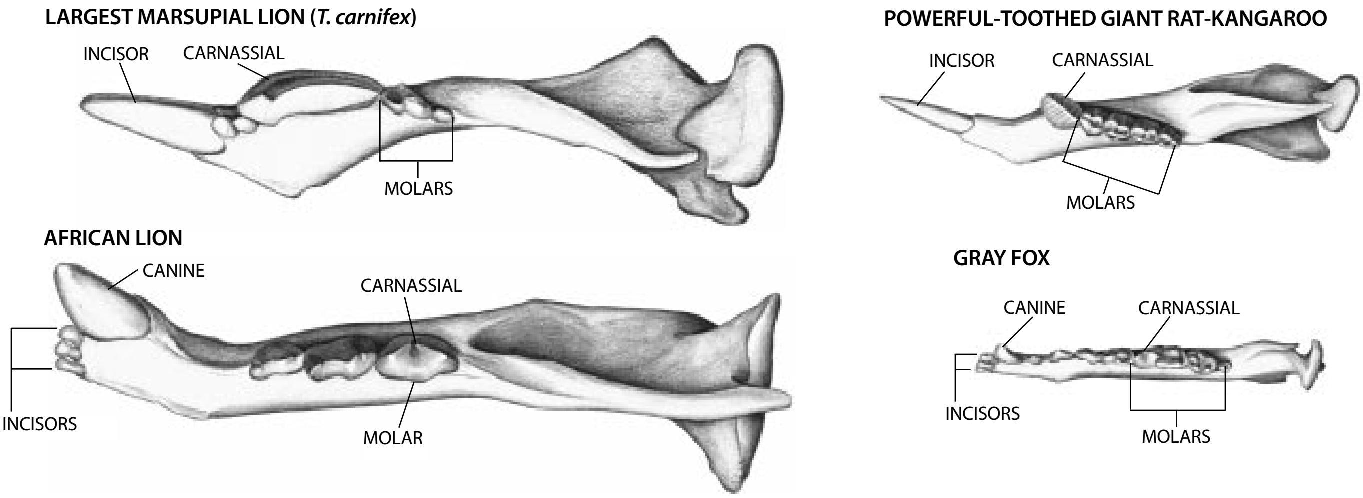
Because these animals descended from plant-eating marsupials, some controversy surrounds the interpretation of their biology. Nevertheless, all recent authors agree that these distinctly uncuddly kangaroos included meat in their diets. Evidence supporting this hypothesis comes from both their skulls and their teeth.

In popular imagination, ferocious meat-eaters usually come with large canines. In the main this holds true, but there are some exceptions. Many humans consume a good deal of flesh—more than some so-called carnivores—but we have small canines, whereas in gorillas, which are vegetarians, these teeth are large. The real hallmark of a terrestrial mammalian killer is a set of distinctive cheek teeth used for cutting and shearing.

In less specialized members of the placental carnivore, giant rat-kangaroo and marsupial lion clans, the last two to four teeth in the upper and lower jaws are broad molars, used primarily for crushing plant material. Immediately in front of these molars are vertical shearing blades, called carnassials, that can efficiently slice through muscle, hide and sinew. Within each of these three groups of animals, however, the carnassials of the most carnivorous species are greatly enlarged, whereas the plant-processing teeth are reduced, even lost. In the mouth of a domestic cat, for instance, can be found the cheek teeth of a highly specialized carnivore.

So the relative importance of the carnassial versus the crushing teeth in an animal's jaws offers a good indication of how much flesh it devoured. In this respect, the giant rat-kangaroos resembled canids such as foxes, which are opportunistic feeders and retain significant capacity to crush. But the skull of *E. ima* featured a number of other attributes typical of carnivores. Its robust architecture, for instance, undoubtedly supported the massive neck and jaw muscles that many predators need to subdue struggling prey. But it never evolved long canines in the lower jaw; instead its lower front incisors became daggerlike blades.

On these grounds, I and others have argued that giant rat-kangaroos were generalists, taking flesh when available but



ANNE MUSSER

CARNASSIAL TEETH—vertical blades for slicing through meat and hide—are the hallmark of a terrestrial mammalian killer. In highly specialized carnivores such as the marsupial lion and the African lion shown, a single tooth on each side of the upper and lower jaws has been modified for this task; all the molars behind this carnassial are reduced or lost. (Only the lower jaw is drawn.) Generalized carnivores, such as the giant rat-kangaroos and foxes, which consume much vegetation, retain their crushing molars.

supplementing their diet with a healthy variety of vegetable matter. These renegades of the kangaroo clan terrorized the Australian continent for at least 25 million years, going extinct only sometime over the past 40,000 years.

While keeping an eye open for meat-eating kangaroos, a human intruder in Miocene Australia would have done well to avoid low-slung branches. The trees were home to another unpleasant surprise: marsupial lions. Like the giant rat-kangaroos, the four species of Miocene "lions" evolved from peaceable, plant-eating types. The most primitive species have generalized molar teeth typical of omnivores, as well as carnassial blades. In other species the crushing molars are reduced or lost, and the flesh-shearing teeth become huge.

At least eight species of marsupial lions have been formally described, and two more are being studied by Anna Gillespie of the University of New South Wales in Sydney. Historically, the interpretation of marsupial lion biology has been contentious. As vombatomorphian marsupials, their closest living relatives are koalas and wombats. Some early paleontologists, prejudiced by the close relationship of these "lions" to herbivorous marsupials, refused to concede the possibility of a carnivorous way of life for them. They offered a variety of unlikely scenarios, culminating in the suggestion that the creatures were specialized melon munchers. (Because the teeth could barely grind, the food was assumed to have been rather soft!)

Nowadays scientists agree that marsupial lions were indeed killers. Many consider that the most recent species, *Thylacoleo carnifex,* was the most specialized mammalian carnivore ever known: it effectively dispensed with plant-processing teeth, whereas the elaboration of its carnassials is unparalleled. It did not have big canines and must have used its long incisors to kill.

T. carnifex is also the only marsupial lion known from a complete skeleton. Many researchers have suggested that it was the size of a large wolf or leopard. Others, myself in-

NORMAN O. TOMALIN *Bruce Coleman Inc.*

JOHN CANCALOSI *Peter Arnold, Inc.*

LAST REMNANTS of a once extensive menagerie of Australian predators, such as the Tasmanian Devil (*left*), do not lack in ferocity. The Spotted-Tailed Quoll (*right*) is a native "cat," whereas the Musky Rat-kangaroo (*above*) is the end of a line reaching back to the carnivorous giant rat-kangaroos.

ERWIN AND PEGGY BAUER *Bruce Coleman Inc.*

FOSSIL SKULL of the Powerful-Toothed Giant Rat-kangaroo displays the fearsome incisors and serrated carnassials (resembling cockleshells) that would have enabled it to kill and consume its prey efficiently. The skull measures 145 millimeters from end to end, and the lower jaw is 122 millimeters.

cluded, believe that such estimates have not accounted for the extreme robustness of the skeleton and that this frightening beast could have been as heavy as a modern lion. It was built for power, not endurance, and had tremendously muscular forelimbs. With teeth like bolt-cutters and a huge, sheathed, switchbladelike claw on the end of each semiopposable thumb, it would have been an awesome predator on any continent.

Pouched Pouncers

Undoubtedly, *T. carnifex* was adapted to take relatively large prey, probably much larger than itself. The exact purpose to which it put its thumb-claw is unclear, but one thing seems certain: once caught in the overpowering embrace of a large marsupial lion, few animals would have survived.

The kinds of marsupial lion known as *Wakaleo* were smaller, about the size of a leopard. Not designed for speed but immensely powerful, species of *Wakaleo* (and possibly *Thylacoleo*) may have specialized in aerial assault. Like the leopard, they could have launched themselves onto unsuspecting prey from trees. At the other end of the scale, at around the size of a domestic cat, *Priscileo roskellyae* may have concentrated on taking arboreal prey. Given their size and extreme predatory adaptations, I believe the larger marsupial lions most likely maintained a position at the top of the Australian food pyramid. And *T. carnifex* lived at least until 50,000 years ago—recently enough, perhaps, to have fed on humans.

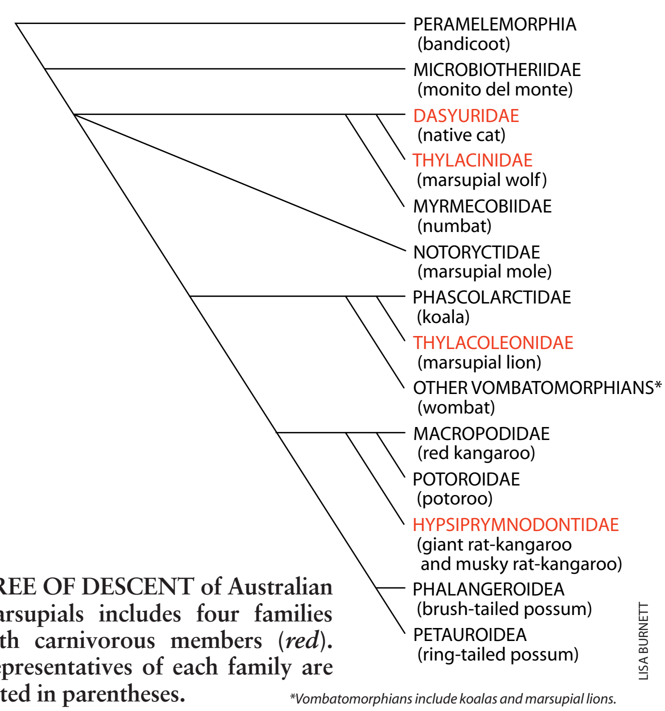
On the forest floor, the marsupial wolves dominated. When Europeans arrived in Australia more than 200 years ago, they found only two marsupial families with carnivorous representatives. These were the "wolves"—only the Tasmanian Tiger remained—and a far more numerous group, the dasyurids. These mostly diminutive but pugnacious beasts are commonly measured in grams, not kilograms, and over 60 living species have been described.

Because in recent times dasyurids have clearly dominated in terms of species diversity, paleontologists had expected to find that they were also far more common than thylacinids in the distant past. We were wrong. Since 1990 seven new species of Miocene-age "wolves" have been found, bringing the total for the family to nine (including the Tasmanian Tiger). Descriptions of four more species are in the pipeline. On the other hand, only one definite dasyurid has been described from Miocene deposits. A few species known from fragmentary material may also turn out to be dasyurids. Even so, the proportion of marsupial wolf to dasyurid species during the Miocene is in stark contrast to that of modern times.

The Tasmanian Tiger is the only thylacinid for which any firsthand accounts of biology and behavior are available. Most of these must be taken with a grain of salt. But the following is fairly certain: the Tasmanian Tiger was similar to most canids in that it was fully terrestrial, long-snouted and probably tended to take prey considerably smaller than itself. It differed in being relatively poorly adapted for running and probably was not a pack hunter. It further differed from the majority of canids in that its cheek teeth were adapted to a completely carnivorous diet.

In thylacinids and dasyurids the dental layout is different from that of most other flesh-eaters. These animals retain both a crushing and a vertical-slicing capacity on each individual molar. Thus, in meat-eating specialists of this type the crushing surfaces are reduced and the vertical shear is increased on each molar tooth.

Indeed, all the marsupial wolves were largely carnivorous, although the smaller, less specialized ones probably also ate insects. A number of these animals departed still further from the canid model. Some Miocene "wolves" were small compared with the Tasmanian Tiger, and one, *Wabulacinus ridei,* had a short, more catlike skull. We cannot even be sure that all Miocene-age thylacinids were terrestrial, because only fragments of the skulls and jaws are known for most. A magnificent exception is a 15-million-year-old individual recently discovered at Riversleigh; its skull and most of its



TREE OF DESCENT of Australian marsupials includes four families with carnivorous members (*red*). Representatives of each family are noted in parentheses.

A Killer Bird?

In November 1998 Peter Murray and Dirk Megirian of the Central Australian Museum described new fossil material from an extinct, terrestrial bird called *Bullockornis planei*. This species belongs to the Australian family Dromornithidae, also called Thunder Birds, known since 1839. Dromornithids could be huge, some weighing perhaps 500 kilograms or more. But with very limited skull material preserved, little that was certain could be said about their biology. Given the paucity of material and the generally accepted view that dromornithids were closely related to predominantly plant-eating birds, most scientists were of the view that these giants were herbivores. But Murray's excellent reconstruction of *B. planei* is startling, showing a massive head possibly more than half a meter long. Furthermore, the muscle attachment sites were enormous. What did a half-ton bird with military-grade jaw muscles and a beak that could hide a football eat?

In 1991 Lawrence M. Witmer, now at Ohio University's College of Osteopathic Medicine, and Kenneth D. Rose of the Johns Hopkins University School of Medicine convincingly argued that the massive beak and jaw musculature of *Diatryma,* an extinct bird from North America and Europe, would have constituted serious "overdesign" unless the bird was a carnivore. Following this line of reasoning, I have lately suggested that at least some dromornithids might similarly have eaten vertebrates, killed or scavenged. If so, Thunder Birds were the largest carnivores on two legs since the demise of the meat-eating dinosaurs. —*S.W.*

skeleton are beautifully preserved. We can be reasonably certain that this animal at least lived on firm ground.

In the past few months Henk Godthelp of the University of New South Wales, Archer and I have described a mouse-size marsupial from deposits around 55 million years old in Murgon in southeastern Queensland. This new species has an extremely generalized dentition, so primitive in fact that its relation to other marsupials is very difficult to ascertain. It may represent an ancestor of thylacinids and dasyurids—or even of all Australian marsupials. An alternative possibility is that this new species does not belong to Australidelphia (a taxonomic category that contains all living Australian marsupials) but instead to the mostly South American group Ameridelphia.

South America and Australia were once joined together in the continent of Gondwana, via Antarctica. And marsupials are believed to have arrived in Australia from South America. Some scientists have suggested that only Australidelphian mammals entered Australia before Gondwana completely broke up. In light of the new fossil finding, this conclusion could be premature.

Death to Killers

Having established that Australia's large marsupial carnivores were very diverse during the Miocene period, paleontologists are now faced with this question: What happened to them? The last of the marsupial lions and giant rat-kangaroos (*T. carnifex* and *Propleopus oscillans,* respectively) died out not so long ago. In fact, they were probably around when the first Aborigines entered Australia, 50,000 or more years ago. Consequently, some scientists have maintained that it was the first humans who sounded their death knell.

Human culpability in this matter has been impossible to prove or disprove and remains a very contentious issue. No doubt the Aborigines helped to drive the Tasmanian Tiger to extinction by introducing the dingo, but their influence regarding other species is less clear-cut. These issues may never be completely resolved, but the fossil record makes one fact clear: marsupial carnivore diversity peaked by the early to middle Miocene and was already in steep decline long before humans arrived. For example, at least five marsupial wolves lived during the mid-Miocene, and two coexisted in the late Miocene, but only one was ever known to humans.

Obviously, some factor other than human influence was at work; perhaps Aborigines simply accelerated an extinction process already long established. The most likely alternative candidate is drought. From mid-Miocene times onward, Australia was subject to increasingly severe ice age conditions as well as declining rainfall and sea levels. This trend peaked over the past two million years or so, with around 20 ice ages exposing the Australian fauna to great stress. The last of these was severe, though not the worst.

Many researchers believe some combination of climate change and pressure imposed by human arrivals extinguished most of the continent's surviving larger herbivores. With their favorite meat dishes gone, the clock began to run out on Australia's marsupial predators. It is now a sad fact that of the dozens of wondrous large marsupial carnivores that have existed, not only in Australia but in the Americas as well, only our own Spotted-Tailed Quoll and Tasmanian Devil remain. Nonindigenous Australians must accept full responsibility for the inexcusable loss of the Tasmanian Tiger, and posterity will surely never forgive us should we allow the same fate to befall our last two pouched killers. SA

The Author

STEPHEN WROE recently received his Ph.D. in paleontology from the University of New South Wales in Sydney. He has published widely on the evolution of Australian marsupial carnivores, living and extinct. His areas of special interest include all aspects of the giant rat-kangaroo and dasyuromorphian marsupial radiations, as well as the biology of giant dromornithid birds and marsupial lions. The illustrations are based on reconstructions by Anne Musser of UNSW.

Further Reading

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The Geologically Oldest Dasyurid, from the Miocene of Riversleigh, Northwestern Queensland. S. Wroe in *Palaeontology* (in press).

The Riversleigh Society Australian Paleontology site is at www.ozemail.com.au/~promote1/auspalaeo/index.html on the World Wide Web.

Ada and the First Computer

The collaboration between Ada, countess of Lovelace, and computer pioneer Charles Babbage resulted in a landmark publication that described how to program the world's first computer

by Eugene Eric Kim and Betty Alexandra Toole

People called Augusta Ada King's father "mad and bad" for his wild ways, but he was better known as Lord Byron, the poet. Ada inherited her famous father's way with words and his zest for life. She was a beautiful, flirtatious woman who hobnobbed with England's elite and who died at the youthful age of 36, the same age at which her father died. And like Byron, Ada is best known for something she wrote.

In 1843 she published an influential set of notes that described Charles Babbage's Analytical Engine, the first automatic, general-purpose computing machine ever designed. Although the Analytical Engine was never built—largely because Babbage could not raise the funds for its construction—Ada's notes included a program for using it to compute a series of figures called Bernoulli numbers [*see box on page 78*].

Ada's notes established her importance in computer science, but her fascinating life and lineage—and her role as a female pioneer in a field in which women have always been notoriously underrepresented—have lately turned her into an icon. In addition to numerous biographies, she has inspired plays and novels written by the likes of such luminaries as Tom Stoppard and Arthur C. Clarke. *Conceiving Ada,* a movie loosely based on her life, was released by Fox Lorber in February. And whereas many women have helped to advance computer science, only Ada has had a computer language named after her; it is used largely for military and aerospace applications.

Not surprisingly, Ada's contributions to computer science have been both embellished and diminished, and her true legacy has elicited controversy among historians in the field. Many people, for instance, incorrectly claim that Ada was the first computer programmer. (Babbage, not Ada, wrote the first programs for his Analytical Engine, although most were never published.) Others unfairly challenge Ada's authorship of the program included in the notes and even of the notes themselves.

As with most things, the truth lies somewhere in the middle. Babbage characterized Ada's contributions best when he referred to her as his "interpretress." He did discuss the notes with Ada and reviewed early drafts, but there can be no question that she herself was the author. And whereas Babbage's groundbreaking work formed the basis of Ada's notes and her thinking, her lucid writing revealed unique insight into the significance and the many possibilities of the Analytical Engine.

A Young Mathematician

Augusta Ada Byron was born on December 10, 1815, in London; she was the daughter of Lord Byron and his wife of 11 months, mathematician Annabella Milbanke. By the time Ada was born, Annabella already had reservations about her marriage to Byron. Rumors, most likely started by Annabella's cousin, Caroline Lamb, were circulating that Byron had had an affair with his half-sister, giving Annabella the excuse to separate from him. Byron left England in April 1816, never to see his daughter again.

Lady Byron raised Ada to be a mathematician and a scientist and discouraged her literary leanings, in part to distance her from her father. Ada received an excellent education: she was tutored in mathematics by Mary Somerville, a prominent scientist best known for

ADA LOVELACE sat for this portrait by A. E. Chalôn around 1838, several years after she first met Charles Babbage, the designer of the world's first computer. The inset shows a stamp released in 1991 by the British postal service to commemorate the 200th anniversary of Babbage's birth. The background depicts programming ideas sketched by Babbage. Ada later extended his proposals.

her translations of the works of French mathematician and physicist Pierre-Simon Laplace, and by logician and mathematician Augustus De Morgan.

Ada's mathematical education was unusual at the time, even for someone of noble lineage. While mathematics flourished in continental Europe in the first half of the 19th century, British mathematics was floundering. Mathematicians De Morgan, George Peacock and their college friend Charles Babbage were helping to rejuvenate British mathematics during Ada's youth, but the state of mathematical education for young people—and especially young women—remained poor. Nevertheless, under De Morgan's tutelage, Ada became well schooled in the principles of algebra, logic and calculus.

On June 5, 1833, 17-year-old Ada attended a party where she met Babbage, a 41-year-old widower who was as well known for his political activism and his outrageous ideas as for his work in mathematics and economics. A few weeks after the meeting, Babbage showed Ada his partially completed Difference Engine, an early calculating machine [see "Redeeming Charles Babbage's Mechanical Computer," by Doron D. Swade; SCIENTIFIC AMERICAN, February 1993]. She was captivated. For the next several years, she followed the development of the Difference Engine closely, reading the few published articles on the engine and discussing it with Babbage.

Babbage devised the Difference Engine as a machine that would generate mathematical tables, automating the "mechanical" steps of calculation. Although it was efficient, it was limited computationally. It could perform only addition and subtraction and solve a series of polynomial equations (such as $0 = a + bx + cx^2 + dx^3 \ldots$).

Babbage, however, had already started thinking about bigger and better things. As their friendship deepened, he began outlining to Ada a new machine he was designing, one that would be significantly more advanced than the Difference Engine. He called it the Analytical Engine and spent the remaining 38 years of his life refining the plans for it.

Bernoulli Numbers

The Bernoulli numbers are found in the polynomial expansion of some trigonometric functions that were once employed for constructing navigational tables, among other uses. They are defined as the constant B_n in the polynomial expansion of the expression:

$$\frac{x}{e^x - 1} = \sum_{n \geq 0} B_n \frac{x^n}{n!}$$

For her program, Ada simplified this expression to:

$$0 = -\frac{1}{2}\frac{(2x-1)}{(2x+1)} + B_1 \frac{2x}{2!} + B_2 \frac{(2x)(2x-1)(2x-2)}{4!} +$$

$$B_3 \frac{(2x)(2x-1)(2x-2)(2x-3)(2x-4)}{6!} +$$

$$\ldots + B_n \frac{(2x)(2x-1)\ldots(2x-2n+2)}{(2n)!}$$

To calculate B_n from this expression, start by letting $x = 1$. Notice that the fraction next to B_1 becomes 1 and that the fractions next to B_2, B_3 and so on all equal 0, because each numerator contains the factor $(2x-2)$, which is 0 when $x = 1$. This leaves:

$$0 = \left(-\frac{1}{2} \times \frac{1}{3}\right) + B_1$$

So $B_1 = 1/6$. Now, if you let $x = 2$, the fraction next to B_2 becomes 1, because both the numerator and the denominator are equal to 4! $(4 \times 3 \times 2 \times 1)$, and the fractions next to B_3, B_4 and so on all equal 0, because each numerator contains the factor $(2x-4)$, which is 0 when $x = 2$. The substituted expression is:

$$0 = \left(-\frac{1}{2} \times \frac{3}{5}\right) + (B_1 \times 2) + B_2$$

You already know the value of B_1 from the previous substitution, so you can easily see that $B_2 = -1/30$. The first five Bernoulli numbers are $1/6, -1/30, 1/42, -1/30$ and $5/66$.

For various reasons, the indices Ada used in her program were all odd numbers: B_1, B_3, B_5 and so on, as opposed to B_1, B_2, B_3 and so on. Computing each Bernoulli number one at a time constituted the outer loop of the program, to use modern computer programming parlance. To compute the fractional value next to each Bernoulli number, Ada used a second loop. She started by dividing the first factor of the numerator by the first factor of the denominator and storing that value. She then divided the second factor of the numerator by the second factor of the denominator and multiplied that value by the previously stored value. These steps were repeated until the value of the fraction was completely calculated, at which point it was multiplied by the appropriate Bernoulli number. *—E.E.K. and B.A.T.*

Working with Babbage

According to Babbage's designs, the Analytical Engine would have none of the restrictions of the Difference Engine. Devised to solve general computational problems, it would possess an architecture remarkably similar to that of today's modern computers, consisting of a "store" (memory), a "mill" (central processing unit, or CPU) and a punched-card reader (input device). Babbage intended to rely on punched cards for programming data input (an idea borrowed from the Jacquard loom, which wove patterns automatically by using such cards). The engine's output would take the form of a printed page or punched cards. The Analytical Engine would perform addition, subtraction, multiplication and division. It would be able to execute or repeat a set of instructions based on certain conditions ("if *x*, then *y*"), a central concept in modern computer science known as conditional branching.

In 1840 Babbage made his first and only public presentation on the Analytical Engine to a group of mathematicians and engineers in Turin, Italy. Among those attending was a young mathematician named Luigi Federico Menabrea (Italy's future prime minister), who took notes at the meeting and, with some additional notes from Babbage, published a paper in French entitled "Sketch of the Analytical Engine."

Ada's Scheme for Computing the Bernoulli Numbers

Ada's program for computing B_7, the fourth Bernoulli number, is shown. The first six columns demonstrate the various operations that would be performed by the Analytical Engine, and the remaining columns represent the values of each of the variables. Each row represents a single operation.

When the program begins, there are six variables in use: V_1, V_2, V_3, V_{21}, V_{22} and V_{23} [*see shaded boxes*]. (The superscripts in the chart indicate the number of times the variable has been used.) The values of these variables are 1, 2, n (which in this case is 4, because Ada is calculating B_7, the fourth Bernoulli number), B_1, B_3 and B_5. V_{10} is used to store the number of iterations left to perform. At the first iteration, V_{10} is equal to $n-1$, at the second iteration, V_{10} is equal to $n-2$, and so on. When V_{10} equals 1, the loop stops, and the program is finished computing the Bernoulli number.

The first six operations calculate (½) × (2n–1) / (2n + 1) and store the value in V_{13}. Operation 7 subtracts 1 from n and assigns it to V_{10} because the first iteration is complete. Operations 8, 9 and 10 calculate 2n/2 and multiply it by B_1, which was calculated earlier and stored in V_{21}; they store the value in V_{12}. Operation 11 takes V_{12} and adds it to V_{13}, and operation 12 subtracts 2 from n and stores that value in V_{10}, because the second iteration is complete. Operations 13 through 21 calculate the next value and multiply it by B_5.

One flaw in Ada's program is that she does not use a variable to keep track of each iteration while calculating the fractional values, as she does with V_{10} when she computes the product of the fractions by the previous Bernoulli numbers. Also, note a bug in Ada's program in Operation 21, where the third factor of the denominator should be 4, not 3. —*E.E.K. and B.A.T.*

Diagram for the computation by the Engine of the Numbers of Bernoulli. See Note G. (page 722 *et seq.*)

Number of Operation.	Nature of Operation.	Variables acted upon.	Variables receiving results.	Indication of change in the value on any Variable.	Statement of Results.	Data. $^1V_1$ ○ 0 0 0 1 [1]	Data. $^1V_2$ ○ 0 0 0 2 [2]	Data. $^1V_3$ ○ 0 0 0 4 [n]	Working Variables. $^0V_4$ ○ 0 0 0 0	$^0V_5$ ○ 0 0 0 0	$^0V_6$ ○ 0 0 0 0	$^0V_7$ ○ 0 0 0 0	$^0V_8$ ○ 0 0 0 0	$^0V_9$ ○ 0 0 0 0	$^0V_{10}$ ○ 0 0 0 0	$^0V_{11}$ ○ 0 0 0 0	$^0V_{12}$ ○ 0 0 0 0	$^0V_{13}$ ○ 0 0 0 0	Result Variables. $^1V_{21}$ ○ B_1 in a decimal fraction. [B_1]	$^1V_{22}$ ○ B_3 in a decimal fraction. [B_3]	$^1V_{23}$ ○ B_5 in a decimal fraction. [B_5]	$^0V_{24}$ ... ○ 0 0 0 0 [B_7]
1	×	$^1V_2 \times {}^1V_3$	$^1V_4, {}^1V_5, {}^1V_6$	$\{^1V_2 = {}^1V_2;\ {}^1V_3 = {}^1V_3\}$	$= 2n$	...	2	n	$2n$	$2n$	$2n$											
2	−	$^1V_4 - {}^1V_1$	$^2V_4$	$\{^1V_4 = {}^2V_4;\ {}^1V_1 = {}^1V_1\}$	$= 2n-1$	1	...	...	$2n-1$													
3	+	$^1V_5 + {}^1V_1$	$^2V_5$	$\{^1V_5 = {}^2V_5;\ {}^1V_1 = {}^1V_1\}$	$= 2n+1$	1	...	...	...	$2n+1$												
4	÷	$^2V_5 \div {}^2V_4$	$^1V_{11}$	$\{^2V_5 = {}^0V_5;\ {}^2V_4 = {}^0V_4\}$	$= \frac{2n-1}{2n+1}$	...	...	...	0	0	...	...	...	...	...	$\frac{2n-1}{2n+1}$						
5	÷	$^1V_{11} \div {}^1V_2$	$^2V_{11}$	$\{^1V_{11} = {}^2V_{11};\ {}^1V_2 = {}^1V_2\}$	$= \frac{1}{2} \cdot \frac{2n-1}{2n+1}$	...	2	...	...	...	...	...	...	...	...	$\frac{1}{2} \cdot \frac{2n-1}{2n+1}$						
6	−	$^0V_{13} - {}^2V_{11}$	$^1V_{13}$	$\{^2V_{11} = {}^0V_{11};\ {}^0V_{13} = {}^1V_{13}\}$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$	...	...	...	...	...	...	...	...	...	...	0	....	$-\frac{1}{2} \cdot \frac{2n-1}{2n+1} = A_0$				
7	−	$^1V_3 - {}^1V_1$	$^1V_{10}$	$\{^1V_3 = {}^1V_3;\ {}^1V_1 = {}^1V_1\}$	$= n - 1\ (= 3)$	1	...	n	...	...	...	...	...	...	$n-1$							
[illegible]	+	$^1V_2 + {}^0V_7$	$^1V_7$	$\{^1V_2 = {}^1V_2;\ {}^0V_7 = {}^1V_7\}$	$= 2 + 0 = 2$	...	2	...	...	...	...	2										
[illegible]	÷	$^1V_6 \div {}^1V_7$	$^3V_{11}$	$\{^1V_6 = {}^1V_6;\ {}^0V_{11} = {}^3V_{11}\}$	$= \frac{2n}{2} = A_1$	...	...	...	...	...	$2n$	2	...	...	...	$\frac{2n}{2} = A_1$						
[illegible]	×	$^1V_{21} \times {}^3V_{11}$	$^1V_{12}$	$\{^1V_{21} = {}^1V_{21};\ {}^3V_{11} = {}^3V_{11}\}$	$= B_1 \cdot \frac{2n}{2} = B_1 A_1$	...	...	...	...	...	...	...	...	...	...	$\frac{2n}{2} = A_1$	$B_1 \cdot \frac{2n}{2} = B_1 A_1$	....	B_1			
[illegible]	+	$^1V_{12} + {}^1V_{13}$	$^2V_{13}$	$\{^1V_{12} = {}^0V_{12};\ {}^1V_{13} = {}^2V_{13}\}$	$= -\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}$ ...	...	...	...	...	...	...	...	...	...	...	....	0	$\left\{-\frac{1}{2} \cdot \frac{2n-1}{2n+1} + B_1 \cdot \frac{2n}{2}\right\}$				
[illegible]	−	$^1V_{10} - {}^1V_1$	$^2V_{10}$	$\{^1V_{10} = {}^2V_{10};\ {}^1V_1 = {}^1V_1\}$	$= n - 2\ (= 2)$	1	...	...	...	...	...	...	...	...	$n-2$							
[illegible]	−	$^1V_6 - {}^1V_1$	$^2V_6$	$\{^1V_6 = {}^2V_6;\ {}^1V_1 = {}^1V_1\}$	$= 2n - 1$	1	...	...	...	...	$2n-1$											
[illegible]	+	$^1V_1 + {}^1V_7$	$^2V_7$	$\{^1V_1 = {}^1V_1;\ {}^1V_7 = {}^2V_7\}$	$= 2 + 1 = 3$	1	...	...	...	...	...	3										
[illegible]	÷	$^2V_6 \div {}^2V_7$	$^1V_8$	$\{^2V_6 = {}^2V_6;\ {}^2V_7 = {}^2V_7\}$	$= \frac{2n-1}{3}$	...	...	...	...	...	$2n-1$	3	$\frac{2n-1}{3}$									
[illegible]	×	$^1V_8 \times {}^3V_{11}$	$^4V_{11}$	$\{^1V_8 = {}^0V_8;\ {}^3V_{11} = {}^4V_{11}\}$	$= \frac{2n}{2} \cdot \frac{2n-1}{3}$	...	...	...	...	...	...	...	0	...	...	$\frac{2n}{2} \cdot \frac{2n-1}{3}$						
[illegible]	−	$^2V_6 - {}^1V_1$	$^3V_6$	$\{^2V_6 = {}^3V_6;\ {}^1V_1 = {}^1V_1\}$	$= 2n - 2$	1	...	...	...	...	$2n-2$											
[illegible]	+	$^1V_1 + {}^2V_7$	$^3V_7$	$\{^2V_7 = {}^3V_7;\ {}^1V_1 = {}^1V_1\}$	$= 3 + 1 = 4$	1	...	...	...	...	...	4										
[illegible]	÷	$^3V_6 \div {}^3V_7$	$^1V_9$	$\{^3V_6 = {}^3V_6;\ {}^3V_7 = {}^3V_7\}$	$= \frac{2n-2}{4}$	...	...	...	...	...	$2n-2$	4	...	$\frac{2n-2}{4}$	...	$\left\{\frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{3} = A_3\right\}$						
[illegible]	×	$^1V_9 \times {}^4V_{11}$	$^5V_{11}$	$\{^1V_9 = {}^0V_9;\ {}^4V_{11} = {}^5V_{11}\}$	$= \frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{4} = A_3$	...	...	...	...	...	...	...	...	0								
[illegible]	×	$^1V_{22} \times {}^5V_{11}$	$^0V_{12}$	$\{^1V_{22} = {}^1V_{22};\ {}^0V_{12} = {}^2V_{12}\}$	$= B_3 \cdot \frac{2n}{2} \cdot \frac{2n-1}{3} \cdot \frac{2n-2}{3} = B_3 A_3$	...	...	...	...	...	...	...	...	...	...	0	$B_3 A_3$	....	......	B_3		
[illegible]	+	$^2V_{12} + {}^2V_{13}$	$^3V_{13}$	$\{^2V_{12} = {}^0V_{12};\ {}^2V_{13} = {}^3V_{13}\}$	$= A_0 + B_1 A_1 + B_3 A_3$	...	...	...	...	...	...	...	...	...	...	....	0	$\{A_3 + B_1 A_1 + B_3 A_3\}$				
[illegible]	−	$^2V_{10} - {}^1V_1$	$^3V_{10}$	$\{^2V_{10} = {}^3V_{10};\ {}^1V_1 = {}^1V_1\}$	$= n - 3\ (= 1)$	1	...	...	...	...	...	...	...	...	$n-3$							
					Here follows a repetition of Operations thirteen to twenty-three.																	
[illegible]	+	$^4V_{13} + {}^0V_{24}$	$^1V_{24}$	$\{^4V_{13} = {}^0V_{13};\ {}^0V_{24} = {}^1V_{24}\}$	$= B_7$	...	...	...	...	...	...	...	...	...	...	....	....	....	......	......	......	B_7
[illegible]	+	$^1V_1 + {}^1V_3$	$^1V_3$	$\{^1V_1 = {}^1V_1;\ {}^1V_3 = {}^1V_3;\ {}^5V_6 = {}^0V_6$ [illegible]	$= n + 1 = 4 + 1 = 5$ .... by a Variable-card.	1	...	$n+1$	...	...	0	0										

REPRINTED FROM *SCIENTIFIC MEMOIRS*, EDITED BY RICHARD TAYLOR, VOL. III, 1843

Menabrea focused his attention primarily on the mathematical underpinnings of both the Difference and Analytical Engines rather than on their underlying mechanical operations. Menabrea outlined the purpose of the various components of the Analytical Engine and recognized that it would be able to compute any algebraic formula properly expressed (or programmed) on the punched cards. "The cards," Menabrea wrote, "are merely a translation of algebraical formulae, or, to express it better, another form of analytical notation."

Ada—who had since married William King, the earl of Lovelace, and become the countess of Lovelace—read Menabrea's paper and began translating it into English. Babbage had remained a good friend of Ada's, and on hearing of her work in early 1843, he encouraged her to annotate the translation.

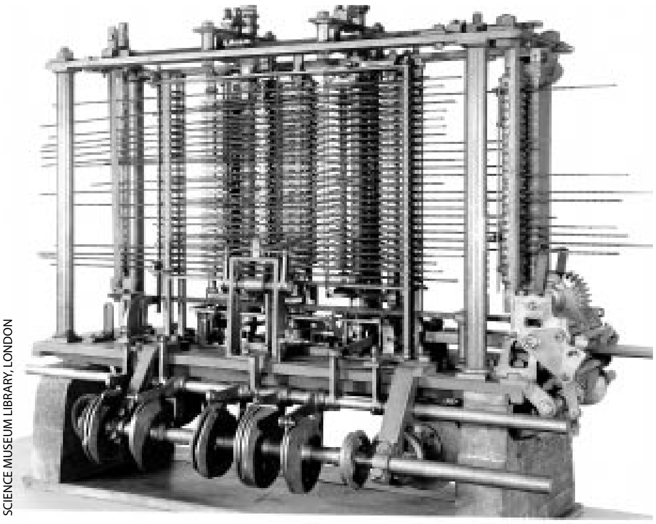
With that suggestion began a major collaboration that resulted in Ada's publishing the first paper to discuss the programming of a computer at great length; it was to be the only such paper in existence for the next century. She included seven notes in all (A through G), which combined are more than twice as long as Menabrea's original article. An important theme was the significance of the Analytical Engine's ability to be programmed using the Jacquard punched cards. "The distinctive characteristic of the Analytical Engine," wrote Ada, "...is the introduction into it of the principle which Jacquard devised for regulating, by means of punched cards, the most complicated patterns in the fabrication of brocaded stuffs.... We say most aptly that the Analytical Engine *weaves algebraical patterns* just as the Jacquard-loom weaves flowers and leaves." Cards were a particularly clever solution for weaving cloth—or for performing calculations—because they allowed any desired pattern—or equation—to be generated automatically.

Ada went on to elaborate greatly on Menabrea's descriptions and to examine the gritty details of programming the Analytical Engine. For example, she emphasized the computational importance of the engine's ability to branch to different instructions based on certain conditions, and she drew the distinction between what was theoretically possible to compute and what was, in reality, impractical. Ada also wrote about the benefits of the Analytical Engine's ability to reuse code. In addition, in describing the symbolic processing powers of the engine, she wrote of its potential to compose music: "Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent."

Finally, Ada debunked the notion that the engine was "thinking" in the ways that humans think. "The Analytical Engine has no pretensions whatever to *originate* anything," she asserted. "It can do whatever we *know how to order it* to perform." Over a century later Alan M. Turing made her sentiment famous in a landmark lecture on artificial intelligence, dubbing it "Lady Lovelace's Objection."

The remainder of Ada's notes were devoted to the mechanics of programming the Analytical Engine, including a description of the punched-card mechanism and of the notation for writing programs. If, as Menabrea had stated in his article and Ada had reaffirmed, the punched cards merely expressed an algebraic formula, then there had to be a rigorous notation for expressing the formula on the punched cards. Babbage had adopted a tabular format for expressing programs, which Ada modified in her publication.

Ada ends her notes with her program for computing Bernoulli numbers. Swiss mathematician Jakob Bernoulli wrote about his numbers in a classic book about probability, *Ars conjectandi* (*The Art of Conjecture*), first published in 1713. Ada's program for deriving Bernoulli numbers demonstrated the Analytical Engine's conditional branching capability and used two loops. It was far more ambitious and complex than any program Babbage had written for the Engine.



BABBAGE'S ANALYTICAL ENGINE was never completed, but a portion (*above*) consisting of part of the mill (CPU) and the printing devices was assembled shortly before his death in 1871. The engine would have been programmed using punched cards, an idea borrowed from the Jacquard loom for weaving patterned cloth (*right*).

All that historians know regarding Ada's work comes from correspondence between Ada and Babbage, Babbage's notebooks and autobiography, and Ada's notes themselves, which were published in Richard Taylor's *Scientific Memoirs*. Of the letters between Ada and Babbage that have survived, most were written by Ada. Sadly, Ada's own notebook is lost; it could have answered many questions about her path of understanding.

Babbage and the Notes

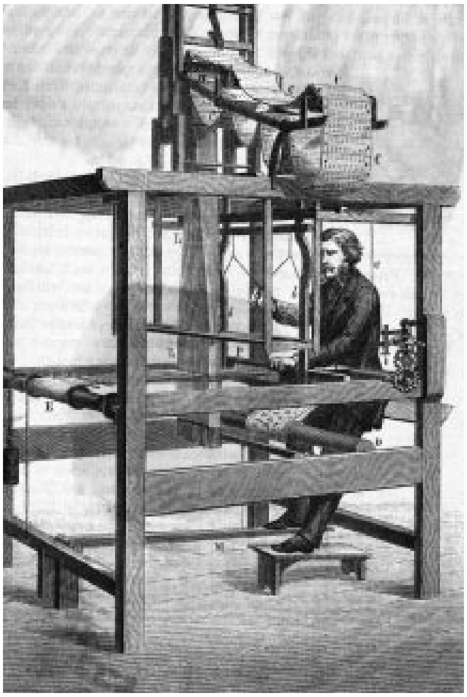
Ada compiled her notes between February and September 1843 and discussed her progress often with Babbage during this period, both through letters and face-to-face. Although she relied on Babbage to explain the inner workings of his machine and to confirm the accuracy of her descriptions, Ada often astonished Babbage with her insights. On reading a draft of Note A, for example, Babbage responded, "I am very reluctant to return your admirable & philosophic Note A. Pray do not alter it.... All this was impossible for you to know by intuition and the more I read your notes the more surprised I am at them and regret not having earlier explored so rich a vein of the noblest metal."

Ada sought Babbage's opinions and was open to suggestions regarding content; she resisted any changes to her prose, however. In August 1843, a month before the final proofs went to the printer, Babbage tried to insert into her notes a preface complaining about the British government's lack of support for his Analytical Engine. Ada was furious and sent him an angry letter. They eventually resolved their differences, and Babbage's preface was published separately and anonymously.

In a letter to Babbage dated July 1843, Ada wrote, "I want to put in something about Bernoulli's Numbers, in one of my Notes, as an example of how an implicit function may be worked out by the engine, without having been worked out by human head & hands first. Give me the necessary data & formulae." (Ada had studied Bernoulli numbers with De Morgan two years before but apparently needed to refresh her memory of the formula for generating them.)

From this letter, two things are clear. First, including a program that computed Bernoulli numbers was Ada's idea. Second, Babbage at the very least provided the formulas for calculating Bernoulli numbers, a fact he confirmed 21 years later in his autobiography, *Passages from the Life of a Philosopher*.

We cannot know for certain the extent to which Babbage helped Ada on the Bernoulli numbers program. She was certainly capable of writing the program herself given the proper formula; this is clear from her depth of understanding regarding the process of programming and from her improvements on Babbage's programming notation. Additionally, letters between


CORBIS-BETTMANN

Babbage and Ada at the time seem to indicate that Babbage's contributions were limited to the mathematical formula and that Ada created the program herself. While she was working on the program, Ada wrote to Babbage, "I have worked incessantly, & most successfully, all day. You will admire the Table & Diagram extremely. They have been made out with extreme care, & all the indices most minutely & scrupulously attended to."

The importance of Ada's choosing to write this program cannot be overstated. Babbage had written several small programs for the Analytical Engine in his notebook in 1836 and 1837, but none of them approached the complexity of the Bernoulli numbers program. Because of her earlier tutelage, Ada was at least familiar with the numbers' properties. It is possible that Ada recognized that a Bernoulli numbers program would nicely demonstrate some of the Analytical Engine's key features, such as conditional branching. Also, because Menabrea had alluded to the Bernoulli numbers in his article, Ada's program tied in nicely with her translation of Menabrea.

Finally, any discussion of Ada's work would not be complete without mentioning Dorothy Stein of the University of London, perhaps Ada's most outspoken critic, who wrote *Ada: A Life and a Legacy* in 1985. One of Stein's assertions was that Ada was an incompetent mathematician who was not capable of writing the Bernoulli numbers program herself, an idea that has since been expressed by others.

Stein's conclusion is based primarily on two pieces of evidence. First, she points out a mathematical error in Ada's translation of Menabrea, in which she translated a French typo into an impossible mathematical statement. Menabrea's original paper read "le cos. de $n = \infty$," when it should have read "le cas de $n = \infty$." The proper translation would have been "in the case of $n = \infty$," but Ada translated the statement literally to "when the cos $n = \infty$," a mathematical impossibility.

Second, Stein quotes letters between Ada and her tutors that show that Ada had difficulty with functional substitution (proving an equation by substituting a function with its identity). Stein writes, "The evidence of the tenuousness with which she grasped the subject of mathematics would be difficult to credit about one who succeeded in gaining a contemporary and posthumous reputation as a mathematical talent, if there were not so much of it."

Ada indeed mistakenly translated one of Menabrea's statements, but it cannot be fairly attributed to mathematical incompetence. It was not the only mistake in her article; Ada even miswrote her initials on her final note as "A.L.L." instead of "A.A.L." Her 65 pages of translation and annotations were peer-reviewed by Babbage and others, who also overlooked the errors.

Stein's charge that Ada did not understand functional substitution is more serious, because it is a vital concept for computer programmers. It is crucial to remember, however, that algebra was cutting-edge mathematics in England at the time and that Ada was learning via correspondence. Recognizing that her tutors were helping her for free, Ada was more likely to write to them about matters she did not understand than about concepts she had already grasped. The level of mathematical sophistication in her late letters shows that despite the fact that Ada may have had trouble with functional substitution before she began working on her notes, she most likely understood it when she began writing them.

Ada's health, which was poor on and off throughout her life, declined further after 1843, limiting her ability to practice mathematics. She died on November 27, 1852, probably of uterine cancer. At her request, she was buried next to her father. Her work remained relatively obscure until 1953, when Bertram V. Bowden compiled *Faster than Thought,* a history of computers that mentioned Ada's work and called her a "prophet."

Many modern computer pioneers eventually became aware of Babbage's work and of Ada's paper, but all of them made their conceptual breakthroughs independently. Howard Aiken, the Harvard University professor who designed and built the Mark I in 1944, liked to consider himself a direct successor of Babbage. He was not familiar with Ada's work, however, and failed to realize the importance of conditional branching.

What we now know about designing and programming computers may not be directly traceable to Babbage and Ada, but they can claim precedence for many of these concepts. And Ada in particular has become a figure whose life and work still stir the imagination of many computer scientists today. S

The Authors

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Further Reading

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CHARLES BABBAGE: PIONEER OF THE COMPUTER. Anthony Hyman. Princeton University Press, 1982.

The Andaman Islanders

The aboriginal inhabitants of a stretch of islands near India offer a fascinating glimpse into the way of life of traditional hunter-gatherers. But how long will this window to our past remain open?

by Sita Venkateswar

BOURNE & SHEPERD *National Geographic Society Image Collection*

The indigenous people who inhabit the lush, verdant rain forests of the Andaman Islands in the Bay of Bengal have made the islands their home for at least the past 2,000 years. Over the centuries, the Andaman Islanders have been a subject of both fascination and dread, often being portrayed as brutish cannibals. The 13th-century explorer Marco Polo, for instance, recorded in accounts of his travels a story he heard of the "dog-headed" inhabitants of the islands. More recently, in Sir Arthur Conan Doyle's *The Sign of Four,* an Andaman Islander appears as a villain, complete with "murderous darts" and a "face [that] was enough to give a man a sleepless night."

These creative flights of fancy aside, the history and culture of the Andamanese continue to intrigue visitors to the islands, as well as anthropologists such as myself. Between 450 and 500 indigenous people still live on the islands, the last representatives of the dwindling population of Negrito people in south Asia. The Andaman Islanders followed the traditional way of life of these people—one of seminomadic hunter-gatherer-fishers—well into the 19th century, when British colonists arrived and began to take over the islands.

Despite intrusions, however, some islanders have managed to hold on to many of their traditional customs. Indeed, even now, one group remains extraordinarily isolated and hostile to any outsiders, defending its territory with potentially deadly force. But the influence of occupation, first British and now Indian, has taken its toll. The number of Andaman Islanders has dropped precipitously over the past two centuries, down from an estimated average of 5,000 islanders living throughout the archipelago in the middle of the 19th century.

DECADES OF COLONIALISM have nearly wiped out the culture of the Great Andamanese people, one of four indigenous societies of the Andaman Islands in the Bay of Bengal. By the 1890s the group felt the influence of British occupation: despite the traditional body decorations shown in a photograph from the time (*opposite page*), the islanders had discovered not only British pipes but also deadly diseases, such as syphilis and measles. Today only about 40 Great Andamanese remain. An older woman in the community, Boro, shown below at the right, finishes an evening of fishing as two young boys arrive on the beach to greet her.

MADHUSREE MUKERJEE

The Andaman Islands

INDIGENOUS POPULATION

	1901	1951	1998
GREAT ANDAMANESE	625	23	39
ONGE	672*	150*	100*
JARAWA	468*	50*	250*
SENTINELESE	117*	50*	100*

*ESTIMATED

PHOTOGRAPHS BY MADHUSREE MUKERJEE; MAPS BY LAURIE GRACE

ANDAMAN ISLANDERS now consist of four tribes: the Great Andamanese, Jarawa, Onge and Sentinelese. Great Andamanese, such as the three boys shown above, typically have both Andamanese, Indian and Karen Burmese heritage. Today the group, which originally occupied North, Middle and South Andaman, has been moved to tiny Strait Island (*map*) by the Indian government. The Jarawa people have remained much more isolated, only sporadically venturing out from the dense forests set aside for them on South and Middle Andaman. Three young Jarawa men are shown wearing decorations and jewelry (*near right*). The Onge now inhabit coastal areas of Little Andaman. This Onge mother and child, shown at the far right, display the traditional practice of painting faces and bodies with white clay. Members of the Sentinelese group are rarely seen. They live on North Sentinel Island, which they vigorously defend from invasion.

At present, only four tribes live on the islands—the Great Andamanese, the Onge, the Jarawa and the Sentinelese. Yet scholars believe that at one time, some 12 distinct linguistic and separate territorial groups inhabited the islands. Time is running out for the last representatives of aboriginal Andamanese culture. In hopes of learning more about the islanders—their past, present and future—I spent some 18 months on the islands between 1989 and 1993, living primarily with members of the Onge tribe.

Paleolithic Pasts

The origins of the Andaman Islanders remain enshrouded in speculation. Current evidence—most recently, excavations by Zarine Cooper of Deccan College in India—supports the theory of a long, continuous occupation of the islands for at least the past 2,200 years. Some scholars believe the ancestors of today's indigenous groups reached the islands some 35,000 years ago. The Andamanese people's small stature and distinctive hair type, in association with their very dark skin, indicate that they are racially separate from the mainland Indian population as well as from the aboriginal population on neighboring Nicobar Islands.

Lidio Cipriani, director of the Port Blair office of the Anthropological Survey of India during the early 1950s, and, more recently, Vishvajit Pandya of Victoria University in New Zealand have suggested that the Andaman Islanders may be related to another Negrito group, the Semang of southeast Asia. And some new, though still tentative, genetic data suggest that the Andaman Islanders may be descendants of the first humans to migrate out of Africa some 100,000 years ago, reaching the islands between 35,000 and 40,000 years ago [see "Out of Africa, into Asia," by Madhusree Mukerjee; Scientific American, News and Analysis, January].

Two possible routes for the Andamanese's arrival in the islands have been offered. During the ice ages 40,000 years ago, when sea levels were significantly lower, people could have both walked and crossed the shallow seas in their dugout canoes either from Sumatra by way of the Nicobar Islands or from the Malay and Burmese coasts.

Contrary to the common misconcep-

BELT PATTERNS BY LAURIE GRACE; SOURCE: *THE JARAWA*, BY JAYANTA SARKAR

tion, the Andamanese are not and never were cannibals. The probable origin of this myth is the islanders' former practice of cutting up the dead bodies of their enemies and throwing the pieces into a fire. Outside observers apparently assumed this act was a preamble to a cannibalistic feast. But scholars now know that the bodies were never consumed and that this practice was simply a precautionary measure for dispersing harmful spirits. In contrast, the islanders bury the bodies of their kin under the communal huts to keep their spirits close to the surviving family members.

People often describe the Andaman Islanders as a Stone Age culture, but it is inaccurate to portray them as having been utterly isolated until the appearance of the British. Even before the arrival of the colonial powers, the islanders had been forcibly drawn into the slave-trading networks of south and southeast Asia. Many of the slaves were supplied to the rajah of Kedah, who then sent them to the king of Siam as part of his tribute. There is even some evidence that Andamanese slaves reached the courts of France. In addition, as island dwellers, the Andaman people have always incorporated into their culture the varied objects washed ashore or introduced by assorted visitors through the centuries.

During my research visits to the Andaman Islands, I spent most of my time with the Onge tribe. Roughly 100 Onge now live on Little Andaman Island [*see map on opposite page*] in two permanent settlements: Dugong Creek, in the north, and South Bay, at the southern tip of the island. The rest of the island is inhabited by ethnically distinct immigrants from India. By piecing together details obtained from diverse sources—tales from the Onge themselves and my own observations, as well as earlier research by Cipriani, by Badal Basu of the Anthropological Survey of India and by Pandya—I have been able to assemble a patchwork of information about aspects of the Onge way of life and about many typical Andamanese traditions.

Daily Life

Over the course of my numerous interviews with approximately 30 Onge women, men and children, previously unknown details emerged about their life in the forest. I conducted these discussions in Onge; some of the most informative accounts came from three men, Bada Raju, Totanange and Tilai. I have integrated these details into the composite account that follows:

"During the dry season, they [ancestral or other Onge] would get *bulundange* [jackfruit], and store it. They would fill up *tole* [big baskets] with fruit, cover them with leaves, tie them up and hide them in the forest. So when there is a lot of rain there is food. They would also hunt, and bring back pork, and when that finished, they ate *bulundange*. There was no tea then, they would only drink water. They would store a lot of dry wood, because once it gets wet it is very difficult to get wood. That's why during *Torale* [the dry season] all the wood is obtained and stored. Then before the rain begins, the big *tokabe* [communal hut] is built, and during the rains it is very comfortable inside.

"In the past, there was no wage work, we had all the time to build our houses, get pork, eat pork rich in fat. They didn't have any utensils, they would make *bucu* [clay pots] … to cook the pork. Then when *Kwalokange* [the southeast monsoon] starts, the boars become thin, and they are not tasty. In the creeks in the forest there is so much fish, we would get fish and *nana* [prawn].

"There was no iron then, we would use the wood from the areca trees … but we would get iron from the sea, when it washed ashore. And use the resin from the forest to sharpen the metal. Otherwise, we used the wood from the forest. We would make *dange* [dugout canoes] using a different wood, but when it was taken to the water it sank, so we knew this wood was no good. So we tried a different wood, took it to the water and saw, yes, it stayed afloat. So, that's what we used afterwards. That's how we learned things.

"In the old days, there was no nylon rope, the fiber used to kill turtles now. We would get into the water and crowd the turtle, we used the incense from the forest, make a torch with *kuendeve* [dried rattan leaves] and light it with the incense, as we crowded around the turtle. We were a lot of Onge then, and that's how

DOMESTIC LIFE for some Andaman Islanders reflects historic customs; for others, the modern world prevails. An Onge woman prepares rice (supplied by the Indian government) for her family's midday meal in a traditional Onge home located in South Bay, Little Andaman Island (*above*). On Strait Island, Golat, a young man who is Great Andamanese, watches a cricket match on the television in the schoolhouse with two boys from the community (*right*).

we would hem in the turtle. We didn't harpoon the turtle then, we only used arrows to hunt boar.

"And that's how we caught dugong as well. We would wait for low tide and then go to hunt turtle and dugong at night. Not when the tide is high—then we would drown. Then when that was done, we would go to the forest again, and get more incense, and light it, and go search for boar.

"We were a lot of Onge then, we were not afraid of *Tommanyo* [a spirit of the night], and we would go into the forest at night. We had no fear then. At that time there were Onge everywhere, many *bera* [a territorial grouping] all over. There were so many of us then. The boars would go to sleep at night, and that's when we would hunt them. It was so easy then. We would come back during the day and go look for the boar we hunted the previous night. Then we would take it back with us, smoke it and cook it. And that's how we lived. We didn't have clothes then, we would wear bark from the forest. The girls would make them with *kuendeve*. Those are some of the things we would do."

Like many other indigenous groups, the Onge perceive themselves as inhabiting an interconnected universe, peopled with spirits that include their ancestors—the *Onkoboykwo*—who play an active role in everyday life. The Onge share this universe with various other spirits, the *tomya,* who make their presence known by blowing in as winds from different directions, thereby marking and naming each season.

Food fuels the cycle of life and death for the Onge. For example, new life is conceived when women eat foods in which the *Onkoboykwo* reside. These ancestor spirits, who otherwise dwell in a realm similar to the Onge's world, have no teeth and cannot chew food. Hence they enter various foods to satisfy their hunger. Thus, when women eat foods containing the spirits, the *Onkoboykwo* become Onge; after death the Onge are again transformed into the *Onkoboykwo*. Food also creates the basis for certain social interactions. Important bonds develop between a child and all the women who nursed the infant, as well as between the child and the man or woman who procured the food that impregnated the mother.

This description emphasizes the deep and symbolic significance embodied in the foods consumed by the Onge—a significance that reflects the Onge's hunting-and-gathering way of life as well as their relationship to the environment. This connection with nature is particularly strong, dictating where the Onge tribes live during the year and what they eat. With the onset of the hot, dry season (usually in March and April), for instance, Onge families move from the coastline, where they had been hunting turtles, into the interior of the forest to collect *tanja,* or honey. This relocation marks the beginning of the season of *Torale,* when the spirits vacate the islands. Families from one *bera* collect in the large, beehive-shaped communal hut where the ancestral bones are buried.

The arrival of the spirit *Dare* in the forest, riding on the back of the southwest monsoon (typically in June), signals the end of *Torale* and the time to leave the interior of the forest for shelters by the creeks and mangrove forests. Here the Onge can find crabs, fish and mangrove fruit. Once the spirit *Dare* leaves in September, the Onge move back to the forests and feast on boar until the approach of the spirit *Kwalokange* and the southeast monsoon in October. At

Jarawa decorative pattern, used on leaf belts

PHOTOGRAPHS BY MADHUSREE MUKERJEE

this time, the Onge return to the coast and begin hunting for dugong. They believe that the spirit *Kwalokange* consumes the remaining boar within the forest, leaving just a small amount for the next spirit, *Mekange*, the northeast wind. The appearance of *Mekange* from November to February indicates that the Onge should resume hunting turtles. The seasonal cycle is complete.

Everything I have described about the customs and beliefs of the Onge relates back to their traditional way of life, one that was shared to a large extent with the other peoples of the islands. This traditional culture has been in decline for almost a century and a half, however, since the beginning of colonial rule over the islands.

The Colonial Era

The British government established a permanent penal colony on the islands in 1858, the first time relatively accurate descriptions of the islands or their inhabitants were written. That year marked the start of a continuous history of colonization. When the first English colonists arrived, the local inhabitants made their homes through most of the some 200 islands that make up the Andamans. Contact with the British brought about the so-called pacification of various groups of the Great Andamanese tribe as well as of some coastal populations of Onge.

Of course, "pacification" is a misnomer—the military used the word to denote the often violent silencing of resistance from local populations. As Carmel Schrire of Rutgers University has written in her book *Digging through Darkness: Chronicles of an Archaeologist* (University Press of Virginia, 1995), although "the opinions and feelings of the dispossessed" seldom become known, "it is not that they were silent.... It is simply that they went unrecorded." As a result, most of our knowledge of this era comes from the reports of those confrontations as chronicled by the colonists.

The British arrival brought first bloodshed and then disease and dispossession to local populations across the North, Middle and South Andaman Islands. In 1901, when the British undertook the first census in the Indian subcontinent, officials counted 625 Great Andamanese and estimated numbers for the other three tribes: 672 Onge, 468 Jarawa and 117 Sentinelese. After a brief Japanese occupation of the Andaman Islands during World War II, India took control of the region in 1947.

The subsequent Indian style of governing was also colonial in its nature, at least as it pertained to the islanders. The change from the British to the Indian regime amounted to no more than a transfer of power, with little to differentiate the two. The Indian government, like its predecessor, attempted to shoulder "the white man's burden" of assisting native populations. Disease and other forces continued to take their toll, however. By 1951, when independent India conducted its first census, the number of Great Andamanese had fallen to a mere 23. Estimates for the other tribes were also low—150 Onge, 50 Jarawa and 50 Sentinelese.

Today, of the nearly 40 people who can claim Great Andamanese heritage, many have recent Indian ancestry as well. Only an estimated 100 Onge, 250 Jarawa and 100 Sentinelese are now alive. The ravages of the earliest and longest duration of contact have been borne by the Great Andamanese, who have been resettled on the small Strait Island; the Indian government arranged this as some measure of reparation for the historical injustices that the people have undergone.

Both the Great Andamanese and the Onge currently lead sedentary lives—instead of hunting and fishing, they have rations allotted to them by the Indian government. The Jarawa and the Sentinelese have survived the colonial era better than the other groups. The Jarawa tribe, living in dense forests, continues to have only limited contact with others, and any contact they do have is on their terms, when they will tolerate it. Members of the Sentinelese tribe (named after the island they inhabit) rarely, if ever, see outsiders.

Both tribes—particularly the Sentinelese—defend their territorial boundaries with bows and arrows, now reinforced with iron arrowheads. Declaring their intentions of including the Jarawa as "full-fledged citizens of the country," Indian officials are trying to lure the Jarawa into more peaceful interactions with the promise of coconuts, bananas, rice, cloth and pieces of iron.

Romulus Whitaker, a prominent ecologist, has asserted that the most serious threat to the Jarawa today is the increasing encroachment by outsiders into their prime hunting and fishing land. He observes that the Jarawa are willing to undertake considerable risks to obtain

PHOTOGRAPHS BY MADHUSREE MUKERJEE

TRADITIONAL ONGE DWELLING (*top*) at Dugong Creek on Little Andaman Island is more popular among some residents of the settlement than are the wooden houses built for them by the government. In contrast, the Great Andamanese live in government-built houses, such as Boro's home on Strait Island (*bottom*).

SITA VENKATESWAR

JARAWA people run to meet a government boat sent to view the aboriginals and to deliver coconuts, bananas, rice, pieces of iron and red cloth. Earlier this century anthropologists began offering red cloth to the Jarawa; the tradition continues to this day.

Jarawa decorative pattern, used on leaf belts

metal for their arrowheads, including raiding road-building camps, forest camps and farms. As the number and scale of "Jarawa incidents" (which receive media attention only if there are deaths on the Indian side) indicate, the settlers, illegal encroachers and the police have taken it on themselves to launch a miniwar against the Jarawa without formal government approval.

The Sentinelese, however, are assured of a certain degree of security by their occupation of a small, isolated island, access to which remains difficult. They continue to present a militant front to the outside world and until eight years ago had actively thwarted any attempt to reach their island. But in 1991 they accepted some coconuts from a team of Indian anthropologists and administrators. There have been no further developments since then. From the little that has been observed and can be inferred of these people, their way of life and material culture are very similar to those of the other Andaman groups.

In recent years, the term "ethnocide" has come into prominence to describe the ongoing destruction of many indigenous cultures around the world. The people themselves are not purposely harmed, but they are often sequestered within enclaves where they are rendered dependent on a dominant majority that has taken over their lands, leaving the group without any alternative means for survival. The dominant people then proceed to improve the condition of these "primitives" by destroying all the elements of their "backward" way of life, resulting in the death of a distinct culture.

On the surface, such policies seem to embody a humanitarian desire to help people, but they also reflect the prejudiced assumption that the way of life of indigenous people is inherently inferior and hence must be supplanted by a different and better one. Moreover, these policies presume that the indigenous peoples are incapable of envisioning or planning their own future, and as a result outsiders feel they must step in to assist.

In truth, the assimilation of the islanders into the Indian mainstream has primarily benefited the colonizers. As the British extended their colony across the North, Middle and South Andaman islands, and plans developed for more commercially profitable uses for land occupied by the Great Andamanese (for lumber, farming and the clearing of forests for roads), the government's policies clearly resolved in favor of moving the islanders into restricted settlements. And after India's independence from the British, the forests of Little Andaman Island, where the Onge live, also became the target of development efforts.

Unfortunately, no matter how policies are framed, for the Andaman Islanders the consequences are a steadily dwindling amount of territory under their control, the gradual destruction of their unique and viable way of life, and the eventual induction of the islanders into the swelling ranks of other dispossessed marginals of mainland Indian society. As David Maybury-Lewis of Cultural Survival notes, "Land and the struggle for it is at the heart of the problem of cultural survival, for the guarantee of their lands is what tribal peoples need most." But because indigenous peoples' claims around the world for land present a challenge to the ruling states' authority, not surprisingly most have met with little success.

Nevertheless, any discussion of international human rights should address indigenous peoples' land claims as well as alternative ways to resolve these disputes. It will be some time before the Andaman Islanders themselves become politically active enough to make a bid to define their own rights. The first step we outsiders must take, then, is at the local level: we must acknowledge that, if they are to survive, the Andaman Islanders can and should be allowed to plan for their own future. SA

The Author

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Further Reading

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XML and the Second-Generation WEB

by Jon Bosak and Tim Bray

The combination of hypertext and a global Internet started a revolution. A new ingredient, XML, is poised to finish the job

XML BRIDGES the incompatibilities of computer systems, allowing people to search for and exchange scientific data, commercial products and multilingual documents with greater ease and speed.

ILLUSTRATIONS BY BRUCIE ROSCH

Give people a few hints, and they can figure out the rest. They can look at this page, see some large type followed by blocks of small type and know that they are looking at the start of a magazine article. They can look at a list of groceries and see shopping instructions. They can look at some rows of numbers and understand the state of their bank account.

Computers, of course, are not that smart; they need to be told exactly what things are, how they are related and how to deal with them. Extensible Markup Language (XML for short) is a new language designed to do just that, to make information self-describing. This simple-sounding change in how computers communicate has the potential to extend the Internet beyond information delivery to many other kinds of human activity. Indeed, since XML was completed in early 1998 by the World Wide Web Consortium (usually called the W3C), the standard has spread like wildfire through science and into industries ranging from manufacturing to medicine.

The enthusiastic response is fueled by a hope that XML will solve some of the Web's biggest problems. These are widely known: the Internet is a speed-of-light network that often moves at a crawl; and although nearly every kind of information is available on-line, it can be maddeningly difficult to find the one piece you need.

Both problems arise in large part from the nature of the Web's main language,

< Together XML and XSL allow publishers to pour a publication into myriad forms—write once and publish everywhere. />

HTML (shorthand for Hypertext Markup Language). Although HTML is the most successful electronic-publishing language ever invented, it is superficial: in essence, it describes how a Web browser should arrange text, images and push-buttons on a page. HTML's concern with appearances makes it relatively easy to learn, but it also has its costs.

One is the difficulty in creating a Web site that functions as more than just a fancy fax machine that sends documents to anyone who asks. People and companies want Web sites that take orders from customers, transmit medical records, even run factories and scientific instruments from half a world away. HTML was never designed for such tasks.

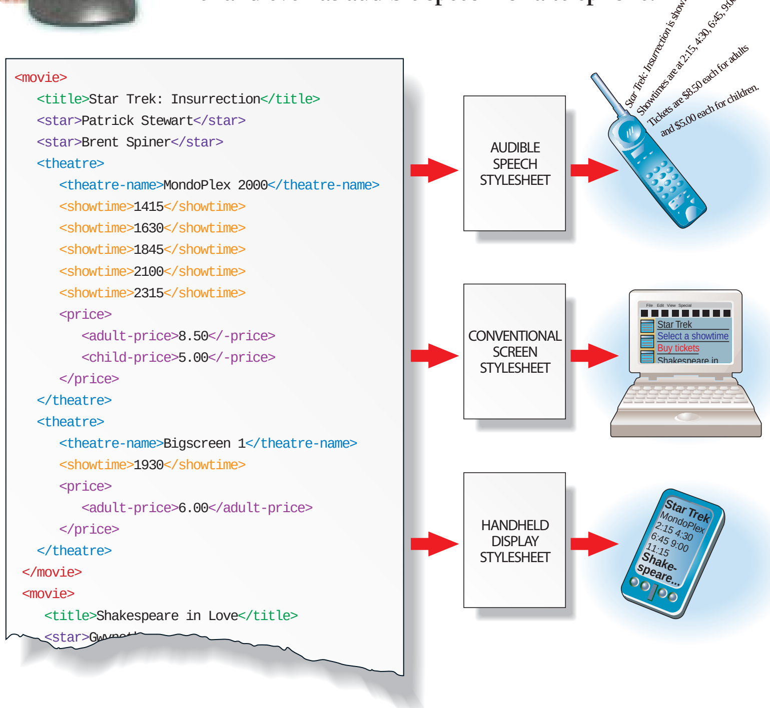
So although your doctor may be able to pull up your drug reaction history on his Web browser, he cannot then e-mail it to a specialist and expect her to be able to paste the records directly into her hospital's database. Her computer would not know what to make of the information, which to its eyes would be no more intelligible than <H1>blah blah </H1> <BOLD>blah blah blah </BOLD>. As programming legend Brian Kernighan once noted, the problem with "What You See Is What You Get" is that what you see is all you've got.

Those angle-bracketed labels in the example just above are called tags. HTML has no tag for a drug reaction, which highlights another of its limitations: it is inflexible. Adding a new tag involves a bureaucratic process that can take so long that few attempt it. And yet every application, not just the interchange of medical records, needs its own tags.

Thus the slow pace of today's on-line bookstores, mail-order catalogues and other interactive Web sites. Change the quantity or shipping method of your order, and to see the handful of digits that have changed in the total, you must ask a distant, overburdened server to send you an entirely new page, graphics and all. Meanwhile your own high-powered machine sits waiting idly, because it has only been told about <H1>s and <BOLD>s, not about prices and shipping options.

Thus also the dissatisfying quality of Web searches. Because there is no way to mark something as a price, it is effectively impossible to use price information in your searches.

MARKED UP WITH XML TAGS, one file—containing, say, movie listings for an entire city—can be displayed on a wide variety of devices. "Stylesheets" can filter, reorder and render the listings as a Web page with graphics for a desktop computer, as a text-only list for a handheld organizer and even as audible speech for a telephone.



LAURIE GRACE

Something Old, Something New

The solution, in theory, is very simple: use tags that say what the information is, not what it looks like. For example, label the parts of an order for a shirt not as boldface, paragraph, row and column—what HTML offers—but as price, size, quantity and color. A program can then recognize this document as a customer order and do whatever it needs to do: display it one way or display it a different way or put it through a bookkeeping system or make a new shirt show up on your doorstep tomorrow.

We, as members of a dozen-strong W3C working group, began crafting such a solution in 1996. Our idea was powerful but not entirely original. For generations, printers scribbled notes on manuscripts to instruct the typesetters. This "markup" evolved on its own until 1986, when, after decades of work, the International Organization for Standardization (ISO) approved a system for the creation of new markup languages.

Named Standard Generalized Markup Language, or SGML, this language for describing languages—a metalanguage—has since proved useful in many large publishing applications. Indeed, HTML was defined using SGML. The only problem with SGML is that it is *too* general—full of clever features designed to minimize keystrokes in an era when every byte had to be accounted for. It is more complex than Web browsers can cope with.

Our team created XML by removing frills from SGML to arrive at a more streamlined, digestible metalanguage. XML consists of rules that anyone can follow to create a markup language from scratch. The rules ensure that a single compact program, often called a parser, can process all these new languages.

Consider again the doctor who wants to e-mail your medical record to a specialist. If the medical profession uses XML to hammer out a markup language for encoding medical records—and in fact several groups have already started work on this—then your doctor's e-mail could contain <patient> <name> blah blah </name> <drug-allergy> blah blah blah </drug-allergy> </patient>. Programming any computer to recognize this standard medical notation and to add this vital statistic to its database becomes straightforward.

Just as HTML created a way for every computer user to read Internet documents, XML makes it possible, despite the Babel of incompatible computer systems, to create an Esperanto that all can read and write. Unlike most computer data formats, XML markup also makes sense to humans, because it consists of nothing more than ordinary text.

The unifying power of XML arises from a few well-chosen rules. One is that tags almost always come in pairs. Like parentheses, they surround the text to which they apply. And like quotation marks, tag pairs can be nested inside one another to multiple levels.

The nesting rule automatically forces a certain simplicity on every XML document, which takes on the structure known in computer science as a tree. As with a genealogical tree, each graphic and bit of text in the document represents a parent, child or sibling of some other element; relationships are unambiguous. Trees cannot represent every kind of information, but they can represent most kinds that we need computers to understand. Trees, moreover, are extraordinarily convenient for programmers. If your bank statement is in the form of a tree, it is a simple matter to write a bit of software that will reorder the transactions or display just the cleared checks.

Another source of XML's unifying strength is its reliance on a new standard called Unicode, a character-encoding system that supports intermingling of text in all the world's major languages. In HTML, as in most word processors, a document is generally in one particular language, whether that be English or Japanese or Arabic. If your software cannot read the characters of that language, then you cannot use the document. The situation can be even worse: software made for use in Taiwan often cannot read mainland-Chinese texts because of incompatible encodings. But software that reads XML properly can deal with any combination of any of these character sets. Thus, XML enables exchange of information not only between different computer systems but also across national and cultural boundaries.

An End to the World Wide Wait

As XML spreads, the Web should become noticeably more responsive. At present, computing devices connected to the Web, whether they are powerful desktop computers or tiny pocket planners, cannot do much more than get a form, fill it out and then swap it back and forth with a Web server until a job is completed. But the structural and semantic information that can be added with XML allows these devices to do a great deal of processing on the spot. That not only will take a big load off Web servers but also should reduce network traffic dramatically.

To understand why, imagine going to an on-line travel agency and asking for all the flights from London to New York on July 4. You would probably receive a list several times longer than your screen could display. You could shorten the list by fine-tuning the departure time, price or airline, but to do that, you would have to send a request across the Internet to the travel agency and wait for its answer. If, however, the long list of flights had been sent in XML, then the travel agency could have sent a small Java program along with the flight records that you could use to sort and winnow them in microseconds, without ever involving the server. Multiply this by a few million Web users, and the global efficiency gains become dramatic.

As more of the information on the Net is labeled with industry-specific XML tags, it will become easier to find exactly what you need. Today an Internet search for "stockbroker jobs" will inundate you with advertisements but probably turn up few job listings—most will be hidden inside the classified ad services of newspaper Web sites, out of a search robot's reach. But the Newspaper Association of America is even now building an XML-based markup language for classified ads that promises to make such searches much more effective.

Even that is just an intermediate step. Librarians figured out a long time ago that the way to find information in a hurry is to look not at the information itself but rather at much smaller, more focused sets of data that guide you to the useful sources: hence the library card catalogue. Such information about information is called metadata.

From the outset, part of the XML project has been to create a sister standard for metadata. The Resource Description Framework (RDF), finished this past February, should do for Web data what catalogue cards do for library books. Deployed across the Web, RDF metadata will make retrieval far faster and more accurate than it is now. Because the Web has no librarians and every Webmaster wants, above all else, to be found, we expect that RDF will achieve a typically astonishing Internet growth rate once its power becomes apparent.

There are of course other ways to find things besides searching. The Web is after all a "hypertext," its billions of pages connected by hyperlinks—those underlined words you click on to get whisked from one to the next. Hyperlinks, too, will do more when powered by XML. A standard for XML-based hypertext, named XLink and due later this year from the W3C, will allow you to choose from a list of multiple destinations. Other kinds of hyperlinks will insert text or images right where you click, instead of forcing you to leave the page.

Perhaps most useful, XLink will enable authors to use indirect links that point to entries in some central database rather than to the linked pages themselves. When a page's address changes, the author will be able to update all the links that point to it by editing just one database record. This should help eliminate the familiar "404 File Not Found" error that signals a broken hyperlink.

The combination of more efficient processing, more accurate searching and more flexible linking will revolutionize

< XML enables exchange of information not only between different computer systems but also across national and cultural boundaries. />

the structure of the Web and make possible completely new ways of accessing information. Users will find this new Web faster, more powerful and more useful than the Web of today.

Some Assembly Required

Of course, it is not quite that simple. XML does allow anyone to design a new, custom-built language, but designing *good* languages is a challenge that should not be undertaken lightly. And the design is just the beginning: the meanings of your tags are not going to be obvious to other people unless you write some prose to explain them, nor to computers unless you write some software to process them.

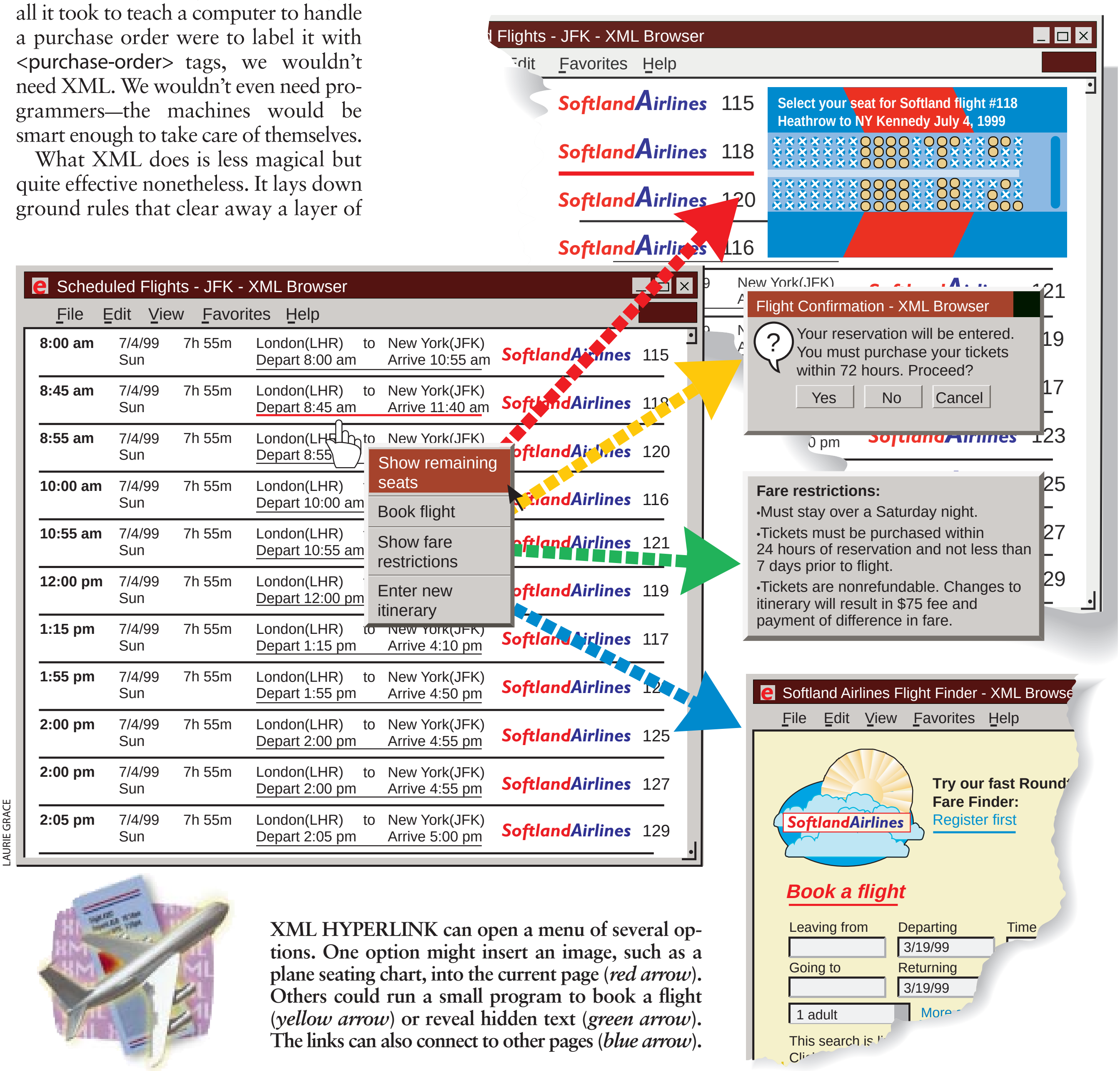
A moment's thought reveals why. If all it took to teach a computer to handle a purchase order were to label it with <purchase-order> tags, we wouldn't need XML. We wouldn't even need programmers—the machines would be smart enough to take care of themselves.

What XML does is less magical but quite effective nonetheless. It lays down ground rules that clear away a layer of programming details so that people with similar interests can concentrate on the hard part—agreeing on how they want to represent the information they commonly exchange. This is not an easy problem to solve, but it is not a new one, either.

Such agreements will be made, because the proliferation of incompatible computer systems has imposed delays, costs and confusion on nearly every area of human activity. People want to share ideas and do business without all having to use the same computers; activity-specific interchange languages go a long way toward making that possible. Indeed, a shower of new acronyms ending in "ML" testifies to the inventiveness unleashed by XML in the sciences, in business and in the scholarly disciplines [*see box on opposite page*].

Before they can draft a new XML language, designers must agree on three things: which tags will be allowed, how tagged elements may nest within one another and how they should be processed. The first two—the language's vocabulary and structure—are typically codified in a Document Type Definition, or DTD. The XML standard does not compel language designers to use DTDs, but most new languages will probably have them, because they make it much easier for programmers to write software that understands the markup and does intelligent things with it.

Programmers will also need a set of guidelines that describe, in human lan-



XML HYPERLINK can open a menu of several options. One option might insert an image, such as a plane seating chart, into the current page (*red arrow*). Others could run a small program to book a flight (*yellow arrow*) or reveal hidden text (*green arrow*). The links can also connect to other pages (*blue arrow*).

guage, what all the tags mean. HTML, for instance, has a DTD but also hundreds of pages of descriptive prose that programmers refer to when they write browsers and other Web software.

A Question of Style

For users, it is what those programs do, not what the descriptions say, that is important. In many cases, people will want software to display XML-encoded information to human readers. But XML tags offer no inherent clues about how the information should look on screen or on paper.

This is actually an advantage for publishers, who would often like to "write once and publish everywhere"—to distill the substance of a publication and then pour it into myriad forms, both printed and electronic. XML lets them do this by tagging content to describe its meaning, independent of the display medium. Publishers can then apply rules organized into "stylesheets" to reformat the work automatically for various devices. The standard now being developed for XML stylesheets is called the Extensible Stylesheet Language, or XSL.

The latest versions of several Web browsers can read an XML document, fetch the appropriate stylesheet, and use it to sort and format the information on the screen. The reader might never know that he is looking at XML rather than HTML—except that XML-based sites run faster and are easier to use.

People with visual disabilities gain a free benefit from this approach to publishing. Stylesheets will let them render XML into Braille or audible speech. The advantages extend to others as well: commuters who want to surf the Web in their cars may also find it handy to have pages read aloud.

Although the Web has been a boon to science and to scholarship, it is commerce (or rather the expectation of future commercial gain) that has fueled its lightning growth. The recent surge in retail sales over the Web has drawn much attention, but business-to-business commerce is moving on-line at least as quickly. The flow of goods through the manufacturing process, for example, begs for automation. But schemes that rely on complex, direct program-to-program interaction have not worked well in practice, because they depend on a uniformity of processing that does not exist.

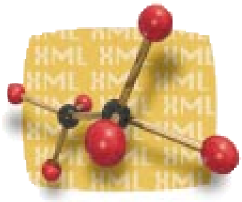
For centuries, humans have successfully done business by exchanging standardized documents: purchase orders, invoices, manifests, receipts and so on. Documents work for commerce because they do not require the parties involved to know about one another's internal procedures. Each record exposes exactly what its recipient needs to know and no more. The exchange of documents is probably the right way to do business on-line, too. But this was not the job for which HTML was built.

XML, in contrast, was designed for document exchange, and it is becoming clear that universal electronic commerce will rely heavily on a flow of agreements, expressed in millions of XML documents pulsing around the Internet.

Thus, for its users, the XML-powered Web will be faster, friendlier and a better place to do business. Web site designers, on the other hand, will find it more demanding. Battalions of programmers will be needed to exploit new XML languages to their fullest. And although the day of the self-trained Web hacker is not yet over, the species is endangered. Tomorrow's Web designers will need to be versed not just in the production of words and graphics but also in the construction of multilayered, interdependent systems of DTDs, data trees, hyperlink structures, metadata and stylesheets—a more robust infrastructure for the Web's second generation. SA

Further reading for this article is available at www.sciam.com/1999/0599issue/0599bosak.html on the World Wide Web.

New Languages for Science



XML offers a particularly convenient way for scientists to exchange theories, calculations and experimental results. Mathematicians, among others, have long been frustrated by Web browsers' ablity to display mathematical expressions only as pictures. **MathML** now allows them to insert equations into their Web pages with a few lines of simple text. Readers can then paste those expressions directly into algebra software for calculation or graphing.

Chemists have gone a step further, developing new browser programs for their XML-based **Chemical Markup Language** (CML) that graphically render the molecular structure of compounds described in CML Web pages. Both CML and **Astronomy Markup Language** will help researchers sift quickly through reams of journal citations to find just the papers that apply to the object of their study. Astronomers, for example, can enter the sky coordinates of a galaxy to pull up a list of images, research papers and instrument data about that heavenly body.

XML will be helpful for running experiments as well as analyzing their results. National Aeronautics and Space Administration engineers began work last year on **Astronomical Instrument ML** (AIML) as a way to enable scientists on the ground to control the SOFIA infrared telescope as it flies on a Boeing 747. AIML should eventually allow astronomers all over the world to control telescopes and perhaps even satellites through straightforward Internet browser software.

Geneticists may soon be using **Biosequence ML** (BSML) to exchange and manipulate the flood of information produced by gene-mapping and gene-sequencing projects. A BSML browser built and distributed free by Visual Genomics in Columbus, Ohio, lets researchers search through vast databases of genetic code and display the resulting snippets as meaningful maps and charts rather than as obtuse strings of letters. *—The Editors*

The Authors

JON BOSAK and TIM BRAY played crucial roles in the development of XML. Bosak, an on-line information technology architect at Sun Microsystems in Mountain View, Calif., organized and led the World Wide Web Consortium working group that created XML. He is currently chair of the W3C XML Coordination Group and a representative to the Organization for the Advancement of Structured Information Standards. Bray is co-editor of the *XML 1.0* specification and the related *Namespaces in XML* and serves as co-chair of the W3C XML Syntax Working Group. He managed the New Oxford English Dictionary Project at the University of Waterloo in 1986, co-founded Open Text Corporation in 1989 and launched Textuality, a programming firm in Vancouver, B.C., in 1996.

by Shawn Carlson

Hot Views of the Microscopic World

Regular readers know that I love microscopy. Through my trusty Spencer I've spent many hours roaming majestic beds of microscopic algae and floating forests of phytoplankton. But until recently, I had never studied crystal growth. Doing so normally involves melting something under the lens and letting it solidify, which requires a way of warming the microscope slides. Over the years I'd tried a few schemes but was never able to get fine temperature control and uniform heating. So I was delighted to receive an innovative design from Ely Silk, an accomplished amateur scientist in Tamarac, Fla. With it, you can create your own startling images of crystals [*see illustrations above*].

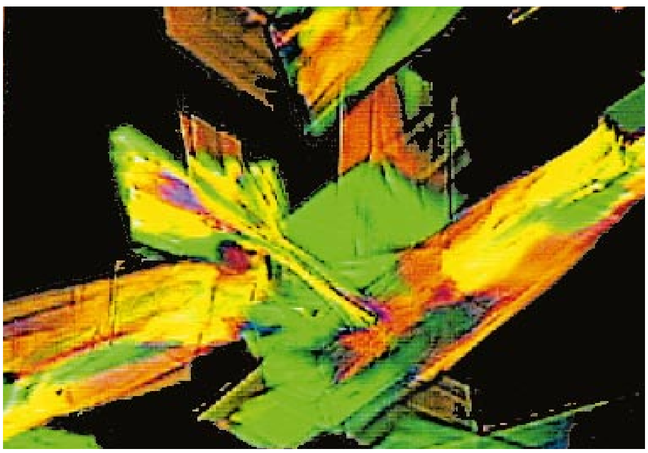
Silk constructed his heater from electroconductive glass of the kind used by automobile manufacturers for defrostable windows. The glass has a thin, transparent layer of either tin oxide or indium-tin oxide deposited on one side. An electric current flowing through this layer can heat the glass to temperatures greater than the boiling point of water. (Although Silk independently developed the idea of using conductive glass, Stephen A. Skirius described a similar project in a 1984 issue of the *Microscope* magazine.) The main drawback is that I have been unable to find an inexpensive source of the material. So I've purchased and cut up a large sheet of it and will make the pieces available through the Society for Amateur Scientists; details are at the end of this article.

Once you have secured the glass, you must prepare it to accept current. Silk used two thin strips of copper about 3 millimeters (about 0.1 inch) wide to form the electrodes. You can cut these strips from a sheet of copper foil, which is stocked by most sheet-metal dealers and art supply shops. Place the glass so that the oxide layer is up and affix the electrodes onto the left and right sides [*see illustration on opposite page*] using a metallized epoxy, which unlike most adhesives will let the electricity through. Resins filled with silver or aluminum powder are available at most hardware stores. If you can't find any, call Epoxies, Etc., in Greenville, R.I. (401-231-2930).

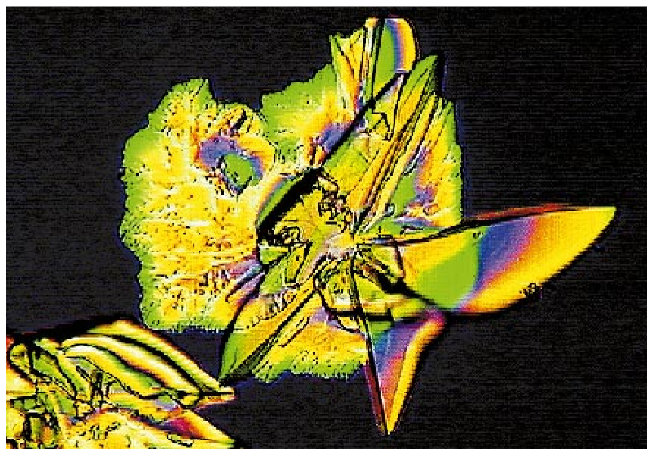
Next you'll need to protect the oxide layer from scratching while exposing specimens to the heat. Silk placed a drop of glycerin at the center of the oxide side of the glass stage and covered it with a large but thin coverslip. If you don't have any glycerin, any fluid with a high boiling point will work, such as radiator fluid, brake fluid or motor oil. For the coverslip, Silk recommended a No. 0 grade (the thinnest grade) that is 22 by 30 millimeters (0.9 by 1.2 inches), but just about any size will work. This arrangement lets your specimens respond quickly to any adjustments you may make in the amount of heating.

The object of study goes on top of the coverslip. Blanket it with an 18-millimeter square glass cover. For ease of handling, this topmost cover should be of a thicker grade, either No. 1 or No. 2. Fisher Science Education in Burr Ridge, Ill., sells a collection of various coverslips in boxes of 100 for $3 (call 800-955-1177; item number CQS17525A).

Finally, attach the electrodes to a power source that can deliver enough current. Silk used a variable 15-volt, 1-amp AC or DC supply. You can probably find such a source at most electronics surplus stores for about $20. Parts suppliers—such as Jameco (800-831-4242 or www.jameco.com)—can also provide lower-power sources, but you may need to wrap the stage partially in insulating material, such as newspaper. Or try picking through the wares of those small electronics suppliers who sell at local swap meets or flea markets. I once came across an entire bin of power supplies for $4 each. Silk reported that his easily heats the stage to 100 degrees Celsius (212 degrees Fahrenheit). Naturally, never leave



***MYRISTIC ACID AND TRIMYRISTIN,** mixed together, crystallize as flat blades. These images were taken at 160× magnification under polarized light.*

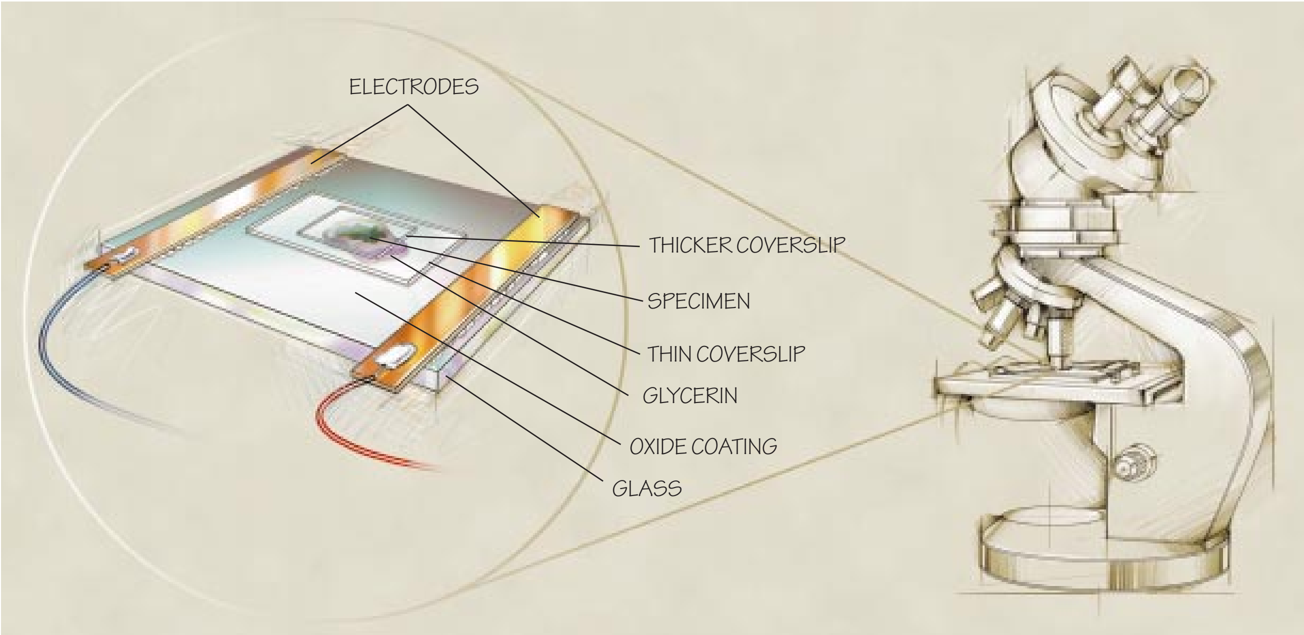


***NAPHTHALENE** crystals can be grown by heating a sand-size grain and condensing the vapors onto a slide.*

PHOTOGRAPHS BY ELY SILK

the stage unattended with the power on.

It is easy to get beautiful multicolored images using a set of polarizing filters. These filters act on the electromagnetic nature of light by passing only that energy whose electric field lies along a particular direction, known as the polarization axis of the filter. A double filter made by rotating two polarizers so that their axes are perpendicular should block all light. Odd as this may sound, adding a third polarizer between them can cause light to be transmitted again. Some light will pass through the added filter because its polarization axis is not at right angles to the



HEATED MICROSCOPE STAGE
is based on the type of glass used in many car window defrosters. The side of the glass with the conductive oxide layer is up. Glycerin protects the oxide, and glass coverslips hold the specimen.

axis of the first filter. Whatever light does get through must be aligned with the intermediate filter's axis. In effect, this filter rotates the electric field. Therefore, when the rotated light reaches the final filter, some can pass through.

Most crystals also polarize light because of the highly regular arrangement of their atoms. A crystal generally polarizes different wavelengths with different efficiencies, which causes some colors to come through more vividly than others. To capture this effect on film, position one polarizing filter above the light source and attach another to the objective lens of your microscope. Most large scientific supply houses carry such filters. Fisher Science Education sells a kit for $23 that allows you to construct both filters and even contains some crystalline material to study (item number CQS19709-3). Or you can experiment with making your own filters. Edmund Scientific in Barrington, N.J., has available high-quality polarizing, thin plastic sheets for $6 (call 609-573-6250; catalogue number H43781).

To study crystallization, place on the stage a material with a melting point between room temperature and 100 degrees C. By tuning the power supply to keep the stage temperature near the melting point of that material, you can alternately create and destroy the crystals by making small adjustments to the power. This experiment is much more satisfying than, say, watching salt crystals form by evaporation, during which you get to see such crystals only once before you must clean and reset the stage.

There are a number of materials that are safe to melt on the stage. Silk recommended thymol, camphor, menthol, stearic acid, trimyristin or myristic acid. You can obtain a mixture of trimyristin and myristic acid by soaking nutmeg in methanol and then filtering and evaporating the solvent. Most of the other substances you should be able to find in drugstores and chemistry sets. Consult the *Merck Index* for other ideas.

Of course, be careful. Some materials, such as naphthalene (once the active ingredient in mothballs), emit harmful gases when heated. (Modern mothballs often use paradichlorobenzene, which, though classified as an irritant, is not considered toxic to humans. And paradichlorobenzene crystals are a delight to study.) Never experiment with something unless you know it is safe or you are sure that nobody could be exposed to potentially poisonous fumes. Dedicated experimenters may want to invent a way to seal the cell hermetically or vent the vapors. A sealed cell could be used to incubate thermophilic organisms. I invite you to share your ideas on the relevant discussion area at the Society for Amateur Scientists Web page. SA

As a service to the amateur community, the Society for Amateur Scientists can provide the conductive glass for this project for $12 plus $3 shipping until May 2000. To place an order, call 619-239-8807 or send a check to 4735 Clairemont Square, Suite 179, San Diego, CA 92117. For more information about this and other projects from this department, check out the Society for Amateur Scientists Web page at www.thesphere.com/SAS/WebX.cgi.

Because of a printing error, labels were omitted from an illustration in April's Amateur Scientist. The full diagram is available at www.sciam.com/1999/0499issue/0499amsci.html on the World Wide Web. SCIENTIFIC AMERICAN *apologizes for the inconvenience.*

MATHEMATICAL RECREATIONS

by Ian Stewart

A Puzzle for Pirates

The logic of mathematics sometimes leads to apparently bizarre conclusions. The rule here is that if the logic doesn't have holes in it, the conclusions are sound, even if they conflict with your intuition. In September 1998 Stephen M. Omohundro of Palo Alto, Calif., sent me a puzzle that falls into exactly this category. The puzzle has been circulating for at least 10 years, but Omohundro came up with a variant in which the logic becomes surprisingly convoluted.

First, the original version of the puzzle. Ten pirates have gotten their hands on a hoard of 100 gold pieces and wish to divide the loot. They are democratic pirates, in their own way, and it is their custom to make such divisions in the following manner: The fiercest pirate makes a proposal about the division, and everybody votes on it, including the proposer. If 50 percent or more are in favor, the proposal passes and is implemented forthwith. Otherwise the proposer is thrown overboard, and the procedure is repeated with the next fiercest pirate.

All the pirates enjoy throwing one of their fellows overboard, but if given a choice they prefer cold, hard cash. They dislike being thrown overboard themselves. All pirates are rational and know that the other pirates are also rational. Moreover, no two pirates are equally fierce, so there is a precise pecking order—and it is known to them all. The gold pieces are indivisible, and arrangements to share pieces are not permitted, because no pirate trusts his fellows to stick to such an arrangement. It's every man for himself.

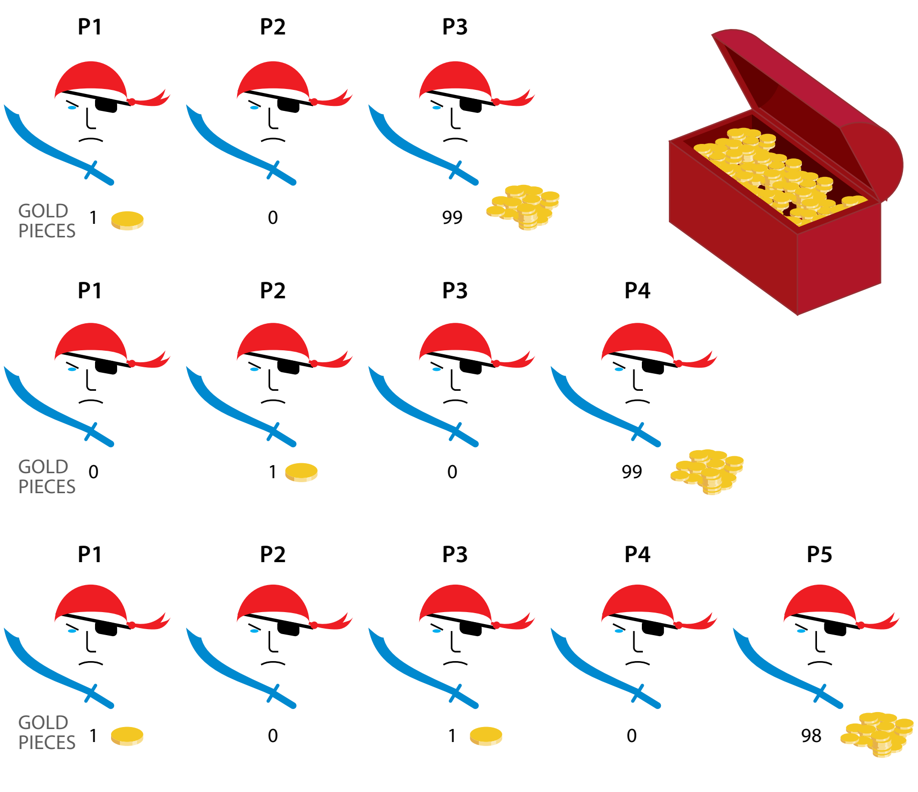
What proposal should the fiercest pirate make to get the most gold? For convenience, number the pirates in order of meekness, so that the least fierce is number 1, the next least fierce number 2 and so on. The fiercest pirate thus gets the biggest number, and proposals proceed in reverse order from the top down.

The secret to analyzing all such games of strategy is to work backward from the end. At the end, you know which decisions are good and which are bad. Having established that, you can transfer that knowledge to the next-to-last decision and so on. Working from the beginning, in the order in which the decisions are actually taken, doesn't get you very far. The reason is that strategic decisions are all about "What will the next person do if I do this?" so the decisions that follow yours are important. The ones that come before yours aren't, because you can't do anything about them anyway.

Bearing this in mind, the place to start is the point at which the game gets down to just two pirates, P1 and P2. The fiercest pirate at this point is P2, and his optimal decision is obvious: propose 100 gold pieces for himself and none for P1. His own vote is 50 percent of the total, so the proposal wins.

Now add in pirate P3. Pirate P1 knows—and P3 knows that he knows—that if P3's proposal is voted down, the game will proceed to the two-pirate stage and P1 will get nothing. So P1 will vote in favor of anything that P3 proposes, provided it yields him more than nothing. P3 therefore uses as little as possible of the gold to bribe P1, leading to the following proposal: 99 for P3, 0 for P2 and 1 for P1 [*see illustration at left*].

The strategy of P4 is similar. He needs 50 percent of the vote, so again he needs to bring exactly one other pirate on board. The minimum bribe he can use is one gold piece, and he can offer this to P2 because P2 will get nothing if P4's proposal fails and P3's is voted on. So P4's proposal is 99 for himself, 0 for P3, 1 for P2 and 0 for P1. The approach taken by P5 is slightly different: he needs to bribe *two* pirates to get a winning vote. The minimum bribe he can use is two gold pieces, and the unique way he can succeed with this bribe is to propose 98 gold pieces for himself, 0 for P4, 1 for P3, 0 for P2 and 1 for P1.



BRYAN CHRISTIE

FIERCEST PIRATES
get the lion's share of gold when the loot is divided among groups of three, four or five pirates.

Possible Recipients of One Gold Piece

202 PIRATES

P1	P2	P3	P4 ……	P197	P198	P199	P200	P201	P202
NO	YES	NO	YES ……	NO	YES	NO	YES	YES	NO

204 PIRATES

P1	P2	P3	P4 ……	P197	P198	P199	P200	P201	P202	P203	P204
YES	NO	YES	NO ……	YES	NO	YES	NO	NO	YES	NO	NO

BRYAN CHRISTIE

IN LARGER GROUPS,
the fiercest pirate must bribe 100 of his fellows with one gold piece each.

The analysis proceeds in the same manner, with each proposal uniquely prescribed to give the proposer the maximum reward while also ensuring a favorable vote. Following this pattern, P10 will propose 96 gold pieces for himself, one gold piece for each of pirates P8, P6, P4 and P2, and none for the odd-numbered pirates. This allocation solves the 10-pirate version of the puzzle.

Omohundro's contribution is to ask the same question but with 500 pirates instead of 10 divvying up the 100 gold pieces. Clearly, the same pattern persists—for a while. In fact, it persists up to the 200th pirate. P200 will offer nothing to the odd-numbered pirates P1 through P199 and one gold piece to each of the even-numbered pirates P2 through P198, leaving one for himself. At first sight, the argument breaks down after P200, because P201 has run out of bribes. Yet P201 still has a vested interest in not being thrown overboard, so he can propose to take nothing himself and offer one gold piece to each of the odd-numbered pirates P1 through P199.

Pirate P202 also is forced to accept nothing—he must use the entire 100 gold pieces to bribe 100 pirates, and these recipients must be among those who would get nothing under P201's proposal. Because there are 101 such pirates, P202's proposal is no longer unique—there are 101 ways to distribute the bribes. The illustration above shows the 101 pirates who *might* get something from P202's proposal and the 101 pirates who would definitely get nothing.

Pirate P203 must obtain 102 favorable votes, including his own, and he clearly doesn't have enough cash available to bribe 101 of his fellow pirates. So P203 goes overboard no matter what he proposes. Even though P203 is destined to walk the plank, this doesn't mean that he plays no part in the proceedings. On the contrary, P204 now knows that P203's sole aim in life is to avoid having to propose a division of the spoils. So P204 can count on P203's vote, whatever P204 proposes. Now P204 just squeaks home: he can count on his own vote, P203's vote and 100 others from bribes of one gold coin each—102 votes in all, the necessary 50 percent. The recipients of the bribes must be among the 101 pirates who would definitely receive nothing under P202's proposal.

What of P205? He is not so fortunate! He cannot count on the votes of P203 or P204: if they vote against him, they will have the fun of throwing him overboard and can still save themselves. So P205 gets thrown overboard no matter what he proposes. So does P206—he can be sure of P205's vote, but that's not enough. Similarly, P207 needs 104 votes—three plus his own plus 100 from bribes. He can get the votes of P205 and P206, but he needs one more, and it's not available. So P207 also walks the plank.

P208 is more fortunate. He also needs 104 votes, but P205, P206 and P207 will vote for him! Add in his own vote and 100 bribes, and he's in business. The recipients of his bribes must be among those who would definitely get nothing under P204's proposal: the even-numbered pirates P2 through P200, P201, P203 and P204.

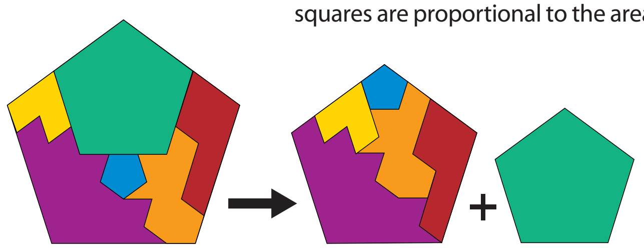
Now a new pattern has set in, and it continues indefinitely. Pirates who can make winning proposals (always to give themselves nothing and to bribe 100 fellow pirates) are separated from one another by ever longer sequences of pirates who will be thrown overboard no matter what proposal they make—and whose vote is therefore ensured for any fiercer pirate's proposal. The pirates who avoid this fate are P201, P202, P204, P208, P216, P232, P264, P328, P456 and so on—pirates whose number equals 200 plus a power of 2.

We must now decide which pirates are the lucky recipients of the bribes, just to make sure they will accept them. As I said, the solution is not unique, but one way to do this is for P201 to offer bribes to the odd-numbered pirates P1 through P199, for P202 to offer bribes to the even-numbered pirates P2 through P200, then P204 to the odd numbers, P208 to the evens and so on, alternating from odd to even and back again.

We conclude that with 500 pirates and optimal strategy, the first 44 pirates are thrown overboard, and then P456 offers one gold piece to each of the odd-numbered pirates P1 through P199. Thanks to their democratic system, the pirates have arranged their affairs so that the very fierce ones mostly get thrown overboard and can consider themselves lucky to escape death with none of the loot. Only the 200 meekest pirates have a chance of getting anything, and only half of *them* will actually receive a gold piece. Truly, the meek shall inherit the worth. SA

FEEDBACK

In response to the column on dissections ["Two-Way Jigsaw Puzzles," October 1997], Gil Lamb of the Principality of Andorra sent me a pentagon dissection (*below*) that provides an ingenious proof of the Pythagorean relation $3^2 + 4^2 = 5^2$. The numbers represent the lengths of the sides of the pentagons, so their squares are proportional to the areas. —*I.S.*

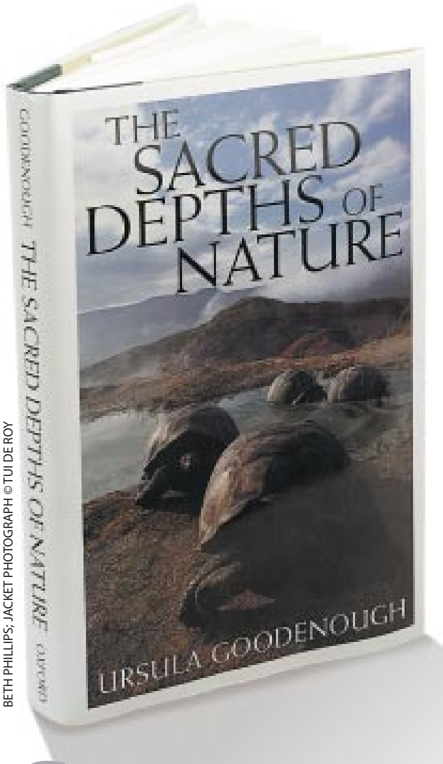


BRYAN CHRISTIE

SANCTIFYING THE COSMOS

Review by Barbara Smuts

The Sacred Depths of Nature
BY URSULA GOODENOUGH
Oxford University Press, New York and Oxford, 1998 ($24)



BETH PHILLIPS; JACKET PHOTOGRAPH © TUI DE ROY

Several years ago I took a day off from research on wild dolphins to walk miles of remote Australian beach. To the west, the meeting of sea and sky was barely discernible; to the east, searing desert extended 2,000 miles. For hours I walked through this exquisite but barren landscape in utter silence, mourning a recent personal loss. Suddenly, with no warning, the hollow feeling within merged with the emptiness all around into a singular, stunning void that engulfed me with dizzying speed. I collapsed to the ground, reduced to a tiny, isolated speck in a vast, impersonal universe. I struggled to a sitting position, blinking in the midday glare, searching for something, anything, to bring me back to my ordinary self. Nothing. Despite the sun's heat, I felt cold and I was afraid. Then, as if from a great distance, I heard a faint, familiar sound that brought immense relief. A few hundred yards away a dozen cormorants were gathering at the sea's edge to dry their wet, oily wings, squawking and scrambling as they settled into their places on the sand. I drew closer, hoping fiercely that they wouldn't rise up in flight, and beheld the luminous surface of their dark feathers. Those birds could have been anywhere, but instead by some miracle they were right there, then, with me. I felt wave upon wave of gratitude for their existence and for the existence of all sentient beings.

In *The Sacred Depths of Nature*, Ursula Goodenough, one of America's leading cell biologists and a professor of biology at Washington University, gives voice to many such moments of communion with nature. The recognition of nature's power to evoke emotions such as awe and gratitude is, of course, not new, as Goodenough acknowledges in her introduction. Two aspects of her approach, however, are novel.

First, Goodenough's "nature" encompasses not just our direct experience of the natural world but also our scientific understanding of it. She argues eloquently that such understanding, far from provoking detachment or despair, can be a wellspring of solace and joy. The second novel aspect is Goodenough's definition of religious experience. For her, experience qualifies as religious if it entails emotions like awe, wonder, gratitude or joy, regardless of whether or not the person associates such emotions with traditional religious creeds, deities or supernatural phenomena. Goodenough, who professes no belief in a god, describes a profoundly religious relationship with the cosmos rooted in her detailed understanding of phenomena such as atoms and stars, the complex workings of a cell, and the astonishing evolutionary emergence of a mind capable of inquiring into its own nature. Such understanding can give rise to what she calls "religious naturalism," a scientifically based reverence for every aspect of the natural world, including ourselves.

Goodenough aims to "present an accessible account of our scientific understanding of Nature and then suggest ways that this account can call forth appealing and abiding religious responses." She does this by beginning each chapter with a factual description of a phenomenon critical to life, such as how DNA codes for proteins or how natural selection works, and concluding with a briefer section labeled "Reflections," in which she shares the thoughts and feelings this scientific knowledge stirs in her. I found this format effective. Her separation of the science and the religious emotions gave me the freedom to first absorb the science as fact, without being distracted by her responses. The "Reflections" were unabashedly personal and gently encouraged me to contemplate my own responses. For a book about a new kind of religion, there is a striking absence of preaching.

The Scientific and the Sacred

Goodenough presents her scientific knowledge as stories, with plot twists and turns that trigger a "what's next?" curiosity. I assigned several chapters of the book to undergraduates with minimal background in biology, and they found them intelligible and informative, so one does not need to know much about science to enjoy this book. For a scientist like myself, Goodenough's elegant narratives provide a refreshing way to encounter familiar material. I was especially impressed with her ability to cut right to the quick, so that within a few short pages the reader is whisked from the big bang to the emergence of our planet and the birth of life on earth. The factual sections of the book are valuable enough to stand on their own as a brief, highly engaging introduction to the epic of evolution. Would that all scientific texts were so carefully conceived and beautifully written.

But the "Reflections" are the best and by far the most original part of the book. Goodenough's luminous prose evokes images and feelings more commonly associated with poetry than science, and her meditations on meaning are infused with wonder and joy. She acknowledges, however, that for many people scientific accounts of nature's workings are more likely to evoke alienation than religious awe (see, for example, Melvin Konner's review of Richard Dawkins's *Unweaving the Rainbow* in the March issue of *Scientific American*).

Goodenough aims to "present an accessible account of our scientific understanding of Nature and then suggest ways that this account can call forth appealing and abiding religious responses."

In the first set of reflections, she shares her own encounter with nihilistic despair when, as an adolescent, she pondered the night sky. She thought about how each star is dying and the fact that "Our sun too will die, frying the Earth to a crisp during its heat-death, spewing its bits and pieces out into the frigid nothingness of curved space-time." Such thoughts overwhelmed her: "The night sky was ruined. I would never be able to look at it again.... A bleak emptiness overtook me whenever I thought about what was really going on out in the cosmos or deep in the atom. So I did my best not to think about such things."

How she came to terms with such feelings reveals the personal foundations of her religious naturalism:

But, since then, I have found a way to defeat the nihilism that lurks in the infinite and the infinitesimal. I have come to understand that I can deflect the apparent pointlessness of it all by realizing that I don't have to seek a point. In any of it. Instead, I can see it as the locus of Mystery.... Inherently pointless, inherently shrouded in its own absence of category. The clouds passing across the face of the deity in the stained-glass images of Heaven.... The realization that I needn't ... seek answers to the Big Questions has served as an epiphany. I lie on my back under the stars and the unseen galaxies and I let their enormity wash over me. I assimilate the vastness of the distances, the impermanence, the fact *of it all. I go all the way out and then I go all the way down, to the fact of photons without mass and gauge bosons that become massless at high temperatures. I take in the abstractions about forces and symmetries and they caress me like Gregorian chants, the meaning of the words not mattering because the words are so haunting.*

Mystery generates wonder, and wonder generates awe. The gasp can terrify or the gasp can emancipate.

Goodenough's emancipation, through what she calls "a covenant with Mystery," represents her very personal, hard-won experience of the Divine. One prime reason Goodenough's covenant with mystery is so emancipating is that it allows her to revel in, rather than retreat from, the paradoxes she encounters everywhere as both a scientist and a mortal being. Her articulation of one such paradox, in the chapter on "Multicellularity and Death," offers a striking example:

... it is here that we arrive at one of the central ironies of human existence. Which is that our sentient brains are uniquely capable of experiencing deep regret and sorrow and fear at the prospect of our own death, yet it was the invention of death, the invention of the germ/soma dichotomy, that made possible the existence of our brains....

Does death have any meaning?

Well, yes, it does. Sex without death gets you single-celled algae and fungi; sex with a mortal soma gets you the rest of the eukaryotic creatures. Death is the price paid to have trees and clams and birds and grasshoppers, and death is the price paid to have human consciousness, to be aware of all that shimmering awareness and all that love.

My somatic life is the wondrous gift wrought by my forthcoming death.

Goodenough's religious naturalism is inspired by the scientific account of cosmic evolution, a story that has important things to say about the universe, where we came from and our place in the larger scheme of things. This particular story is brand-new in the timescale of human life on earth, but, as Goodenough points out, all people feel compelled to develop accounts of the cosmos that tell them "how things are" and which things matter. Although we refer to such stories as myths, in a prescientific world these accounts did exactly what science does for us today: they provided a conceptual framework within which people could comprehend and relate to a mysterious universe. But myths were not just helpful stories; they also served to sanctify the cosmos and our place in it, thereby eliciting a direct experience of the sacred.

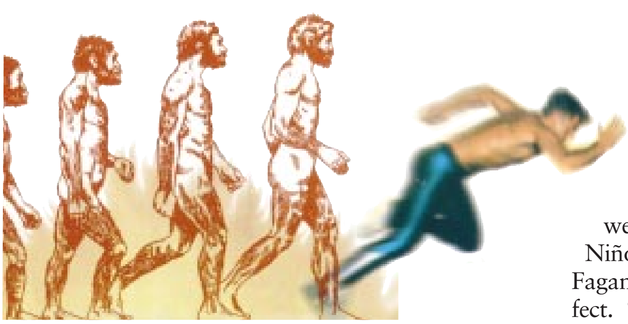
An Inherited Awe

Perhaps an imperative to experience our world as numinous lurks deep within us all, a legacy of tens of thousands of years of ancestral religious practice. *The Sacred Depths of Nature* can thus be viewed as an invitation to bring together aspects of experience only recently rendered separate by the rise of modern science—but to bring them together in a new way, based on an account of reality potentially shared by people everywhere. Although the emergence of a universal religion based on a shared scientific worldview seems like a distant dream, Goodenough might be right that this is our best hope for a desperately needed global ethic dedicated to the preservation of life on earth.

BARBARA SMUTS is a professor in the psychology and anthropology departments at the University of Michigan. She has studied social relations among wild baboons, chimpanzees and bottlenose dolphins and is the author of Sex and Friendship in Baboons, *soon to be published in a new paperback edition by Harvard University Press.*

CHILDREN OF PROMETHEUS: THE ACCELERATING PACE OF HUMAN EVOLUTION. Christopher Wills. Perseus Books, Reading, Mass., 1998 ($25).

On a Saturday in 1997 Wills and his wife went to the X-games (X for "extreme") in San Diego and found themselves among 30,000 "bronzed and healthy young people, watching a range of contests that their parents would have found unimaginable." The contests included snowboarding, in-line skating and bungee-jumping—all invoking challenges new to athletes and reinforcing Wills's view that "part of our success is due to our ability to modify our behaviors in the face of new environmental challenges, and to build on a knowledge base in order to do so." Reviewing in this splendidly eclectic book the evolutionary reasons that human beings have taken a path much different from those traveled by all other animals, he undertakes to "show not only that we are still evolving, but that our evolution—particularly the evolution of our minds—is actually proceeding at an accelerating pace."



LINDA RICHARDS (*illustration*); TERJE RAKKE (*photograph*)

In his journey he examines people who live at high altitudes in Tibet and the Andes, the effects of disease on human development and the singular selective pressures that bear on workers low in the hierarchy of the British civil service. "There seems no doubt," he concludes, "that the environment of the late twentieth century is revealing more than ever of our underlying genetic variation for brain function and perhaps for other characteristics, and is accelerating our evolution as a result."

THE FIFTH MIRACLE: THE SEARCH FOR THE ORIGIN AND MEANING OF LIFE. Paul Davies. Simon & Schuster, New York, 1999 ($25).

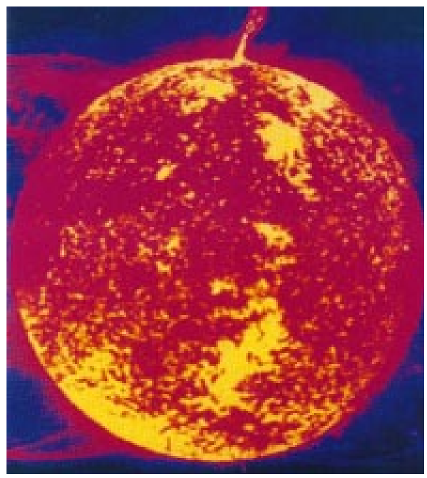
The title is catchy but misleading. It derives from a line in Genesis: "Let the land produce vegetation." That is the first biblical mention of life and, according to Davies, seems to be the tale's fifth miracle. But he does not intend to suggest that the origin of life was a miracle. His thesis is that "the first terrestrial organisms lived deep underground, entombed within geothermally heated rocks in pressure-cooker conditions." Davies also looks at the theories that life began by chemical assembly in a watery medium and that it came to the earth from space in the form of already viable microbes—the panspermia hypothesis. "We have," he says, "a good idea of the where and the when of life's origin, but we are a very long way from comprehending the how." He is confident, however, that science will "eventually give a convincing explanation" of the how.

FLOODS, FAMINES AND EMPERORS: EL NIÑO AND THE FATE OF CIVILIZATIONS. Brian Fagan. Basic Books, New York, 1999 ($25).

The aberrant and often devastating weather patterns brought on by El Niño are by now familiar. According to Fagan, they have had a less recognized effect. "There is a strong correlation between unusual climatic shifts and unusual historical events." He cites the fall of the Old Kingdom in ancient Egypt, the Moche society of Peru and the Maya of lowland Central America as examples. Other societies—the Anasazi of the American Southwest and today's San foragers of southern Africa's Kalahari Desert—have survived the impact of severe climatic stress. Fagan asks what determines whether a society passes or fails such a test. Those that pass, he answers, have decisive centralized leadership, or develop innovations that increase the carrying capacity of the land, or, if they can, simply pack up and move elsewhere. Those that fail are less adaptable because their thinking is too rigid for the circumstances. Fagan describes the mechanisms and effects of El Niños, La Niñas and other far-reaching meteorological events and then discusses how several societies have coped with them. Could severe climatic change topple a modern civilization? "No one force—overpopulation, global warming, or rapid climate change—will destroy our civilization. But the combination of all three makes us prey to the knockout blow that could."

EMPIRE OF THE SUN: PLANETS AND MOONS OF THE SOLAR SYSTEM. John Gribbin and Simon Goodwin. New York University Press, New York, 1998 ($24.95).

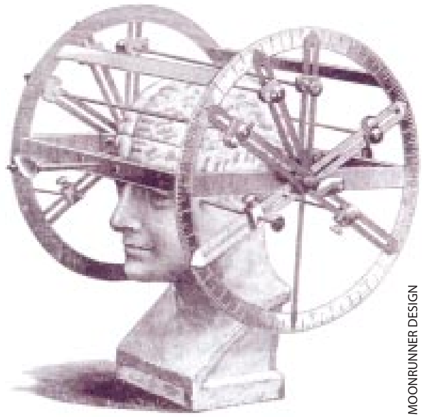
This is essentially a picture book, but the science is here, too. And what pictures! The sun, its planets and their moons appear in stunning photographs obtained from spacecraft. "Our aim in this book," Gribbin and Goodwin write, "is to focus unashamedly on the visual delights, offering you our selection of the best vistas of the Solar System that have yet been unveiled. We use some images from the first wave of planetary exploration (but usually dressed up in new, digitally enhanced finery), many from the new wave of planetary probes, and some from our old friend, the Hubble Space Telescope, which provides the best images we can get from Earth orbit of the other members of the Solar System." As for the science, Gribbin and Goodwin present a brief but wonderfully coherent account of the formation of the solar system and what is known about the sun, the planets, the moons, the asteroids and the comets. Three appendixes provide a list of principal planetary missions, 1973 to 1997, a look at the future of planetary probes and four useful astronomical sites on the Internet. The "Empire of the Sun" is special to humankind, the authors say, but it is surely not unique. "In all probability, this means that life—even intelligent life—may be quite common, and that at this very moment there are other civilisations exploring other planetary worlds, and marvelling over the images being sent back to their home planet."



NASA

MAPPING THE MIND. Rita Carter. Univ. of California Press, Berkeley, 1998 ($29.95).

Vladimir Nabokov is best known for his novels and poems, but he had another distinction: he heard in colors. "The long 'aaa' of the English alphabet has for me the tint of weathered wood," he wrote in his autobiography, going on to list several other associations he made between sounds and colors. The condition is called synaesthesia. It is one of many mental oddities that Carter cites as helping to show how the mind



MOONRUNNER DESIGN

works. The brain has been slow to give up its secrets, she says, but as we approach the 21st century, "brain scanning machines are opening up the territory of the mind just as the first ocean-going ships once opened up the globe." She recounts comprehensively, aided by an abundance of illustrations, what has been discovered about brain structure and function. What is known now, however, is only a beginning, Carter says—"the task of creating a detailed picture is one for the new millennium and beyond."

SYMBIOTIC PLANET: A NEW VIEW OF EVOLUTION. Lynn Margulis. Basic Books, New York, 1998 ($21).

Gracing her tale with personal touches and with lines from the poems of Emily Dickinson as chapter headings, Margulis describes the development of her theory of symbiosis and ponders how it relates to the Gaia concept of a living Earth. "No species existed before bacteria merged to form larger cells including ancestors to both plants and animals," she writes. "The permanent incorporation of bacteria inside plant and animal cells as plastids and mitochondria is the part of my serial endosymbiosis theory that now appears even in high school textbooks. But the full impact of the symbiotic view of evolution has yet to be felt. And the idea that new species arise from symbiotic mergers among members of old ones is still not even discussed in polite scientific society."

The Gaia concept is that aspects of Earth's atmospheric gases and surface rocks and water are regulated by the growth, death, integration and other activities of living organisms. Gaia, Margulis says, "is a convenient name for an Earthwide phenomenon: temperature, acidity/alkalinity, and gas composition regulation" through the series of interacting ecosystems that compose a single huge ecosystem at Earth's surface. How do symbiosis and the Gaia concept relate to each other? Greg Hinkle, once Margulis's student and now a professor at the University of Massachusetts, provides an answer that Margulis likes: "Gaia is just symbiosis as seen from space."

LIVING ON THE WIND: ACROSS THE GLOBE WITH MIGRATORY BIRDS. Scott Weidensaul. North Point Press, New York, 1999 ($26).

"At whatever moment you read these words, day or night, there are birds aloft in the skies of the Western Hemisphere, migrating." Thus Weidensaul begins his compelling tale, adding shortly afterward what must be a widely shared thought: "That such delicate creatures undertake these epic journeys defies belief." With helpful supporting maps, he describes the migrating habits of many bird species and considers the intriguing question of how they do it.

At the end, he focuses on a single bird—a redstart that he hears and sees singing while he sits alongside a stream in the mountains of northern Pennsylvania. "What I cannot see, no matter how closely I look, is what drives this small creature, barely heavier than air, to make the journeys that it must make.... Its secrets are locked in that tiny packet of brain and muscle and instinct, a few feet away but separated from me by an immense, uncrossable distance. It knows, and I do not."

DOROTHY HODGKIN: A LIFE. Georgina Ferry. Granta Books, London, 1998 ($29.95).

At the age of 10, Dorothy Crowfoot, as she was then, did a school experiment that involved making solutions of alum and copper sulfate from which to grow crystals. When the crystals appeared, she was enchanted. "'I was captured for life,' she later wrote, 'by chemistry and crystals.'" Her fascination led her to a distinguished career in x-ray crystallography, and that led her to the Nobel Prize in Chemistry—

FROM *DOROTHY HODGKIN: A LIFE*

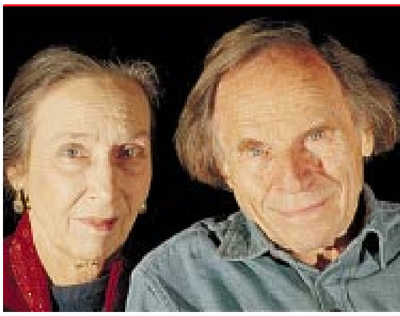
awarded in 1964 for her determination of the structure of biologically important molecules. By the end of her life, her achievements in that field included determining the structures of penicillin, vitamin B_{12} and insulin. She was also an activist in the cause of international understanding. When she died in 1994 at the age of 84, her good friend Max Perutz—winner of the 1962 Nobel Prize in Chemistry—said at her memorial service: "Dorothy will be remembered as a great chemist, a saintly, tolerant and gentle lover of people and a devoted protagonist of peace." Ferry, good at the science and good at the life, has produced a biography that illuminates all those facets of Hodgkin's persona.

ASTROPHYSICAL CONCEPTS. Third edition. Martin Harwit. Springer-Verlag, New York, 1998 ($69.95).

Astronomer Harwit has finally updated his classic textbook to encompass the exciting developments of the decade since its last edition. It is ideal for those *Scientific American* readers who are mathematically literate and who want to pursue topics covered in the magazine to greater depth. Harwit takes a thematic approach to the subject, oriented around the guiding physical principles rather than the conventional sequence of planet, star, galaxy and cosmos. The approach rewards readers who just want to flip through the book as well as students who want to derive for themselves some of the basic equations in astronomy. Harwit also includes an idiosyncratic sampling of unorthodox topics such as faster-than-light particles, steady-state cosmology and panspermia.

EVIL: INSIDE HUMAN VIOLENCE AND CRUELTY. Roy F. Baumeister. W. H. Freeman, New York, 1999 (paperbound, $15.95).

The question of why people hurt others is perhaps humanity's oldest and most urgent, long the subject of literature and religion. Can social science provide any answers? Social psychologist Baumeister assembles the available research, such as experiments on how people justify small transgressions and react to hypothetical situations, as well as close readings of accounts by murderers, rapists and torturers. He concludes that "pure evil"—brutality inflicted on innocent victims for sadistic pleasure—is largely a myth. Most violence springs from the same sources as other human behavior: ambition, lust, fear, pride, idealism. It breaks out when self-control breaks down, often because of group pressures or a slow escalation from seemingly innocuous decisions. Most perpetrators do not enjoy their acts, at least at first, but feel they must be done. "To understand evil," Baumeister writes, "we must set aside the comfortable belief that we would never do anything wrong. Instead, we must begin to ask ourselves, what would it take for *me* to do such things?" Although few of these ideas are original to Baumeister, and the book is sometimes pedantic, it is a worthy synthesis both for victims who want to know why and for policymakers who need to know what to do. SA



COMMENTARY

WONDERS

by Philip and Phylis Morrison

Galileo's Cicada

A parable that is both a moving reflection on science and an early investigation in acoustics

The alphabet has fascinated Phylis ever since she first learned her ABCs. She taught calligraphy and still displays a fine italic hand. Apprenticed to a neighbor artist-printer, she learned to set old type the old way: by hand, for hand-powered impression. Nowadays she holds many fonts, not in wooden cases heavy with lead castings but in microscopic magnetic patterns of metal oxide particles spotted on the hard disk, and she prints out by laser jet. Some years back we came across her long-stored handpress and a supply of type. Out of nostalgia we printed during one hardworking week a small run of a very brief paperbound book of letterpress for friends. (Phil, acting as printer's devil, left only one subtle bug in his proofing duty: between just a single pair of text lines there had crept one thin lead spacer too many!)

What to print? Travel to Florence and Padua and the influence of a couple of gifted and charming Italian collaborators in astrophysics led us, no linguists, to decipher some Italian texts. At 60 years of age, Galileo Galilei, bound by a promise to the Vatican to avoid promoting the Copernican worldview, published a serious nontechnical book in Italian, to express for a wider reading public his own take on the methods and aims of science. That book, *The Assayer,* is to this day admired as literature. We offer our own rendering in English of one parable—personal, witty and warm—published in Florence in 1623:

Once upon a time in a rather lonely place, there lived a man gifted by nature with extraordinary curiosity and a keen mind. For pleasure, he raised different birds whose songs he enjoyed. With wonder, he observed how artfully they were able to form their songs with the very air they breathed, all of them so sweet.

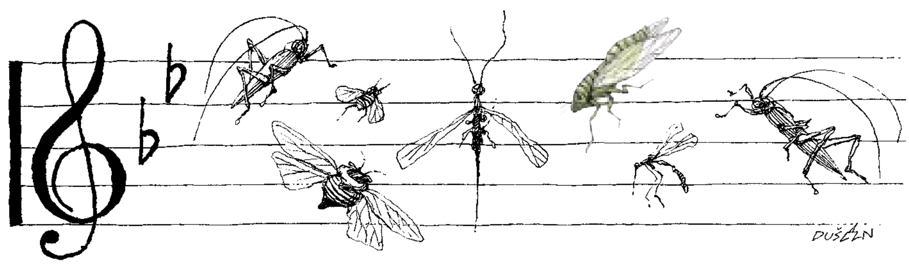
One night near his house he chanced to hear a delicate tune; not being able to imagine that it was anything but some bird, he set out to locate it. Coming to a road, he found a shepherd boy blowing into a kind of hollow tube of wood. As he moved his fingers along the tube, now opening and again closing the holes that were let into the tube, the shepherd brought from it airs like those of birds, but even more varied. Overcome by natural curiosity, the man traded the boy a calf to win the flute.

Once home alone, he came to realize that had he not happened to meet the shepherd, he would never have known that in nature there were two ways of forming sweet song. He decided to set out into the world, looking forward to meeting with some other adventure.

The next day he happened to pass close by a little hut. He could hear within it another, similar tone. To satisfy himself that it was a flute, or perhaps a caged blackbird, he went in, to find a youth with a bow in his right hand, drawing it across some strings stretched taut on a hollow, wooden box. With his left hand the young man held the instrument while his fingers played over it. Without the use of breath at all, the fiddler brought forth diverse and melodious sounds.

Judge the man's astonishment, you who share his curiosity and see the workings of his mind. Having now been surprised by two new and unexpected ways of forming tunes, he began to believe that still other means could exist in nature. What was his wonder, then, when on entering a certain temple, he looked behind the gate to see what had sounded only to find that the tone had come from the hinges and metal fastenings that moved when he opened the door?

Another time, full of curiosity, he went into a tavern, expecting to see someone lightly playing a bow across the strings of a violin, only to see a man rubbing a fingertip around the rim of a goblet, to bring out a pleasant tone.



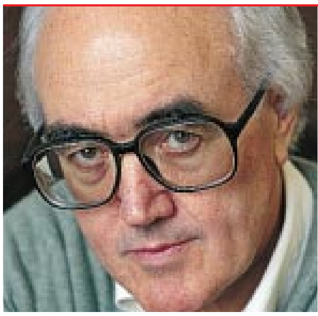
DUSAN PETRICIC

But when he observed that wasps, mosquitoes and flies formed their unending hum not, like his birds, by making notes one by one with the breath but by beating their wings with great speed, he was so surprised that his conviction that he knew how sounds were made was diminished.

He saw that from all his experience he did not know enough to understand or even to believe that crickets not able to fly, possessing no breath, can yet extract their sweet and sonorous calls by slowly scraping their wings.

He finally came to believe that it was next to impossible that there could be any new way to form tone, having observed not only all these methods but also organs, trumpets, fifes, stringed instruments of every kind and even that lit-

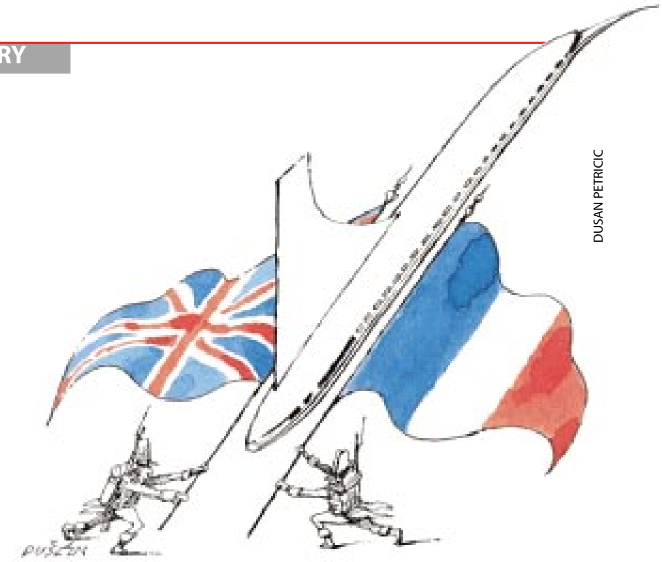
Continued on page 107



CONNECTIONS

by James Burke

Entente Cordiale



DUSAN PETRICIC

It was only the other week that I realized that the Anglo-French SST is called Concorde to celebrate Anglo-French amity. This hit me at 60,000 feet over the Atlantic, as I watched everybody else on board pretending to be bored as we belted along at Mach 2.

Of course, apart from the Mach number on the panel at the front of the cabin there was no sensation of being supersonic. Ernst Mach himself foretold this back in the late 19th century, when he spun people around with paper bags on their heads to investigate adaptation to acceleration. After the initial surge, your semicircular canals get totally ho-hum.

Given the knockout stuff he did, it's a pity Mach never gets the press Einstein does, because Mach was into relativity long before the Great Man. For Mach, there were no absolutes—just frames of reference—because perception (note paper bag experiment above) was all subjective. The fancy name for this school of thought was Positivism, and many people believe Mach founded it in Vienna. Which is why an interesting French thinker (who jumped off a bridge, married a hooker and started sociology) named Auguste Comte never gets the press Mach does. But let me short-circuit this before it gets out of hand: Mach got Positivism from Comte, who got it from Saint-Simon, who got it from Condillac, who got it from Locke, who. . . .

Anyway, Comte. The guy who first said the aim of science was prediction and who split history into three eras: it's all gods; it's all mysterious forces; it's natural laws we'll formulate when we work out the math. Comte also came up with social physics, the way to predict behavior and make life easier for the zoners, planners and politicians (give him a 5?). One of the other things Comte was positive about was the "general science of life" developed by Marie-François-Xavier Bichat, who boiled, dried, fried, baked, stewed, steamed, soaked, fricasseed (and in general applied the culinary act of reduction to) bits of animal and human. He identified 21 different types of tissue, whereupon remarking that because each tissue had different properties, each tissue would catch different diseases. You were looking for cause of death? *Cherchez la tissue.* Fortunately for devotees of *Columbo* and forensics in general, Bichat's noodling became known as pathological anatomy.

Of course, this physiological bottom-line approach of Bichat's . . . wasn't. In the new, late 18th-century nature-philosophy school, Bichat was only a follower. The leader being Friedrich von Schelling. (Well, I could argue that von Schelling got it from Fichte, who got it from Kant, et cetera, but you'd throw this magazine away in a fit.)

What else would you call 500 repeats of Franklin's kite-in-a-thunderstorm experiment?

Nature-philosophy was all about a Grand Unified Theory before the Grand Unified Theory, postulating the existence of a fundamental substrate from which everything was made (like Bichat's tissue, which is why von Schelling went looking for it). In 1797 von Schelling also gave Romanticism some oomph with the idea that nature was all about opposites: north-south magnetic poles, acid and base, hot and cold, that stuff. Moreover, life processes were all about the constant struggle between these opposites. Out of which would come "unification on a higher plane." This kind of blah-blah made late-model Enlightenment thinkers tear their hair out.

Not so a Danish wig maker's apprentice, Hans Christian Oersted, who logically went on to a degree in pharmaceutics and then got all excited about this Romantic nature-conflict business. Reckoning that the conflicting positive-negative "magnetical" nature of electricity could be made to conflict so much that if you shoved a current down a very thin wire it'd make a magnetic field, Oersted managed to do so in 1820. It did so. Five years later an English boot maker, William Sturgeon, wrapped a live wire around a soft iron bar, and the magnetic field that happened was strong enough to move things. Like a telegraph receiver key when bursts of current came down the line. Not bad for a boot maker, right?

Sturgeon's electromagnetic obsession (what else would you call 500 repeats of Ben Franklin's kite-in-a-thunderstorm experiment?) got him a job as lecturer at the East India Company Royal Military College, thanks to a word from the school's math professor, Samuel H. Christie. Christie's father had founded the art-auctioneer firm Christie's, which may be why as a young kid Sam is said to have been great pals with Sir Joshua Reynolds. Sir J. was the art biggie's biggie: president of the Royal Academy, friend of the king and portraitist extraordinaire. You name 'em, he painted 'em. Including one young woman from Switzerland, about whom he is said to have had a bit of a thing. I've spoken of her before: Angelica Kauffmann, toast of London in 1770. She painted, too, though more houses than people, perhaps.

Kauffmann had spent a few formative months in Rome in the company of Johann Winckelmann, inventor of the history of art and aesthetics—and all that stuff well-bred young women do between degree and marriage. Winckelmann was the guy who told Europe to go and look at Pompeii, Herculaneum et al. not long after they'd been dug up, so people could get a feel for what it must have been like back in A.D. 1 and in this way understand classical art. Others, like Giambattista Piranesi, just drew every ruin they came across. Piranesi showed his work to Scottish architect Robert Adam, who then went home and turned lumpy British ancestral homes into bijou Greek and Roman villas, complete with the trimmings, some of which were done by Kauffmann.

Adam commissioned anything vaguely metallic from Matthew Boulton, who had all kinds of cutting and stamping machines in his Birmingham factory, where the rest of his time was spent running James Watt's life. Boulton had started out as a maker of shoe buckles. Not a bad idea before the era of laces. No fool, Boulton also got into the steam-powered (thank you, James) coin-stamping game just as England was thinking about issuing a complete new coinage. In 1797 he got two contracts: to make the new British copper money and to set up a new Royal Mint at the Tower of London. Where they were then able to downsize because Boulton's new machines could strike 200 coins a minute with only one minder in attendance.

The fine detail made possible by the switch to steam presses encouraged a new, more artistic approach to coin design. In 1817 the director of the mint brought in a flamboyant Italian named Benedetto Pistrucci, who put St. George and the Dragon on the sovereign and crown coins for the first time. Pistrucci was able to be so deft with his designs because he used a new pantograph reduction machine that would reproduce the tiniest detail. On one occasion this included Pistrucci's full name instead of the customary initials only. This lack of good manners and the fact that he was a foreigner meant he never got the chief engraver's job he deserved.

A few years before he died in 1855, Pistrucci delivered his designs for the medallion commemorating the battle of Waterloo. That event would sour Anglo-French relations enough so that over 100 years later we'd still be busy with kiss-and-make-up gestures, like giving the SST a French name: Concord with an "e." SA

Wonders, continued from page 105

tle iron tongue held between the teeth that in a strange way uses the mouth as sounding box and the breath as a vehicle of sound. When, I say, this man believed he had seen everything, he found himself thrown deeper than ever into ignorance and astonishment when he caught a cicada in his hands.

Neither by stopping its mouth nor by holding its wings could he at all lessen its high stridency. Yet he could see no other scaly part moving, until finally he lifted up the casing of its chest to find underneath certain hard, thin membranes. Believing that the sound might originate from their vibration, he undertook to break the disks to silence the song.

But all was in vain, for piercing the insect he took away its life with its voice, and still he was not sure from whence the song had come.

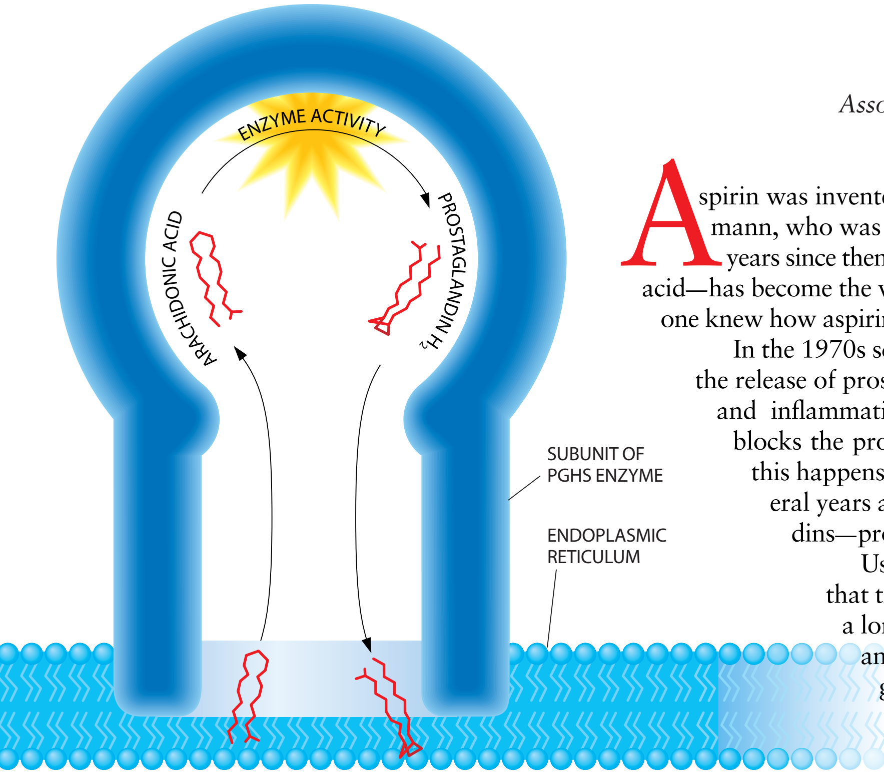
Thereafter he was reduced to such diffidence about his knowledge that when one asked him how sounds were made, he freely allowed that although he knew some ways, he was sure that there must be hundreds of others still unknown and unimaginable.

It is not hard to find here the Galileo who was the musical son of musician Vincenzo Galilei, who had himself written seriously about musical theory. The son's book *The Assayer* is credited with the first expression of the concept that impersonal waves in air carry all that is in a vibrating string over to a vibrating eardrum, personal music played and personal music heard, but pressures and motions in between.

The loudest sounds made by any insect are the shrill calls of a big, green cicada that resound through Australian spring evenings. Collaborators David Young of the University of Melbourne and Henry C. Bennet-Clark of the University of Oxford have over the years used the instruments and insights of modern acoustics to analyze the subtle resonators that sharpen and sustain that cicada's powerful signal. Drawings and text in the May 1998 *Scientific American* recount how the noisy "greengrocer" makes his alluring sounds. Galileo would feel kinship with today's investigators and soon, we believe, would come to understand the system they have uncovered. As it was for him, it is the questions that drive science to this day, not the answers. SA

WORKING KNOWLEDGE

ASPIRIN



PGHS ENZYME produces the prostaglandins that cause fever and inflammation. Arachidonic acid from the endoplasmic reticulum, an internal cell membrane, moves through a channel to the core of the enzyme, where it is converted to prostaglandin H_2.

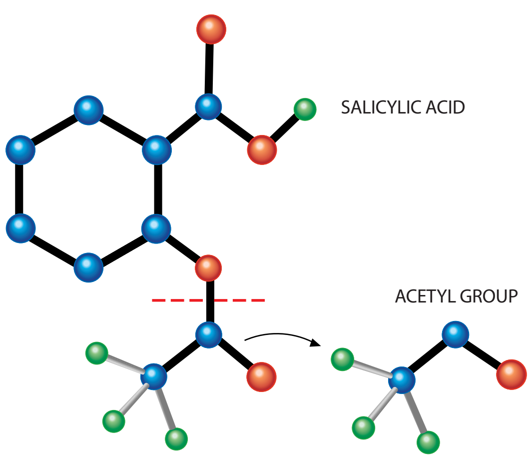
by R. Michael Garavito
Associate Professor of Biochemistry, Michigan State University

Aspirin was invented in the late 1890s by German chemist Felix Hoffmann, who was seeking to ease his father's arthritis pain. In the 100 years since then, aspirin—or as it is known to chemists, acetylsalicylic acid—has become the world's most widely used drug. But until recently, no one knew how aspirin actually works.

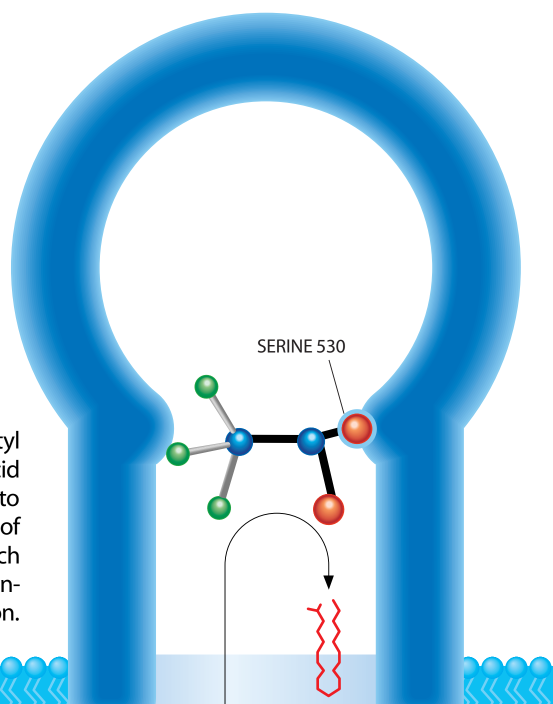
In the 1970s scientists learned that injuries to human tissue trigger the release of prostaglandins, hormonelike molecules that cause fever and inflammation. They also discovered that aspirin somehow blocks the production of these molecules. To reveal exactly how this happens, a team of researchers, including myself, began several years ago to analyze the enzyme that produces prostaglandins—prostaglandin H_2 synthase, or PGHS.

Using x-ray analysis of PGHS crystals, we discovered that the enzyme contains two protein subunits, each with a long interior channel. Molecules of arachidonic acid—an essential fatty acid—enter these channels and undergo a chemical transformation in the enzyme's core, converting to molecules of prostaglandin H_2. Aspirin prevents this change by sealing the channels: the aspirin molecule's acetyl group binds to a site inside the channel, blocking the path of the arachidonic acid. Other anti-inflammatory drugs, such as ibuprofen and naproxen, work by physically plugging the enzyme's channels rather than chemically altering them.

GEORGE RETSECK AND BRYAN CHRISTIE



ASPIRIN MOLECULE contains an acetyl group linked to salicylic acid, including atoms of carbon (●), oxygen (●) and hydrogen (●). When aspirin enters the interior channel of the PGHS enzyme, the molecule splits in two, with the acetyl group binding to a site inside the channel and the salicylic acid usually floating away.



NEW CONFIGURATION of the PGHS enzyme—with the acetyl group bound to a site called serine 530—blocks arachidonic acid from the core of the enzyme, thus preventing its conversion to prostaglandin H_2. Unfortunately, aspirin shuts down all forms of the PGHS enzyme, including the form that protects the stomach lining. Drug companies are now developing a new class of painkillers that target only the form of PGHS that causes inflammation.