INVISIBLE UNIVERSE: PHYSICS CLOSING IN ON DARK MATTER

# SCIENTIFIC AMERICAN

Dismantling Nuclear Reactors

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## DINOSAUR FEATHERS

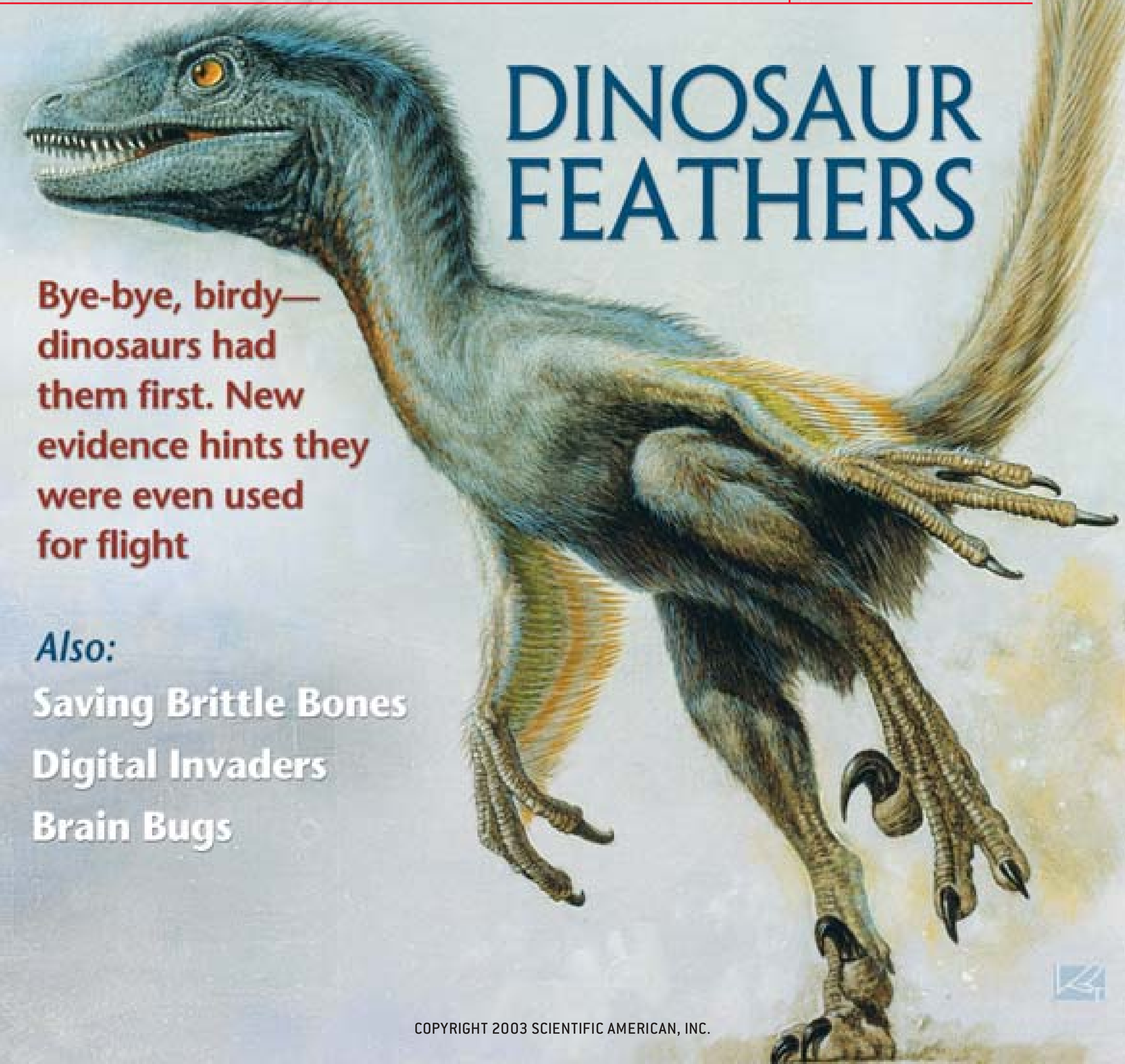
Bye-bye, birdy—dinosaurs had them first. New evidence hints they were even used for flight

*Also:*

**Saving Brittle Bones**

**Digital Invaders**

**Brain Bugs**



march 2003

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SCIENTIFIC AMERICAN Volume 288 Number 3



84 A plumed predator

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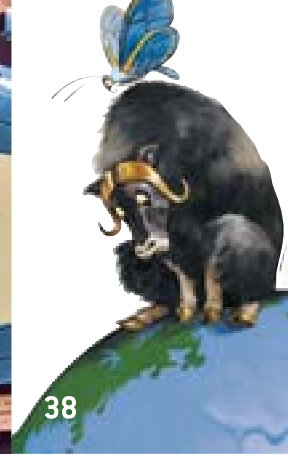




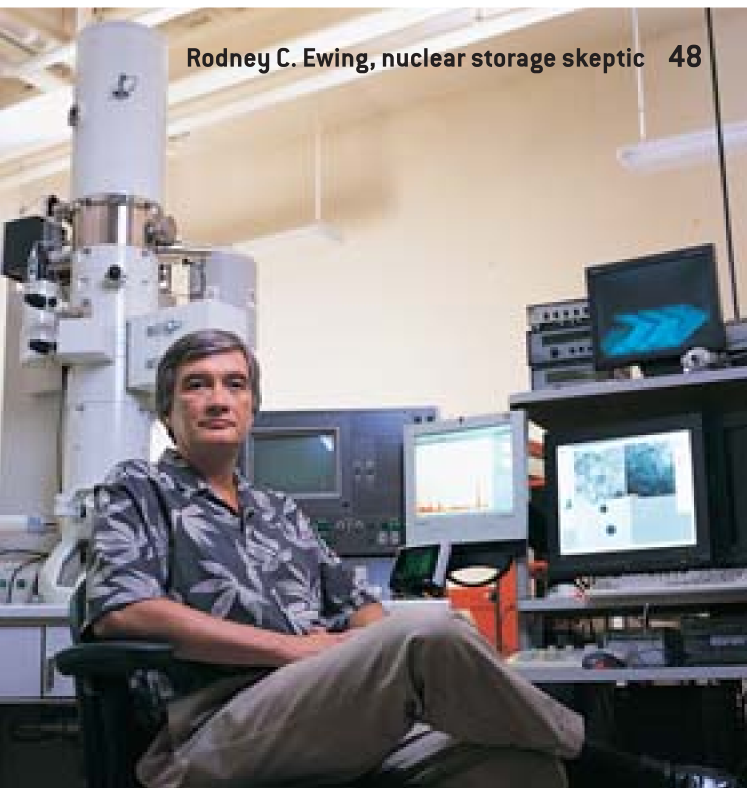

Rodney C. Ewing, nuclear storage skeptic 48

# columns



Cover painting by Kazuhiko Sano

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# SA Perspectives

## Total Information Overload

**Last year, as has been widely reported,** the Pentagon started a program called Total Information Awareness to link databases of personal information and scan them for signs of terrorist threats. Officials there say that every credit-card purchase you make, every prescription you fill, every phone call you place could go into a government computer. The Transportation Security Administration has similar goals for version 2.0 of its Computer Assisted Passenger Prescreening System (CAPPS). Leaving aside the possible implications for civil liberties, would such systems really make us more secure?

Homeland Security officials and private contractors gush about the potential for "data mining." But for scientists—unlike, say, marketers—data mining is something of a dirty word. It connotes a blind search through data, an effort that tends to confuse real patterns with mere coincidences. In the past decade, many statisticians have rehabilitated the word and tried to inject more rigor into the procedure. The government programs, however, are bumping up against fundamental limitations.


AIRPORT SECURITY SEARCHES could soon be supplemented by computerized background checks.

GRETCHEN ERTL *AP Photo*

To begin with, what are they looking for, exactly? Somehow the data miners have to find a set of innocent activities that correlates with a hidden terrorist agenda. Advocates cite patterns in the activities of the September 11 hijackers. Yet every data set has patterns. At issue is whether they mean anything and whether we can discern that meaning before the horrible fact, rather than after.

Second, terrorism is very rare—which is good for us but bad for data miners. Even with a low error rate, the vast majority of red flags will be red herrings. Suppose that there are 1,000 terrorists in the U.S. and that the data-mining process has an amazing 99 percent success rate. Then 10 of the terrorists will probably still slip through—and 2.8 million innocent people will also be fingered. To reduce these false positives to a manageable level, the data miners will have to narrow their search criteria, which in turn means that they will miss more (or perhaps all) of the terrorists.

A third problem is data quality. Most people find at least one error in their credit reports, and well over 100,000 people said they were victims of identity theft last year. Data collected for a specific purpose (ascertaining creditworthiness, in this case) are often unfit for even that job, let alone for a gravely different one (unmasking a terrorist). And even when the data themselves are correct, biases in how they were collected can introduce spurious patterns or hide real ones.

In short, the data miners commit the fallacy of determinism: they falsely assume that if you just amass enough data, you will know what is going to happen. Total information awareness is impossible even in the objectively measurable physical world. What hope is there in the world of human behavior?

None of this makes the cause of homeland security futile. The point is that broad dragnets are unlikely to work as well as targeted solutions. Beefing up cockpit doors and security searches are more immediate and efficient ways to stop hijackers than running a credit check on every passenger. Inspecting trucks entering sensitive areas is proven to stop truck bombers; looking at magazine subscription records isn't. If the backers of data mining disagree, they need to produce hard evidence for why we should believe them.

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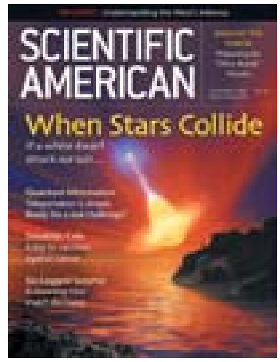



**SOME OF THE TYPES of science covered in the November 2002 issue met with rather strident reader criticisms. Among those were notes about animal research and how to prevent catastrophic forest fires, as well as the following letter on the SETI efforts discussed in "An Ear to the Stars," a profile of Jill C. Tarter. "I am the founder and head of SUKR, the Search for Unicorns in Known Reality," writes Mark Devane of Chicago. "We have scientifically proven that unicorns exist. By factoring a really big number by a series of fractions, we have determined that there are at least 10,000 planets in this galaxy home to unicorns. As in your November issue, I suggest you run my profile on the very next page after two articles in which you take quack science to task. I await your pleasure." We can't make any promises, but we can offer other letters sounding off about the issue on the following pages.**

## FIERY POINTS

**In "Burning Questions,"** Douglas Gantenbein writes that crown fires, "the most devastating type," can "easily cross a five-foot firebreak scratched out by crews." Certainly, but using ground crews to scratch out firebreaks is not the best way to fight such a conflagration. The primary means is by application of fire-retardant lines downwind using aircraft or by direct application of water with foam (to increase penetration) using water bombers.

Also, both the article and the issue's opening editorial ["Land of Fire," Perspectives] perpetuate a myth about fire history. As Perspectives states, "Western forests are supremely adapted to coexist with natural, lightning-sparked burns." But current research in British Columbia is showing that the "natural" cycle in Western forests was actually from fires lit by aboriginal peoples. Even today, with our fire-prevention ethic, humans cause more blazes than lightning does.

**Colin Buss**
Registered Professional Forester
British Columbia, Canada

**As always, the devil** is in the details, but the basic equation seems unavoidable. Growth in a forest inexorably produces new combustible material each year. If not removed, it accumulates. There are only three avenues of removal: physically carting it away (logging), frequent small fires and infrequent massive fires. If the first two, or some combination of them, do not occur, the third becomes inevitable.

**Jack Childers, Jr.**
Baltimore

**Your article was biased** in favor of thinning, the idea of removing small trees and brush that could fuel catastrophic fires. The single mention of the opposite point of view was that "environmental groups are deeply suspicious of activities they view as illegal logging dressed up as 'restoration.'" Such suspicions are grounded in very real concerns, which might at least also have been explored in the interests of balanced reporting.

There are currently mutually incompatible bills pending in Congress that espouse these two paradigms. On one side, the National Forest Roadless Area Conservation Act, HR 4865, and the National Forest Protection and Restoration Act, HR 1494, are based on the need to protect the remaining pristine areas of national forest from further logging intrusions. Meanwhile the ironically named Healthy Forests Reform Act, HR 5319, is founded on the proposed need to increase access, procedural freedoms and ever higher subsidies for the logging industry to enter pristine forests to conduct the thinning it advocates. By publishing this article during the crucial time while these bills are pending, *Scientific American* is acting to convince the lawmakers and their constituents of the logging lobby's propaganda, at the expense of environmental conservation.

Bryan Erickson
via e-mail

## DISRUPTIVE ARTICLE?

**In "Weapons of Mass Disruption,"** Michael A. Levi and Henry C. Kelly perform a public service by explaining the technology of dirty bombs that could be used in an attack. They perform a public disservice by claiming that such terrorist acts would create panic. Neither this article, nor the technical report that it summarizes, provides any evidence to support the notion that there would be a "frenzied exodus" from affected areas in such an event. It also does not prove that people would refuse to return following decontamination or that they could not understand the facts of an attack, if they were cogently presented. These sensational images fly in the face of the relevant scientific evidence, which finds that panic flight is rare, even under conditions of extreme danger. Authorities who assume that panic will occur could contribute to the cause of that situation, by denying citizens the frank and clear information that they need to make decisions for themselves and their loved ones. The social value of Levi and Kelly's analysis is limited, unless it is translated into scientifically sound and empirically evaluated risk communications and public-warning strategies, which would help individuals and groups to cope effectively should attacks occur.

Kathleen Tierney
Director, Disaster Research Center
University of Delaware
Baruch Fischhoff
Carnegie Mellon University

*LEVI AND KELLY REPLY: We did not predict that panic would necessarily result from a dirty bomb attack. But authorities faced with the possibility of a large radiological release would be irresponsible to assume that people would react rationally and to thus avoid developing plans to deal with the possibility of public panic. In addition, whether one calls it "panic" or not, a mass flight of people could involve risks greater than the immediate effects of a dirty bomb attack. Unless such factors are thought through in advance, they could strain our emergency response system.*

*We are pleased that the letter writers agree with us that it is essential to translate our analysis into risk communications and public-warning strategies. Along with many others, we have been working diligently to do so.*


CLEANUP of a dirty bomb would require hazmat-suited workers to scrub fallout from surfaces.

## LOVE LOST

**Robert Sapolsky's** review of Deborah Blum's book *Love at Goon Park: Harry Harlow and the Science of Affection* ["The Loveless Man," Reviews] reveals the wrenching ambivalence that many of us have toward animal experimentation. Sapolsky describes Harlow's work with rhesus monkeys to learn about infant love as "revolutionary" and "overturning damaging dogma" but then condemns the isolation studies as brutal and not justified, conducted by an unfeeling person. The focus on Harlow's personality and his attitude toward his experimental subjects, while interesting, doesn't really illuminate the dilemma. Would the same experiments, carried out by a sensitive person who shed tears, be less ethically disturbing?

If we leave out the extremists who would forbid all animal experimentation, the debate seems to focus on two points: Does human well-being have priority over animal suffering in all cases? If not, do the results of an experiment justify the suffering? Unfortunately, the second question is not viable, given the nature of science. The answer may not be knowable until many years later and even then may be ambiguous. This is why experimental guidelines will always come from the political realm.

Lyman Lyons
McFarland, Wis.

## COINCIDENTAL INSECTS

**As I read your article** about gladiators ["Gladiators: A New Order of Insect," by Joachim Adis, Oliver Zompro, Esther Moombolah-Goagoses and Eugène Marais], I wondered to myself how the bug project in east Tennessee was going—and in "A Search for All Species," by W. Wayt Gibbs [Voyages], I found out. What a nice coincidence. Living on an east Tennessee mountain that wasn't even deep forest but a developed suburb, my family constantly found insects that didn't appear in any bug books. I'm glad that people are documenting their discoveries of the exotica right here in North America.

Andrea Rossillon
Birmingham, Ala.

**ERRATA** "Stringing Along," by Ken Howard [News Scan], should have credited Nikos C. Kyrpides, director of genome analysis at Integrated Genomics of Chicago, for use of the GOLD Genomes OnLine Database, http://wit.integratedgenomics.com/GOLD/

The MODIS instrument has a resolution of 250 meters to one kilometer, depending on the data band, not 10 meters ["Burning Questions," by Douglas Gantenbein].

Several errors appeared in the profile of Jill C. Tarter ["An Ear to the Stars"]. Stuart Bowyer's name was spelled incorrectly. The Allen Telescope Array, the first built specifically for SETI projects, will be managed by the University of California, Berkeley, not NASA. Tarter was initially interested in engineering physics in college, not mechanical engineering. Her marriage to Jack Welch took place in 1980, not 1978.

YUN JAI-HYOUNG *AP Photo*

# 50, 100 & 150 Years Ago
FROM SCIENTIFIC AMERICAN

## Our Soil ▪ New World ▪ Moon Air

### MARCH 1953

**NITROGEN SCARCITY**—"Nitrogen tantalizes mankind with the paradox of poverty in the midst of plenty. All living things on this planet—animal and vegetable—must have nitrogen in their food. Yet the free nitrogen in the air is so difficult to incorporate into foodstuffs that man must engage in back-breaking toil to conserve the comparatively small amount that nature captures and fixes in the soil. However, since 1949 a flurry of discovery has turned up undreamed numbers of microorganisms that fix nitrogen. We can look forward to the possibility that we may some day be able to exploit the power of these organisms, and so help nature's nitrogen cycle to enrich our earth."

**MILKY WAY NOT FREAKISH!**—"The universe may be twice as large, and twice as old, as astronomers have supposed, according to Harlow Shapley of the Harvard College Observatory. If every galaxy is twice as far away as we had thought, it must also be twice as big. As a consequence, the Milky Way, which was supposed to be an exceptionally large galaxy, would be about the same size as the Andromeda nebula and many other galaxies. This is a relief to astronomers, who have been unable to see any reason for the local galaxy's being a giant freak. The new estimate would clear up another discrepancy. The universe was previously estimated to be about two billion years old, whereas geological evidence indicates that the earth is over three billion years old. The revised estimate of the universe's size also doubles its age to four billion years."

### MARCH 1903

**WORLDWIDE WELCOME**—"Landed at the port of New York during last year, of cabin passengers there were 139,848, plus the enormous total of 574,276 steerage passengers. But just to think of it! Over half a million foreigners, composed chiefly of the very poorest and most ignorant peoples of Europe, are absorbed by this country, so easily and naturally that this multitude makes no visible impression upon the routine of our daily life. Our easy assimilation of these heterogeneous millions is due to our magnificent public school system, which is undoubtedly the chief agency in making the immigrants' children who are native by birth, native also in sympathy and training."

RAILWAY TECHNOLOGY struggles with safety, 1903

**RAILROAD PERILS**—"Safety devices and automatic apparatus, as they are adopted for railways, lessen the liability of accidents, but the iron horse can never be taken entirely out of the hands of fallible man. With wet face and sweating body, sitting hour after hour watching, it is a wonder the driver of the steel steed makes as few mistakes as he does. Our illustration shows a wreck in Belfast, Ireland. On a slippery day the train went through the wall at the depot."

### MARCH 1853

**LUNAR AIR**—"Of late, a selenologist at Rome, M. Decuppis, has arrived at the conclusion that the moon has an atmosphere, though on a very moderate scale, it being only about a quarter of a mile in height, two hundred times less, probably, than the height of the earth's atmosphere. There are those who believe that this shallow atmosphere may be one like that belonging to our planet in the course of formation, when the atmosphere of this earth was chiefly composed of carbonic acid gas, and that races of animals lived in it having organs specially adapted for living in the same."

**HOG HOAX**—"The adulteration of American lard can be easily explained: in the West, many of the hogs fall down through fatigue during their journey in droves to the Eastern markets, and have to be killed on the spot. As the only available means of turning their carcasses to pecuniary advantage, they are submitted to the action of a press, and thus forced down into a substance sold as lard, which, from not having been melted, necessarily contains a large amount of foreign matter."

news SCAN

POLICY

# From Lab to Embassy

A PLAN TO GET SCIENTISTS INVOLVED IN U.S. FOREIGN POLICY **BY SALLY LEHRMAN**

**Bioengineered food** has exploded into a hot-button trade issue: the U.S. Department of State is threatening to file suit as European countries balk at accepting American-grown genetically modified goods. Early input from scientists could have helped the State Department handle the policy crisis more effectively, suggests George H. Atkinson, a biophysicist at the University of Arizona. Atkinson experienced the tension firsthand when he visited Europe two years ago as a science fellow brought in to augment the agency's meager technical resources. "It's as if people are trying to communicate in different languages without access to a good translator," he says. "If you can get policymakers to understand where science is going instead of where it just went, there are opportunities to avoid major problems."

STATE DEPARTMENT SCIENCE: George H. Atkinson, a biophysicist at the University of Arizona, hopes to get scientists into the realm of policy making.

TOM WOLFF

In the hopes of changing the situation, Atkinson is trying to establish a competitive fellowship program that would bring up to 20 accomplished scientists every year to U.S. agencies and embassies throughout the world. They would work closely with diplomats, then return to their labs and remain on call for special projects for another five years. Over time, a growing cadre of tenured experts with international reputations in their disciplines would retain ties to the highest levels of the State Department, helping to bind policy approaches to an awareness of science.

In this age of genomics, cyber-security and energy geopolitics, it's hard to think of a foreign-policy problem that wouldn't benefit from technical input. Nuclear physicists could give a realistic assessment of the ease with which nuclear materials could be stolen, determine the potential harm of "dirty bombs" and identify the best use of funds to contend with the problem. Biologists and chemists could shed more light on the risk of biological and chemical weapons attacks. And ecologists and plant biologists might have enabled U.S. diplomats to debate the potential risk of gene-altered foods more concretely and with more credibility. But the State Department is notoriously technophobic and has a tendency to downplay such expertise, according to recent reports by the National Research Council and the National Science Board. "The entire U.S. foreign policy community ... currently gives relatively little attention to science, technology and health considerations," noted a 1999 NRC report.

A one-year, $50,000 planning grant from the MacArthur Foundation has allowed

news SCAN

## MIXING SCIENCE WITH POLITICS

**A 1999 National Research Council report criticized the U.S. State Department's lack of attention to science and technology in foreign policy. The department responded by appointing a science and technology adviser to the secretary of state and increasing fellowships that place external scientists in the department for up to a year. The American Association for the Advancement of Science will sponsor 15 Diplomacy Fellows in 2003–2004. These positions usually attract scientists with a few years of postdegree experience. The American Institute of Physics began one fellowship for mid- to late-career professionals in 2001, and the Institute of Electrical and Electronic Engineers begins two this year. Separately, staff at technical agencies such as the National Science Foundation can become "detailees" on temporary assignment at embassies.**

Atkinson to get the new program going. He has had to bridge several institutional cultures that assume science should stay out of politics: foreign officers worry that scientists will be loose cannons, and scientists fear that political engagement will harm their careers. By mid-January, Atkinson had won the support of more than a dozen professional society presidents, along with as many universities, several foundations and three State Department undersecretaries. In mid-February, the executive organizing committee was to have met to consider a proposal for a three-year pilot program that would annually fund five senior science fellows.

The plan builds on efforts by Norman P. Neureiter, science and technology adviser to Secretary of State Colin Powell, to beef up the visibility of science in the department over the past two years. He says that the Senior Science Fellowships, as the venture is called, would contribute in an important way by attracting a new level of high-powered, mid-career people who formerly would not have considered abandoning tenured posts and active labs for a year. Nominated by their universities, scientists would be chosen for their communication skills, adaptability and foreign-policy interests—not just their research prominence. Fellows would need to recognize that State Department decisions are propelled by the political process, not necessarily scientific data, Neureiter observes.

He acknowledges that integrating the fellows into the agency will be difficult. So rather than foist fellows' expertise on unappreciative embassies or Washington bureaus, the project would rely on work plans developed by foreign-service offices themselves. For instance, a group of embassies might request a plan to develop an international collaboration in biomedicine or ask for a review of ocean treaties to see whether they were supported by the latest research findings.

A physicist now working in the State Department as a technical adviser (and who requested anonymity) remarks that more science is sorely needed but has his doubts that a fellowship would do much good. "There's a general belief that scientists should be locked in their rooms and asked for technical advice but not policy advice," he laments. Pointing to areas such as dirty bombs, birth control, AIDS and global warming, he adds: "When ideology comes up against scientific understanding, it can be very frustrating."

*Sally Lehrman is based in San Francisco.*

DEFENSE

# Connect the Pings

STEALTH RADAR FROM CELL-PHONE RADIATION **BY WENDY M. GROSSMAN**

WIDESPREAD CELL-PHONE USE may enable the development of stealth radar.

NANCY HONEY *Photonica*

**The law of** unintended consequences: build a cellular-phone network and get a sophisticated surveillance system along with it. At least that is what may happen in the U.K., thanks to England's contract research and development firm Roke Manor Research and aeronautics company BAe Systems. The two are working on a way of using the radio waves broadcast by the world's mobile-phone base stations as the transmission element of a radar system. They call it Celldar.

Radar works by transmitting radio pulses (or pings) and listening for an echo. Measuring the Doppler shift of the echo can give an object's distance and speed. Celldar proposes to take advantage of U.K. base stations, which transmit radio waves from known locations in a known microwave frequency band. Instead of erecting a radar transmitter, a Celldar operator would only need to set up passive receivers that can measure the cellular-network radio waves reflected from nearby objects and process the data. Because they would not transmit, Celldar receivers can, according to BAe Systems, be smaller and more mobile than traditional systems—and undetectable. Celldar operators would not require the cooperation of the cell-phone-network operators, either.

The physics itself is nothing new. It dates back to research carried out in the 1930s by Scottish meteorologist Robert Watson-Watt and the engineering team that developed Chain

## SEE YOU WITH RADAR?

**Despite concerns of a new government surveillance tool, the Celldar project is unlikely to have implications for personal privacy. Reflected signals and multiple targets in a crowded city would make it impossible to use Celldar to follow a perambulating individual. What's more, cell phones increasingly offer a much easier way to track users: they have built-in abilities to transmit detailed location information under the U.S.'s enhanced 911 rules. Mobile-phone companies also hope to make money from selling location-based services and so will probably design phones to store more position data. Plus, security cameras have proliferated since September 11, 2001. All those avenues of personal surveillance make Celldar irrelevant by comparison.**

Home Radar. This system of coastal radar towers went up just in time to give Britain early warning of the air attacks of World War II.

Distinguishing the moving target from myriad signal reflections is more of a problem for the narrow-bandwidth, low-power radiation emitted by mobile-phone masts than it is for traditional radar transmissions. BAe Systems says the keys to Celldar are the algorithms devised at Roke Manor to turn the cell-phone data into useful information and the emergence of widespread, cheap computing power. But neither Roke Manor (part of Siemens) nor BAe Systems will go into much detail about the technical innards of Celldar, which has attracted funding from the British Ministry of Defense. Given the companies' secrecy, no one really knows if Celldar will work. Mark R. Bell, an electrical and computer engineer at Purdue University, believes it is feasible; the main challenge will be the weak signal strength of the base stations (compared with radar systems). "It is really going to push signal-processing technology very, very hard," he remarks.

Roke Manor has suggested only military applications so far: monitoring coastlines, spotting tanks and stealth aircraft, or tracking people in open areas, such as the perimeter of a military base. Roke Manor claims that the system might enable such high-security installations to deploy fewer cameras, keeping one or two that can be trained on the locations Celldar pinpoints.

The implications for stealth aircraft are intriguing: Celldar may force some design changes. BAe Systems says, for example, that today's stealth aircraft were not designed to evade multistatic radar (radar with multiple transmitters) or cell-phone frequencies. Existing stealth planes should be detectable by Celldar.

Celldar is not the only passive radar project around. Lockheed Martin's Silent Sentry uses ordinary television and FM radio waves, and researchers at the University of Illinois at Urbana-Champaign are trying to incorporate automatic target recognition into the system. Passive radar might go beyond defense-related uses: Robert K. Vincent, a geologist at Bowling Green State University, has proposed using the radiation from telephone microwave towers to detect tornado touchdowns. That would provide earlier warnings for those in a tornado's path—an unintended consequence that no one could complain about.

*Wendy M. Grossman is based in London.*

PALEONTOLOGY

# Out on a Limb

A STUNNING NEW FOSSIL SHOWS HOW SIMIANS GOT THEIR START **BY KATE WONG**

PRIMEVAL PRIMATE: *Carpolestes simpsoni.*

**Living primates exhibit** a dazzling diversity of forms—from the saucer-eyed bush babies of sub-Saharan Africa to Borneo's proboscis monkey (the Pinocchio of primates) to humans, the cosmopolitan bipeds. They are united, however, in having large brains, forward-facing eyes, nails instead of claws, an ability to grasp and an ability to leap. For almost three decades, evolutionary biologists have puzzled over how modern primates came to possess this distinctive suite of characteristics. Some workers reasoned that these features evolved to permit predation on insects, others proposed that they enabled the procurement of fruit from the tips of tree branches, and still others envisioned these traits as adaptations to a mode of locomotion combining grasping and leaping. But the scrappy fossil record of early primates—mostly teeth and isolated skeletal bones—left researchers hard put to test these hypotheses.

A spectacular find from the badlands of Wyoming is bringing some answers to light. Paleontologists recently uncovered a nearly complete 55-million-year-old skeleton of a mouse-size creature known as *Carpolestes simpsoni*. Like modern primates (or euprimates, as they are termed), it has long fingers and toes, as well as nails on its opposable digits—good for grasping spindly tree limbs. But

© SCIENCE

## CRETACEOUS PRIMATES?

**Last spring Robert D. Martin of Chicago's Field Museum estimated using a statistical approach that primates originated some 80 million years ago, during the Cretaceous period, when dinosaurs still roamed the earth. That date accords fairly well with conclusions from molecular studies. The oldest undisputed primate fossils were only 55 million years old, however. Now the characterization of *Carpolestes* and other plesiadapiforms as primates extends the fossil record of this group back to 65 million years ago. Might paleontologists eventually find Cretaceous primates? Unlikely, but not impossible, says Jonathan I. Bloch of the South Dakota School of Mines and Technology. Although the Cretaceous fossil record has been fairly thoroughly documented in North America, Europe and Asia, there may still be some surprises in store in southern Africa and the Indian subcontinent.**

unlike euprimates, this animal exhibits laterally positioned eyes and legs built for climbing, not leaping. Previously some scholars had placed carpolestids and their kin—a group known as the plesiadapiforms—in a category of gliding mammals called dermopterans. But the anatomy evident in the new specimen signifies to discoverers Jonathan I. Bloch, now at the South Dakota School of Mines and Technology, and Doug M. Boyer of the University of Michigan at Ann Arbor that *Carpolestes* and its fellow plesiadapiforms were in fact archaic primates closely related to the ancestor of modern lemurs, monkeys, apes and humans.

TOEHOLD ON slender tree branches gave *Carpolestes* access to fruit.

DOUG M. BOYER *University of Michigan at Ann Arbor*

As such, *Carpolestes* provides the first fossil evidence that primates acquired their distinctive traits piecemeal. "Originally, theories about primate origins took all these characteristics as a package," remarks Washington University paleontologist D. Tab Rasmussen, noting that until this discovery, the fossil record had yielded only specimens bearing all or none of the features. Bloch and Boyer, Rasmussen says, "managed to break it down and show that the grasping terminal branch adaptations are primary and that some of the other things probably came in a little bit later."

The finding dovetails with the paleobotanical record, which shows that the flowering plants had just invented a veritable cornucopia of new fruits, flowers, gums and nectars with which to entice pollinators and seed dispersers. A mammal capable of venturing out onto the unstable branch tips where fruit and flowers abound would have been richly rewarded. And once primates got a grip on terminal branch feeding, it may have been only a matter of time before they evolved forward-facing eyes to hunt the insects swarming around the plants' offerings. (Bloch and Boyer further speculate that competition with partly arboreal rodents, which were spreading across the globe at this time, may have helped drive early primates out onto the boughs.)

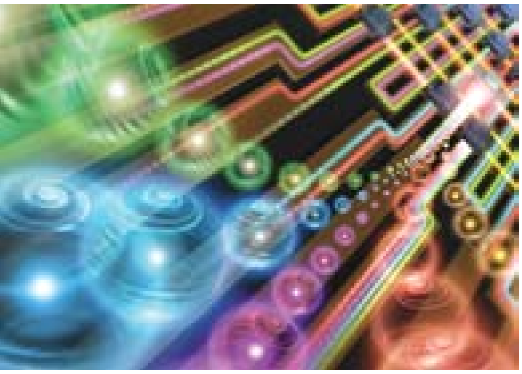
More fossils will be needed to discern exactly how and when the other defining euprimate features arose. Clues may come from the five additional plesiadapiform specimens the team is currently analyzing—all recovered from the same shoebox-size block of limestone that entombed *Carpolestes*. And this summer Bloch and Boyer are heading to Montana's Crazy Mountain Basin to collect fossils from even older deposits. But freeing the remains from the rock is painstakingly slow work. The limestone must be dissolved gradually and the position of each bone documented meticulously to preserve critical information about which bones belong to which skeleton. So it will be a while before the roots of the primate family tree are fully exposed.

SPINTRONICS

# Getting Warmer

MAGNETIC SEMICONDUCTORS REACH HIGHER TEMPERATURES **BY GRAHAM P. COLLINS**

**Most electronic gadgets** function by moving around electric charges. The nascent technology of spintronics, however, makes use of not only the charge of electrons but also their spin. Spin is closely related to magnetism, and the first spintronic devices include read heads of computer disk drives and magnetic random-access memory (MRAM); the latter retains its data even when the power is off [see "Spintronics," by David D. Awschalom, Michael E. Flatté and Nitin Samarth; SCIENTIFIC AMERICAN, June 2002]. But spintronic computer chips and other more complex gear are not yet possible—unlike MRAMs and read heads, they might need magnetic semiconductors, and existing



ELECTRONS' SPINS are as important as electric charge in spintronics.

semiconductors are not magnetic at room temperature. Several groups have recently made significant progress in this direction.

One of the most studied magnetic semiconductors is gallium arsenide doped with manganese. In 1998 a group led by Hideo Ohno of Tohoku University demonstrated that this substance can remain ferromagnetic up to 110 kelvins (–163 degrees Celsius). (Ferromagnetism is the technical term for magnetism that persists after an applied field is turned off.) At liquid-nitrogen temperatures, this material has been used to demonstrate devices such as spintronic light-emitting diodes (LEDs), which emit light polarized according to the spin polarization of the electrons and holes that generate it.

In late 2002 Masaaki Tanaka and his co-workers at the University of Tokyo found that applying a relatively simple annealing process to manganese-doped gallium arsenide boosts its maximum working temperature (known as the Curie temperature) as high as 172 kelvins. That is still far below room temperature, but the result constitutes "a genuine milestone," according to spintronics expert David D. Awschalom of the University of California at Santa Barbara.

The material made by the Tokyo group is a heterostructure: it consists of a series of layers carefully deposited one at a time by a beam of molecules (a process called molecular beam epitaxy). The manganese-doped layer is only three atoms thick, sandwiched between two layers of undoped gallium arsenide, all of which sits atop a layer doped with beryllium. More recently, researchers at several institutes have achieved Curie temperatures almost as high—150 kelvins—by annealing manganese-doped gallium arsenide without needing an elaborate heterostructure.

A much higher Curie temperature has been seen by Arthur F. Hebard and his colleagues at the University of Florida. His team uses carbon-doped gallium phosphide, to which manganese is added by firing a beam of high-energy ions at the sample. Magnetic properties remain as high as about 300 kelvins—room temperature. To be useful for devices, the result must be reproduced with a more orderly material grown by a more controlled process, such as molecular beam epitaxy. Hebard points out that gallium phosphide is well suited for integration with silicon because the atomic spacing in the two materials is nearly the same. It is also possible that a similar high-temperature ferromagnetism can be achieved in alloys of indium and aluminum with gallium phosphide, which are used to make LEDs.

Semiconductors with indications of still higher Curie temperatures have been reported. For instance, in early 2002 a group led by Hidenobu Hori of the Japan Advanced Institute of Science and Technology in Ishikawa announced a Curie temperature of 940 kelvins, extrapolated from measurements conducted up to 750 kelvins. That group's material is gallium nitride, again doped by manganese, this time made by molecular beam epitaxy. More research needs to be done, however, to confirm to everyone's satisfaction that ferromagnetism really is at work at such a high temperature.

All the materials now being studied will require a great deal of engineering to go from a demonstrated ferromagnetic semiconductor to a working device. "The proof of the pudding," Hebard says, "will be when someone makes a useful device."

SLIM FILMS

### NEED TO KNOW: SPIN CONTROL

**Advanced spintronic devices will also require electron spins to be controlled. The usual techniques rely on magnetic fields, but they are not well suited for thousands of components on a chip. Now David D. Awschalom of the University of California at Santa Barbara, Jeremy Levy of the University of Pittsburgh and their colleagues have demonstrated how to control electron spins in an appropriately designed semiconductor device simply by applying voltages, just as today's transistors on a chip are controlled by electric gates. The work, conducted at five kelvins, was posted online at the *Science Express* Web site on January 23.**

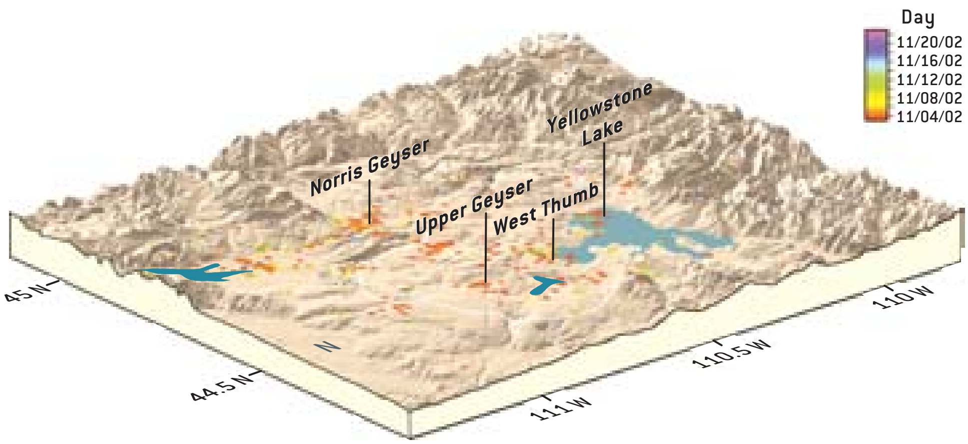
GEOPHYSICS

# Triggered Swarms

## A QUAKE IN ALASKA SETS OFF A SERIES OF RUMBLES IN THE U.S. BY NAOMI LUBICK

**The enormous earthquake** last November along Alaska's Denali Fault buckled highways and shook the trans-Alaska oil pipeline. But the magnitude 7.9 shock also set off surprising swarms of small tremors thousands of kilometers to the south. This discovery is convincing geologists that far-reaching effects—only recently documented—are very likely a common result of most major shocks.

The Denali temblor is the third major earthquake in the West in the past 10 years known to have caused smaller quakes. The oth-




SMALL EARTHQUAKES shook the Yellowstone caldera in the days following the Alaskan earthquake of November 3, 2002. Researchers remain unsure about the causes of these minor tremblings.

er two were in southern California: the Landers earthquake in 1992 and the Hector Mine quake in 1999. All three quakes affected the same geothermal volcanic fields in Wyoming's Yellowstone National Park, Mount Rainier in Washington State, and several sites in California. These fields, which are hot springs fueled by magma roiling deep underground, normally rumble at low levels. But the secondary quakes that were triggered far exceeded the background seismicity, and researchers aren't quite sure why.

Alaska's quake, which was centered about 283 kilometers (176 miles) northeast of Anchorage, sent out a train of seismic waves. It could have caused a subtle expansion and contraction of the earth's crust, which in turn could have tripped faults that were on the edge of failure. That's a tidy explanation for the earthquake swarms that immediately followed the Denali shock. But some of the secondary tremors occurred a day or more later, indicating a more complex scenario at play.

Many researchers have cited gas bubbles in the magma chamber to explain the delay. Geophysicist Alan T. Linde of the Carnegie Institution of Washington suggests that the passing waves can dislodge the bubbles, which typically stick to the walls of the chamber like champagne bubbles to the sides of a glass. In addition, the seismic waves might stir the magma enough to create new bubbles, notes geophysicist Emily E. Brodsky of the University of California at Los Angeles. In either case, as the bubbles rise, they expand, thereby increasing pressure in the fluid. They may also expand and contract as seismic waves pass through them, further changing the pressure, according to Brodsky. The pressure changes deform the overlying rocks, possibly jarring certain faults into action.

Magma bubbles may not be the only possible earthquake triggers. In Greece, Brodsky has found that hot springs are fueled not by a magma chamber but by changes in the pressure of fluids coursing through underlying crystalline rocks. Crustal deposits from the mineral-laden fluids frequently clog channels that the fluids once followed. Seismic surges from a large earthquake might crack those seals, Brodsky says. The change in pressure from renewed fluid flow is enough to start earthquakes on tiny nearby faults, a process that would apply to the hot springs in California and Yellowstone.

Magma bubbles and cracked geothermal seals can't account for all the secondary quakes, however. North-central Utah shook as well, but that area is a nonvolcanic, nongeothermal zone. Moreover, the region saw a weeklong increase in seismicity, a phenomenon that bubbles and cracked seals cannot explain.

Research geophysicist Michael Blanpied of the U.S. Geological Survey coordinated the analyses of the Denali earthquake. He says that the Utah rumbling makes him more inclined to rely on stress changes solely from seismic waves. He points out, though, that multiple mechanisms may be responsible for the variety of events. Denali provided an enormous amount of data over a broad area, but ultimately, Blanpied says, they "didn't answer any questions." It may take more tremors for the theories to shake out.

*Naomi Lubick is based in Palo Alto, Calif.*

## YELLOWSTONE RUMBLINGS

**The November 3, 2002, Denali earthquake in Alaska initiated several quakes in the geyser basins of Yellowstone National Park in Wyoming.**

| Geyser basins | Events per year | Events between Nov. 3 and Nov. 23 |
|---|---|---|
| Upper Geyser | 1 | 20 |
| Norris Geyser | 18 | 20 |
| Northern Yellowstone Lake | 1.2 | 17 |
| West Thumb | 6 | 27 |

*SOURCE: Stephan Husen, University of Utah. "Events per year" represents an approximate average since 1995.*

STEPHAN HUSEN *University of Utah*; DATA: YELLOWSTONE VOLCANO OBSERVATORY, A PARTNERSHIP BETWEEN THE UNIVERSITY OF UTAH, THE U.S.G.S. AND YELLOWSTONE NATIONAL PARK

NEUROSCIENCE

# Sustainable Surgery

CUBA PIONEERS A MEDICAL PROCEDURE TO RELIEVE PARKINSON'S **BY GARY STIX**

**In its hard-currency-based** health economy, Cuba has tried to attract foreign patients from all over the world, who come for the country's inexpensive or unique therapies, such as a surgery for retinitis pigmentosa or vitiligo treatment with a substance extracted from the human placenta. Although many physicians outside Cuba have frowned on these treatments, a number are applauding a research program at Havana's International Center for Neurological Restoration (CIREN). The center has assumed a leading role in developing a surgical procedure that appears to provide significant relief for patients experiencing the slowness of movement, tremor and muscle rigidity in middle- to late-stage Parkinson's disease.

HAVANA BRAIN SURGERY: International Center for Neurological Restoration has performed subthalamotomies on nearly 80 patients.

INTERNATIONAL CENTER FOR NEUROLOGICAL RESTORATION (CIREN)

In the surgery, physicians create lesions in either one or both subthalamic nuclei, deep-brain structures that, in Parkinson's, trigger movement disorders. The center, which has U.S. and Spanish collaborators, reported at the American Neurological Association meeting last October that two years after undergoing a bilateral dorsal subthalamotomy, 17 Cuban patients improved by an average of 50 percent on movement tests — and they could dramatically reduce their daily ingestion of the Parkinson's drug levodopa.

Some of the patients in the Cuban study developed complications from the surgery, including severe involuntary movements, but the symptoms abated (to the point where patients could tolerate them) after three to six months. Investigators continue to explore a number of open questions, such as to what extent the benefits of the surgery diminish over time.

But before these issues are resolved, subthalamotomies—and other lesioning surgeries—are emerging in developing nations as an alternative to the high cost of an increasingly popular Parkinson's treatment called deep-brain stimulation (DBS). It entails placing electrodes on the subthalamic nucleus (or nearby areas) and stimulating it with a pacemakerlike device to achieve benefits similar to lesioning. Subthalamic lesioning has also been tried in India, China, Taiwan, the U.K. and Spain, among others. "In the Third World, some of these patients don't have adequate access to the drugs. So, for them, the algorithm is that if you're diagnosed, you have a lesion surgery," says Andres M. Lozano, a professor of neurosurgery at the University of Toronto.

The Cubans have performed subthalamotomies on nearly 80 patients since 1995. Development of the technique has not escaped the entanglements of Cuban politics. Hilda Molina, the neurological center's founding director, says she rejected requests to do these operations in the early 1990s because she was disturbed at the prospect of Cubans becoming "guinea pigs to the world." Besides, she says, the U.S. and Spanish collaborators were better equipped to do the procedure. Molina recalls being told that conducting studies in Cuba would avoid problems with ethics commissions and lawsuits overseas. (She quit her post in 1994 because she claimed that she was asked to increase the number of hard-currency-laden foreign patients. Her cause was taken up by the Cuban exile community, which has charged that the well-appointed health-tourism facilities are diverting basic medical resources from Cubans.)

Officials from the neurological center note that a national ethics commission has approved the research. Meanwhile Emory University physicians, who have lent the Cubans imaging expertise for their studies and have served as co-authors on scientific papers, had already made a commitment to deep-brain stimulation by the time of the first surgery in Cuba. The Havana center now performs subthalamotomies on foreign patients.

The Cuban experience may have some benefit in high-tech meccas as well. Some patients are not good candidates for DBS because of their susceptibility to infection from the stimulator implants. Emory neurologist Jorge Juncos says that one incentive to get involved with the project was to gain understanding in case American health care reform necessitates lower-cost procedures. Will Cuban physicians come to the U.S. one day to teach the surgery? Let's hope the trade embargo is not extended to ideas as well as goods.

## MYSTERY OF THE SHAKING PALSY

**The cause of most Parkinson's disease cases is unknown. But its debilitating motor symptoms result from the loss of dopamine-producing cells in an area of the brain called the substantia nigra. Drugs, surgery and medical devices can treat the disease. None of these approaches, however, is a cure, and over time the disease inevitably progresses. Neurosurgery to relieve the symptoms of Parkinson's was practiced routinely until the advent of levodopa in the 1960s. Its popularity revived in the early 1990s as neurologists sought ways to complement drug therapies, which produce their own complications. The earlier surgery generally targeted other deep-brain structures, the thalamus and the globus pallidus, two other sites involved in controlling movement, but may have involved the subthalamic nucleus at times as well. It is thought by some investigators that subthalamotomies may be more effective than the other surgeries.**

BY THE NUMBERS

# Sizing Up Evangelicals

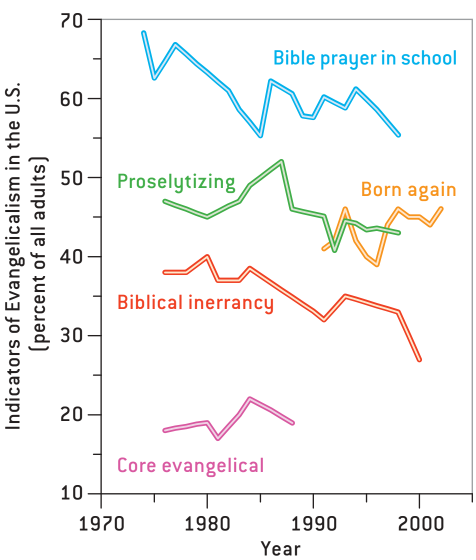
FUNDAMENTALISM PERSISTS BUT SHOWS SIGNS OF MODERATION **BY RODGER DOYLE**

**Fundamentalism** represents more than a continuation of traditional religion; it is also a transformation of old religious attitudes that arose in reaction to modernity and, in particular, Darwinism and progressive Protestantism. Its most prominent feature—the doctrine of biblical inerrancy—was a creation not of the 16th-century Reformation but of 19th-century Princeton University theologians attempting to preserve traditional belief in divine origins. Unlike the Calvinist tradition from which it grew, American fundamentalism is unsympathetic to science. After the Scopes "monkey trial" of 1925, it entered a quiescent period, reawakening in the 1960s and 1970s as a reaction to feminism and events such as the U.S. Supreme Court's 1963 decision banning prayer in public schools and its 1973 decision overturning laws against abortion in 46 states.

In the U.S., fundamentalism is one of several strains of evangelistic religion, which also includes charismatics and Pentecostals. Tracking the course of fundamentalism and its sister beliefs has long been difficult, in part because church statistics are unreliable and incomplete. Furthermore, fundamentalists and other evangelicals are not confined to certain denominations. Only 57 percent of Southern Baptists believe in the literal interpretation of the Bible, whereas about a fourth of the clergy in one typical division of the United Methodist Church, the biggest mainline Protestant denomination, participates in evangelical renewal movements. Catholics who call themselves charismatic can fall under the evangelical classification.

Survey data on four indicators of evangelical belief and practice—the top lines on the chart—suggest that evangelicalism has held the allegiance of 40 to 50 percent of the U.S. population over the past quarter of a century. But the data include many for whom such beliefs are not primary. The size of the evangelical core—the most committed believers—has fluctuated around 20 percent and includes only those characterized by all three central beliefs: in biblical inerrancy, in having been "born again" and in proselytizing. The decline in the number of those believing in the inerrancy of the Bible and those supporting prayer in schools suggests that evangelicals are becoming more like other Americans in that they are more accepting of gender and racial equality and are moderating extreme antiabortion attitudes, according to additional research.

The widespread assumption that, worldwide, fundamentalism is rising remains untested. Researchers have not yet gathered enough data to explore this assumption outside of Judeo-Christian countries. Fundamentalism in Europe generally persists at a far lower level than in the U.S. and presumably far lower than at the beginning of the 20th century. Only in Portugal and Poland does belief in inerrancy range higher than in the U.S. During the 1990s no Western country experienced substantial change except Northern Ireland, which registered a decline from about one third to one fifth believing in inerrancy.




*SOURCE: Gallup Organization, General Social Survey. Wording of questions is as follows: Inerrancy—"The Bible is the actual word of God and is to be taken literally" (agree); Born again—"Would you describe yourself as a 'born-again' or evangelical Christian?" (yes); Proselytizing—"Have you ever tried to encourage someone to believe in Jesus Christ or to accept Him as his or her Savior?" (yes); Bible prayer—"The United States Supreme Court has ruled that no state or local government may require the reading of the Lord's Prayer or Bible verses in public schools" (disapprove).*

RODGER DOYLE

*Rodger Doyle can be reached at rdoyle2@adelphia.net*

## DEFINING EVANGELICALS

**Evangelicals** are "born again" (that is, have had a conversion experience resulting in a personal relationship with Jesus Christ), accept the full authority of the Bible in matters of faith and personal conduct, and are committed to spreading the gospel. Not all evangelicals are fundamentalists.

**Fundamentalists**, such as Jerry Falwell, emphasize doctrine and, in particular, biblical inerrancy.

**Pentecostals**, such as Jim Bakker and Jimmy Swaggart, are theologically and culturally akin to fundamentalists but accentuate religious experience rather than doctrine.

**Charismatics**, such as Pat Robertson, accentuate spiritual gifts such as prophecy and are nondenominational.

**Neoevangelicals**, such as Billy Graham, accept the basic tenets of conservative Protestantism but reject the extreme anti-intellectualism and sectarianism of fundamentalism.

## FURTHER READING

**Contemporary Evangelicals: Born-Again and World-Affirming.** Mark A. Shibley in *Annals of the American Academy of Political and Social Sciences*, Vol. 558; July 1998.

**Reviving the Mainline: An Overview of Clergy Support for Evangelical Renewal Movements.** Jennifer McKinney and Roger Finke in *Journal for the Scientific Study of Religion*, Vol. 41, No. 4; December 2002.

news SCAN

## DATA POINTS: TOO EARLY SPRING

**Global warming is affecting the behavior of plants and animals—for most species, the start of spring is advancing (based on activities such as migration, breeding and blooming). Two recent meta-analyses—by Terry L. Root of Stanford University and his colleagues and by Camille Parmesan of the University of Texas at Austin and Gary Yohe of Wesleyan University—review the effects of warming on about 1,500 species. The rapid shifting of habitats could upset ecological balances as some species start entering the ranges of others.**

**Worldwide temperature increase over past 100 years:** 0.6 degree Celsius

**Percent of species showing spring advancement:** 62

**Percent showing delayed spring:** 9

**Rate at which ranges have shifted poleward:** 6 kilometers a decade

**Creatures showing greatest range changes:**
Butterflies, 200 kilometers
Marine copepods (crustaceans), 1,000 kilometers

**Global average rate of spring advancement, per decade:** 2.3 days

**Average for temperate-zone species:** 4.2 days

**Largest shift to earlier spring:** North American murre (seabird), 24 days

**Largest shift to delayed spring:** Fowler's toad, 6.3 days

*SOURCE:* Nature, *January 2, 2003*

ASTRONOMY

# Has a Nice Ring to It

**A fair number of the stars** in the Milky Way are puzzlingly un–Milky Way–like. At the January meeting of the American Astronomical Society, Heidi Jo Newberg of the Rensselaer Polytechnic Institute, Brian Yanny of Fermilab and their colleagues described the largest batch of such anomalies yet. Detected by the Sloan Digital Sky Survey, the stars are packed more tightly, move slower (110 kilometers a second, half the usual speed) and contain fewer heavy elements than typical stars in the outer galaxy. They form an arc about 60,000 light-years from the galaxy's center, twice as far out as the sun. The arc may be part of a complete ring, with a total of 500 million or so stars. It could be the remains of a small galaxy that got ripped apart 10 billion years ago, but other researchers think it is actually a cast-off from the Milky Way itself. Rings and other coherent patterns are sensitive to the shape of the galaxy's gravitational field, so astronomers hope to use them to map the distribution of dark matter. *—George Musser*

GALACTIC GIRDLE: Artist's conception of a band of stars that may encircle the Milky Way.

PHYSICS

# Self-Organized Scenery

**Various filigreed patterns** of stone circles, polygons, stripes and labyrinths are seen in arctic soils, but researchers have never been able to account for the full panoply of shapes. Now Mark A. Kessler of the University of California at Santa Cruz and Brad Werner of the University of California at San Diego have used a computer model to determine that the rhythm of freeze-thaw cycles produces two main mechanisms that generate any stone pattern.

NOT FROM ALIENS: The physics of freezing and thawing explains these two-meter-wide stone circles in Spitsbergen, Norway.

In lateral sorting, freezing soil expands as small, lens-shaped frost crystals form parallel to the stone-soil boundary. The expansion exaggerates the existing soil shape. Small hills enlarge and depressions widen, and stones roll from the former toward the latter. When the soil thaws, it expands only vertically because of gravity. This rise helps to prevent other stones from rolling, thus maintaining the new, more separated configuration of stone and soil. The process repeats, feeding back on itself. The same ice crystals also pinch and elongate the growing stone piles, in a process called stone domain squeezing. Daniel H. Mann of the University of Alaska–Fairbanks says the result suggests that some geological shapes are not simply by-products of the microscopic physics of dirt but obey higher-order rules, such as sorting and squeezing, that operate on a range of timescales and size scales. The research and comment appear in the January 17 *Science*. *—JR Minkel*

RON MILLER (*top*); MARK A. KESSLER *University of California, Santa Cruz* (*bottom*); ILLUSTRATIONS BY MATT COLLINS

news
SCAN

MOLECULAR BIOLOGY

## Immunity Sapped

**Vaccines rely on the ability** of the immune system to remember and respond again to past invaders. Now vaccine investigators have discovered the first gene that underpins this long-term immunity, indicating that drugs targeting the gene might boost resistance to some diseases. People who lack a gene called *SAP* are immunodeficient and often succumb to Epstein-Barr virus. Shane Crotty, Rafi Ahmed and their colleagues at Emory University knocked out the gene in mice and found that despite a normal initial antibody response to a virus, the *SAP*-less animals failed to produce virus-specific plasma cells or B cells, which make sure that antibodies stick around for years. Normally T cells stimulate the growth of both kinds of cell, but they seem to be helpless without *SAP*. The January 16 *Nature* has the details. —*JR Minkel*

CHILDHOOD VACCINES protect into adulthood, thanks in part to an immunity memory gene.

BRIEF BITS

- Lifesaving saris: pouring drinking water through the cloth of sari robes can catch tiny crustaceans on which cholera bacteria cling. The method cut the incidence of cholera in Bangladeshi villages by almost half.

*Proceedings of the National Academy of Sciences*, published online January 14, 2003

- Reducing the blood level of beta-amyloid, the Alzheimer's disease protein, could reduce the protein's buildup in the brain, according to a study in mice.

*Journal of Neuroscience*, January 1, 2003

- Researchers have built a semiconductor-based nanowire laser that can be driven electrically. Previous nanowire lasers needed to be jump-started by another laser, hindering their incorporation into silicon chips.

*Nature*, January 16, 2003

- Contrary to widespread thinking, seeds don't need to be touching wet soil to germinate; water vapor by itself is sufficient.

*Soil Science Society of America Journal*, November–December 2002

BIOLOGY

## Re-evolution

**Stick insects' resemblance** to twigs hides them from predators. A standard genetic analysis used to determine evolutionary lineages shows that they have kept something else long hidden: winged species evolved from wingless ancestors, whose own ancestors were winged. "To our knowledge, this is the first example of a complex feature being lost and later recovered in an evolutionary lineage," write Michael F. Whiting of Brigham Young University and his colleagues in the January 16 *Nature*. The authors further note that the new wings did not re-evolve from scratch; genetic blueprints seem to have lain in wait for at least 50 million years, until flight was favored over fecundity (wingless insects tend to lay more eggs). The researchers predict that more examples exist in which complex structures re-evolved.

—*Steve Mirsky*

WINGING IT: Walking stick lost and recovered its wings.

BIOTECH

## Unnatural at 21

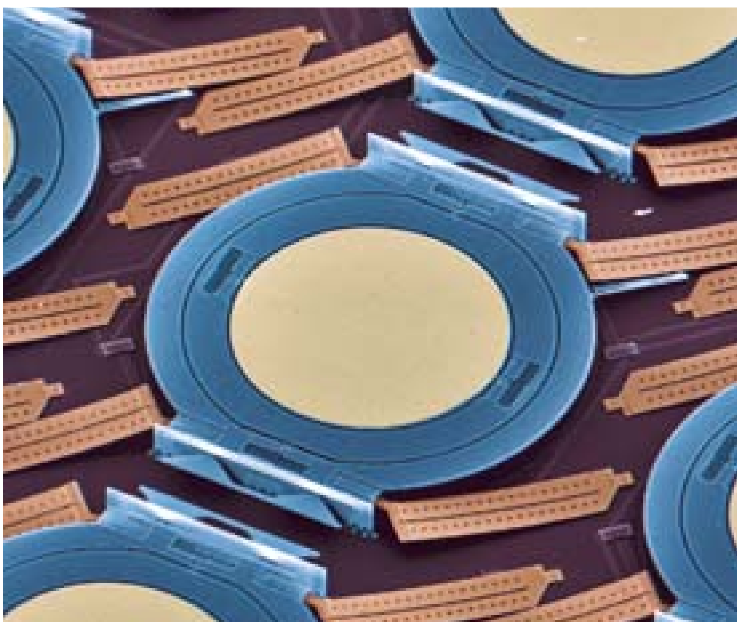
**The standard genetic code** calls for just 20 amino acids, enough to make all of life's proteins. Now researchers have made *E. coli* that generates an amino acid not found in nature, known as *p*-aminophenylalanine, or *p*AF. The team, led by Peter G. Schultz of the Scripps Research Institute in La Jolla, Calif., altered one of the bacterium's "stop" codons—a bit of genetic data that instructs the cell when to cease making protein—so that it coded for *p*AF. The bacterium's genes could subsequently make *p*AF and weave it into proteins on its own, in contrast with previous work, in which the bacterium had to be given *p*AF. A few exotic microbes make nonstandard amino acids, but *E. coli* is a better lab organism. The investigators hope they will help answer why most life settled on 20, whether added nonstandard amino acids confer benefits, and if new proteins can be made. The findings appear in the January 29 *Journal of the American Chemical Society*. —*Charles Choi*

AARON HAUPT *Photo Researchers, Inc.* (*top*); ALLISON WHITING *Brigham Young University* (*bottom*)

# The Relentless Storm

**Bell Labs weathers the worst crisis of its 78-year history** By GARY STIX

**For years, David Bishop** has served as a standard-bearer for the postdivestiture Bell Labs. Trained as a condensed-matter physicist, Bishop demonstrated how someone who spent the formative years of his career doing high-temperature superconductivity experiments at one of the nation's top industrial laboratories could make the transition to overseeing early-stage product development. In the mid-1990s, as the emphasis on market-oriented research was growing, Bishop managed a group that fabricated microelectromechanical systems (MEMS), which contain tiny mirrors that can change the direction of optical signals. The initial research on MEMS resulted in his heading a team of about 100 people that built the LambdaRouter: a switch that could take a wavelength from one optical fiber and route it to hundreds of other pathways in a network.



MICROMIRROR LIGHT SWITCH created at Bell Labs was taken off the market during the telecommunications meltdown.

LUCENT TECHNOLOGIES/BELL LABORATORIES

The product was a showpiece of innovation at the laboratories. But in the summer of 2002, as the depression in the telecommunications sector reduced demand dramatically for new long-haul optical pipes, the LambdaRouter was pulled off the market. Not much interest lingered in a switch equipped to handle 10 terabits (trillions of bits) of switching capacity. Speaking of this experience, Bishop invokes the perfect storm, which, along with the nuclear winter, is constantly repeated as a metaphor for the telecommunications industry's financial implosion of the past two years or so. "Never before in the history of the company has its survival been so actively discussed," Bishop laments.

From the moment of the AT&T divestiture in 1984, questions arose about whether the unparalleled mix of scientists and engineers that produced the transistor, the laser and the fractional quantum Hall effect could survive outside the shelter of a monopoly. The push for market relevance at Bell Labs began just a few years afterward and has continued to emerge with the morphing of corporate parenthood from AT&T to Lucent, which later cast off its microelectronic, fiber and business-networking divisions.

Through spin-offs, layoffs and attrition, Bell Labs Research—the locus of the company's basic science investigations—has diminished from 1,200 employees in 1997 to about 500 today. A three-year-old Bell Labs Research facility in Silicon Valley was shuttered in 2001. The umbrella organization—Bell Labs, which includes the development side of Lucent's business—has shrunk from 24,000 in 1999 to 10,000 today. Overall R&D spending has dropped from $3.54 billion in the company's 1999 fiscal year to $2.31 billion in fiscal 2002, although as a percentage of dwindling company revenues it has actually increased.

The current crisis, exacerbated by numerous missteps by Lucent upper management, is the worst since the laboratories were founded in 1925. Some outsiders question whether basic research at Bell Labs will survive, the rationale for its existence having been frittered away over time; for instance, the spin-off in 2001 of Lucent's microelectronics division into Agere Systems undercut some of the justification for maintaining a physical sciences group, a linchpin of the research division. "Bell Labs Research is currently misaligned with Lucent's future, so ultimately it's going to be disassembled," says Greg Blonder, a venture capitalist who spent about 15 years at Bell Labs.

The physicists, materials scientists, chemists, mathematicians, engineers and even some biologists who are members of the core research team reject that argument, contending that the organization has a new role to play in staging a turnaround. In the past few years, many of these scientists have begun to work more closely with product developers than at any time before in the labs' history. Laboratory managers battled to alter the ivory tower mind-set of basic researchers beginning in the early 1990s. But officials assert that collaborations between Bell Labs and the business units have never been undertaken in such a systematic manner as they are now.

For his part, Bishop has managed smaller projects since the LambdaRouter was put on hold, including development of automated methods for assembling optical components. Lucent is also attempting to market its intellectual property more broadly. Government agencies and Ford Motor Company, among others, are evaluating quantum cascade lasers, designer light emitters invented at Bell Labs, as chemical sensors. World-class chemist Elsa Reichmanis worked at Bell Labs for about 15 years developing chemicals for semiconductor manufacturing, but this expertise was no longer needed after the Agere spin-off. She now leads a team that is lending know-how, along with Lucent patents, to DuPont and Sarnoff Corporation to help create organic light-emitting diode displays.

Basic scientific investigations have not disappeared either, as a greater focus on applied research has emerged. “We’re still in the damn good science business,” Bishop says. The emphasis on the practical sometimes works backward from application to science—scheduling algorithms for wireless networks have helped address nettlesome theoretical questions, for example. Research by Bishop and his colleagues on MEMS went into making a type of sensor that measures a quantum-mechanical effect called the Casimir force. Two scientists from unrelated disciplines can still strike up a collaboration over cafeteria hamburgers or sushi and begin work on a project the same afternoon, a difficult proposition at universities, where the need to seek grant money constrains such impromptu alliances. This atmosphere prevails despite a recent scandal that led to the firing of physicist J. Hendrik Schön over misrepresented data about organic electronics and high-temperature superconductivity.

Bell Labs’s continued existence obviously depends on its parent’s survival. “I think what’s critical for Lucent is to show better success in commercializing R&D, whether that’s done by Bell Labs or wherever,” observes Nikos Theodosopoulos, a financial analyst with UBS Warburg who holds stock in Lucent. Too often Bell Labs inventions—from the Unix operating system to advanced chipmaking techniques—were ones that ultimately furnished as much or even more benefit to other companies as they did to AT&T and its offspring.

For the most part, other companies have eschewed de novo research in favor of different models—for instance, buying smaller companies or tapping research from national laboratories or universities. But Jeffrey M. Jaffe, president of Bell Labs Research and Advanced Technologies, defends Lucent’s approach. “Developing technology in house is more efficient than making acquisitions,” he says. “Companies pay premiums for acquisitions—and at times have difficulty integrating them.”

Even if Jaffe is right—and other research leaders might disagree with his assessment—the monopoly-era notion that research should originate in the organization that ultimately brings it to market has changed unalterably. The demands of commercial research require a heterogeneous mix of collaborations extending far beyond any single company. The danger, however, is that without the critical mass of scientists engaged in undirected pursuits, pathbreaking telecommunications technologies will not emerge. “The problem with not doing research is that you never know what you’re going to lose. You never know what you might have had that would have changed things in some way,” says Robert Lucky, a former research executive at both Bell Labs and one of the AT&T progeny, Bell Communications Research (later Telcordia). The National Research Council has recruited Lucky to head a study group this year to determine whether the U.S. research base in telecommunications is being eroded. When the participants begin examining the merits of new research models, one thing is certain: Bell Labs and its more than 40,000 inventions will serve as a frame of reference against which all alternatives will be compared. SA

**Can basic research survive as Lucent absorbs blow after financial blow?**

# Some Rights Reserved

**Cyber-law activists devise a set of licenses for sharing creative works   By GARY STIX**

**In a book published in 2001,** Stanford Law School professor Lawrence Lessig decried the threat to the Internet from both large media interests and burgeoning intellectual-property laws. In Lessig's view, the Internet should serve as a commons, a medium that encourages creativity through the exchange of photographs, music, literature, academic treatises, even entire course curricula. Lessig and like-minded law and technology experts have now decided to go beyond making academic arguments to counter the perceived danger.

On December 16, 2002, the nonprofit Creative Commons opened its digital doors to provide, without charge, a series of licenses that enable a copyrighted work to be shared more easily. The licenses attempt to overcome the inherently restrictive nature of copyright law. Under existing rules, a doodle of a lunchtime companion's face on a paper napkin is copyrighted as soon as the budding artist lifts up the pen. No "©" is needed at the bottom of the napkin. All rights are reserved.

The licenses issued through Creative Commons have changed that. They allow the creator of a work to retain the copyright while stipulating merely "some rights reserved." A user can build a custom license: One option lets the copyright holder specify that a piece of music or an essay can be used for any purpose as long as attribution is given. Another, which can be combined with the first, permits usage for any noncommercial end. Separately, the site offers a document that lets someone's creation be donated to the public domain.

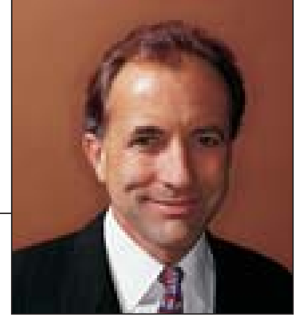
A copyright owner can fill out a simple questionnaire posted on the Creative Commons Web site (www.creativecommons.org) and get an electronic copy of a license. Because a copyright notice (or any modification to one) is optional, no standard method exists for tracking down works to which others can gain access. The Creative Commons license is affixed with electronic tags so that a browser equipped to read a tag—specified in XML, or Extensible Markup Language—can find copyrighted items that fall into the various licensing categories. An aspiring photographer who wants her images noticed could permit shots she took of Ground Zero in Manhattan to be used if she is given credit. A graphic artist assembling a digital collage of September 11 pictures could then do a search on both "Ground Zero" and the Creative Commons tag for an "attribution only" license, which would let the photographer's images be copied and put up on the Web, as long as her name is mentioned.

Lessig and the other cyber-activists who started Creative Commons, which operates out of an office on the Stanford campus, found inspiration in the free-software movement and in previous licensing endeavors such as the Electronic Frontier Foundation's Open Audio License. The organization is receiving $850,000 from the Center for the Public Domain and $1.2 million over three years from the John D. and Catherine T. MacArthur Foundation.

Some legal pundits will question whether an idea that downplays the profit motive will ever be widely embraced. Creative Commons, however, could help ensure that the Internet remains more than a shopping mall. For his part, Lessig, who last year argued futilely before the U.S. Supreme Court against an extension of the term of existing copyrights, has translated words into action. Now it will be up to scholars, scientists, independent filmmakers and others to show that at least part of their work can be shared and that a commons for creative exchange can become a reality in cyberspace. SA

*Please let us know about interesting and unusual patents. Send suggestions to: patents@sciam.com*

JENNIFER KANE



# Demon-Haunted Brain

**If the brain mediates all experience, then paranormal phenomena are nothing more than neuronal events   By MICHAEL SHERMER**

**Five centuries ago** demons haunted our world, with incubi and succubi tormenting victims as they lay asleep. Two centuries ago spirits haunted our world, with ghosts and ghouls harassing sufferers during all hours of the night. This past century aliens haunted our world, with grays and greens abducting captives and whisking them away for probing and prodding. Nowadays people are reporting out-of-body experiences, floating above their beds.What is going on here? Are these elusive creatures and mysterious phenomena in our world or in our minds? New evidence adds weight to the notion that they are, in fact, products of the brain. Neuroscientist Michael Persinger, in his laboratory at Laurentian University in Sudbury, Ontario, for example, can induce all these perceptions in subjects by subjecting their temporal lobes to patterns of magnetic fields. (I tried it myself and had a mild out-of-body experience.)

Similarly, the September 19, 2002, issue of *Nature* reported that neuroscientist Olaf Blanke of Geneva University Hospital in Switzerland and his colleagues were able to bring about out-of-body experiences through electrical stimulation of the right angular gyrus in the temporal lobe of a 43-year-old woman suffering from severe epileptic seizures. With initial mild stimulation, she felt she was "sinking into the bed" or "falling from a height." With more intense stimulation, she said she could "see myself lying in bed, from above, but I only see my legs and lower trunk." Another trial induced "an instantaneous feeling of 'lightness' and 'floating' about two meters above the bed, close to the ceiling."

**The fate of the paranormal and the supernatural is to be subsumed into the normal and the natural.**

A related study is cited in the 2001 book *Why God Won't Go Away*. In it, Andrew Newberg of the University of Pennsylvania Medical Center and the late Eugene D'Aquili found that when Buddhist monks meditate and Franciscan nuns pray, their brain scans show strikingly low activity in the posterior superior parietal lobe, a region the authors have dubbed the orientation association area (OAA). The OAA provides bearings for the body in physical space; people with damage to this area have a difficult time negotiating their way around a house, for instance. When the OAA is booted up and running smoothly, there is a sharp distinction between self and nonself. When the OAA is in sleep mode—as in deep meditation or prayer—that division breaks down, leading to a blurring of the lines between feeling in body and out of body. Perhaps this is what happens to monks who discern a sense of oneness with the universe, or nuns who feel the presence of God, or alien abductees who believe they are floating out of their beds to the mother ship.

Sometimes trauma can become a trigger. The December 15, 2001, issue of the *Lancet* published a Dutch study in which 12 percent of 344 cardiac patients resuscitated from clinical death reported near-death experiences, some having a sensation of being out of body, others seeing a light at the end of a tunnel. Some even described speaking to dead relatives. Because the everyday occurrence is of stimuli coming from the outside, when a part of the brain abnormally generates these illusions, another part of the brain interprets them as external events. Hence, the abnormal is thought to be the paranormal.

These studies are only the latest to deliver blows against the belief that mind and spirit are separate from brain and body. In reality, all experience is mediated by the brain. Large brain areas such as the cortex coordinate inputs from smaller brain areas such as the temporal lobes, which themselves collate neural events from still smaller brain modules such as the angular gyrus. Of course, we are not aware of the workings of our own electrochemical systems. What we experience is what philosophers call qualia, or subjective states of thoughts and feelings that arise from a concatenation of neural events.

It is the fate of the paranormal and the supernatural to be subsumed into the normal and the natural. In fact, there is no paranormal or supernatural; there are only the normal and the natural—and mysteries yet to be explained. It is the job of science, not pseudoscience, to solve those puzzles with natural, rather than supernatural, explanations. SA

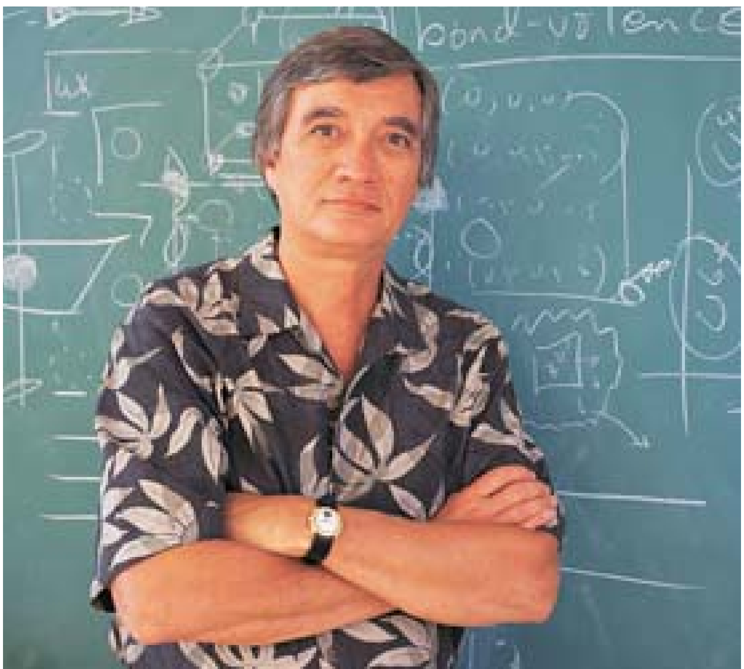
*Michael Shermer is publisher of* Skeptic *(www.skeptic.com) and author of* Why People Believe Weird Things.

BRAD HINES

# Man against a Mountain

**Yucca Mountain is set to become the nation's prime nuclear waste site, but geologist Rodney C. Ewing thinks that federal enthusiasm for it has outstripped the science** By STEVE NADIS

**Some 75,000 feet of core samples** and 18,000 geologic and water specimens have been retrieved from a desolate ridge in the Nevada Desert called Yucca Mountain. Products of a 20-year investigation by the Department of Energy, the recovered materials and their subsequent analyses have made the volcanic protrusion among the most studied features on earth. And such statistics make DOE officials confident that Yucca Mountain would be a suitable disposal site for the nation's high-level nuclear waste, able to hold 70,000 metric tons of radioactive poison safely for 10,000 years.



JEFFREY M. SAUGER

## RODNEY C. EWING: SAYING NO TO YUCCA

- A multidepartmental professor at the University of Michigan at Ann Arbor, spanning nuclear engineering, geology and materials science.
- With geologist Allison Macfarlane of the Massachusetts Institute of Technology, Ewing is finishing a book, due out early next year, on Yucca Mountain's unresolved technical issues.
- "The game is not rigged like a crooked card game, but the lack of choice at every step drives us inexorably to Yucca Mountain."

Rodney C. Ewing begs to differ. Citing the amount of research is "not the way you measure good science, any more than you judge the merits of a book by the number of words," says the 56-year-old geologist, who holds an interdisciplinary professorship at the University of Michigan at Ann Arbor. Ewing sits on the National Academy of Sciences (NAS) Board on Radioactive Waste Management and has served on the Yucca Mountain peer-review panel. One of Yucca's most knowledgeable critics, he believes that the mass of information collected, which can be measured in tons, masks even greater unknowns.

In 1987 Congress named Yucca Mountain as the preferred site in amendments to the Nuclear Waste Policy Act of 1982, cutting off consideration of alternative sites in Texas and Washington State. Opponents of the legislation have sometimes called it the "screw Nevada" bill. The law enabled the DOE to spend $7 billion laying the foundation for a repository and building some nine kilometers of tunnels through the mountain to facilitate studies and to provide access for waste disposal.

The DOE's risk evaluation hinges on an elaborate computer calculation that tries to predict the fate of wastes buried for millennia. This "probabilistic performance assessment" has revealed no deal breakers, prompting the agency to press for continued development. The Bush administration and Congress endorsed the site in 2002. After the DOE files for a construction permit, which is not expected before December 2004, the Nuclear Regulatory Commission (NRC) will have four years to rule on the repository's future. With the NRC's sanction, the DOE can begin construction.

Ewing thinks the process has outpaced the science: "We've learned a lot about this mountain, but when you look at the substance of it, our knowledge is actually quite thin." According to Ewing, a host of problems stem from the exclusive investment in Yucca since 1987. His chief complaint is that the rules of the game have changed to fit the site. The linchpin of geologic disposal has traditionally been "defense in depth"—that is, the reliance on favorable geology plus engineered barriers, such as multilayered glass and metal packaging, to isolate wastes. At Yucca, this philosophy was quietly abandoned; site-specific standards replaced general ones, Ewing insists. "Instead of devising a regulation and finding a site that meets it," he says, "we picked a site and made a regulation for it."

UNTESTED SCIENCE? Geologist Ewing argues that a host of questions should be answered before nuclear waste goes past the entrance of Yucca Mountain.

LAURA RAUCH *AP Photo*

In this case, the Environmental Protection Agency has set the annual exposure limit of 15 millirems (about a third the strength of a medical x-ray) measured at 18 kilometers from the repository over 10,000 years. Satisfying this standard rests on a probabilistic assessment that incorporates thousands of assumptions—an approach never before applied to such a complex system. Some parameters (such as the density of water) are well known; others (such as the likelihood of volcanic activity) vary by a factor of 100,000. No one has figured out how to combine all these uncertainties, Ewing notes.

The mathematical approach, in his opinion, keeps us from seeing how the individual components are working. For example, much stock is being placed in Alloy 22, a relatively untested metal that is supposed to confine wastes over the long haul. The corrosion rate for the alloy depends on geochemical conditions—such as the pH and carbon dioxide content of the groundwater—that are inherently difficult to predict. "We're betting on a new material about which we know little, while making optimistic assumptions about its behavior under conditions we can only guess at," Ewing states. "Uncertainties throughout the model are rolled together, which makes it hard to tell whether any of the barriers are effective." He adds that there's been no attempt to test this model on a real geological system. Further complicating the model are still unresolved concerns about the site's geology, including seismic activity and volcanism.

Ewing finds the EPA guidelines deficient as well. The designated limit of 10,000 years is too short, he says; exposures are likely to peak millennia later. That is because some of the long-lived radionuclides to be buried there have half-lives of at least 24,000 years, and the geologic and engineered barriers will inevitably weaken over time. "We should do the analysis first to find out when the peak dose occurs, rather than setting the time limit in advance." He also considers the 18-kilometer distance at which the radiation is measured to be too far from the source.

When pressed, Ewing can't find much good to say about the endeavor except that some capable scientists and engineers have been employed. "But because of the way the program is designed, the work is so fragmented that people can't put it all together," he says.

Unlike most Yucca Mountain foes, Ewing has faith in geologic waste disposal and nuclear power. For example, he approves of New Mexico's underground Waste Isolation Pilot Plant. At WIPP, burial of plutonium-contaminated debris from nuclear weapons work started in 1999, after more than 20 years of scientific and political wrangling (Ewing also served on WIPP's review panel). Compared with those for Yucca Mountain, the wastes at WIPP are not as "hot": a much smaller amount of radioactivity will ultimately be stored there, greatly reducing the possibility of thermal problems. And the geology at WIPP is much simpler, according to Ewing, raising fewer concerns about water, earthquakes and volcanic activity.

Ewing's 12-year stint on the WIPP panel was his first prolonged involvement in the radioactive waste business. It all began as a "hobby," an offshoot of his main research on the effects of radiation on materials. While at the University of New Mexico in the 1970s (he taught there until his 1997 move to Ann Arbor), he found that none of the guest speakers from the nearby national labs could answer his questions on how radiation would damage a waste repository. The only way to find out, he concluded, was to do the experiments himself. Before he knew it, he had become an expert in the field.

Given the advanced stage of the project, Ewing sees little opportunity for scientific input at Yucca Mountain. As a result, he is taking a broader look at the environmental impacts of the nuclear fuel cycle. But he hasn't fired his last shot at Yucca: he expects to have a book out on the subject next year.

Ewing may induce heartburn among advocates of the Nevada facility, but he nonetheless has the respect of most of his colleagues. "He's a good scientist, someone who digs very deeply," says John F. Ahearne, chair of the NAS radioactive waste board. Although Ahearne calls him a "thoughtful critic and not at all intransigent," Ewing can be a formidable adversary because he follows a problem to the end, regardless of disciplinary boundaries. Before he's done, Yucca enthusiasts may wish he'd taken up a more traditional hobby, like stamp collecting. SA

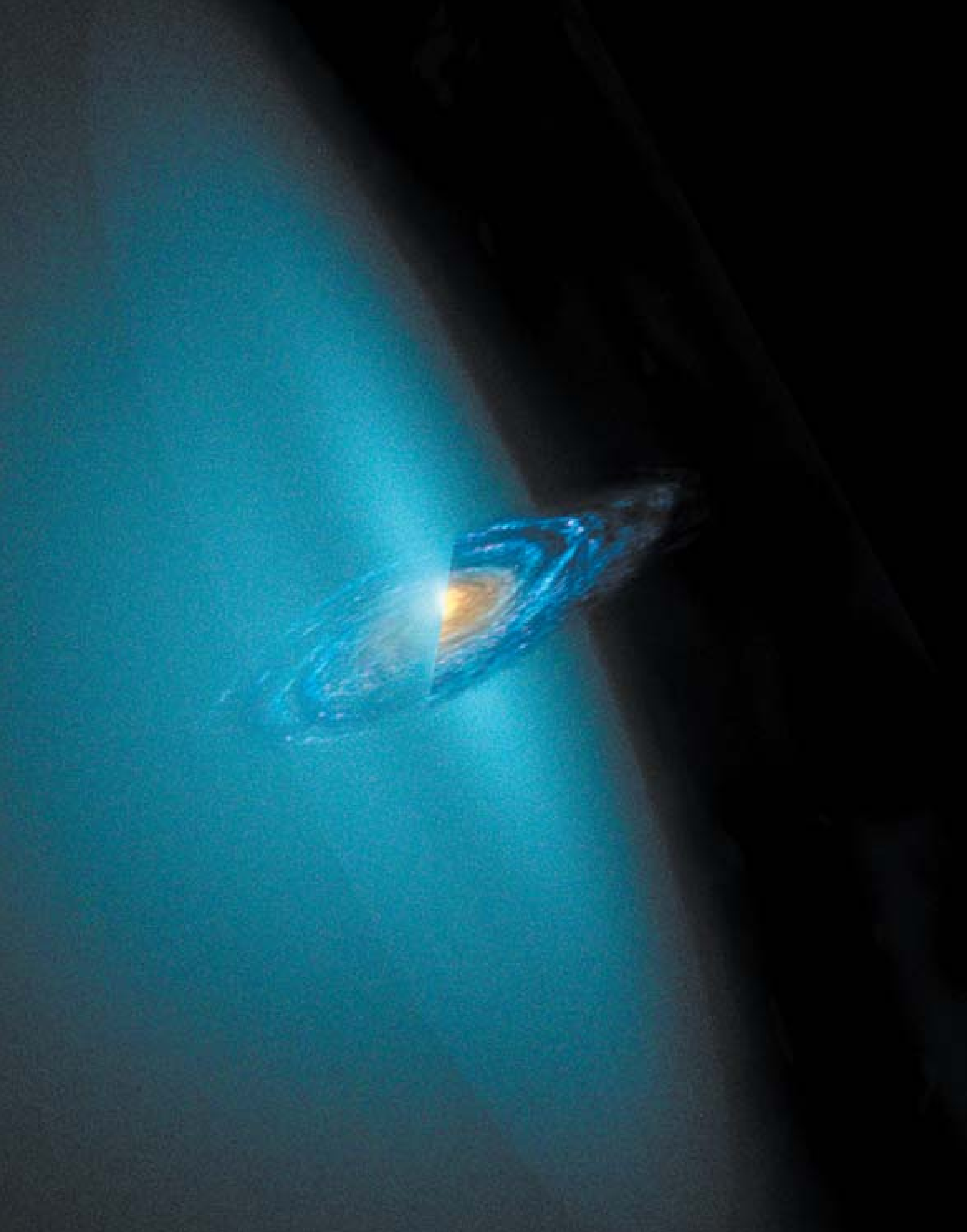
*Steve Nadis is based in Cambridge, Mass.*

# the search for Dark Matter

**Dark matter is usually thought of as something "out there." But we will never truly understand it unless we can bring it down to earth**

By David B. Cline

**IF WE COULD SEE DARK MATTER,** the Milky Way galaxy would look like a much different place. The familiar spiral disk, where most of the stars reside, would be shrouded by a dense haze of dark matter particles. Astronomers think the dark haze is 10 times as massive as the disk and nearly 10 times as big in diameter.



**The universe around us is not what it appears to be. The stars make up less** than 1 percent of its mass; all the loose gas and other forms of ordinary matter, less than 5 percent. The motions of this visible material reveal that it is mere flotsam on an unseen sea of unknown material. We know little about that sea. The terms we use to describe its components, “dark matter” and “dark energy,” serve mainly as expressions of our ignorance.

For 70 years, astronomers have steadily gathered circumstantial evidence for the existence of dark matter, and nearly everyone accepts that it is real. But circumstantial evidence is unsatisfying. It cannot conclusively rule out alternatives, such as modified laws of physics [see “Does Dark Matter Really Exist?” by Mordehai Milgrom; SCIENTIFIC AMERICAN, August 2002]. Nor does it reveal much about the properties of the supposed material. Essentially, all we know is that dark matter clumps together, providing a gravitational anchor for galaxies and larger structures such as galaxy clusters. It almost certainly consists of a hitherto undiscovered type of elementary particle. Dark energy, despite its confusingly similar name, is a separate substance that entered the picture only in 1998. It is spread uniformly through space, exerts a negative pressure and causes the expansion of the universe to accelerate.

Ultimately the details of these dark components will have to be filled in not by astronomy but by particle physics. Over the past eight years the two disciplines have pooled their resources, coming together at meetings such as the Symposia on Sources and Detection of Dark Matter and Dark Energy in the Universe. The next symposium will be held in February 2004 in Marina del Rey, Calif. The goal has been to find ways to detect and study dark matter using the same techniques that have been so successful for analyzing particles such as positrons and neutrinos. Rather than inferring its presence by looking at distant objects, scientists would seek the dark matter here on Earth.

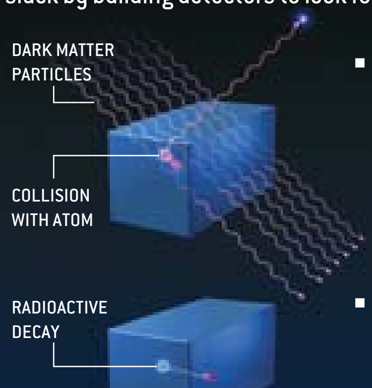
The search for dark matter particles is among the most difficult experiments ever attempted in physics. (The search for particles of dark energy is even less tractable and has been put aside, at least for the time being.) At the first symposium, in February 1994, participants expressed a nearly total lack of confidence that a particle detector in an Earth-based lab could ever register dark matter. The sensitivity of even the best instruments was a factor of 1,000 too low to pick up hypothesized types of dark particles. But since then, detector sensitivity has improved 1,000-fold, and instrument builders expect soon to wring out another factor of 1,000. More than 15 years of research and development on detector methods are finally bearing fruit. We may soon know what the universe is really like. Either dark matter will prove to be real, or else the theories that underlie modern physics will have to fall on their swords.

## Through the Looking Glass

WHAT KIND OF particle could dark matter be made of? Astronomical observation and theory provide some general clues. It cannot be protons, neutrons, or anything that was once made of protons or neutrons, such as massive stars that became black holes. According to calculations of particle synthesis during the big bang, such particles are simply too few in number to make up the dark mat-

## Overview/*Dark Matter Detectors*

Most astronomers think the heavens are filled with dark matter, but their observations are too imprecise to provide unequivocal proof, let alone measure the detailed properties of the supposed material. Particle physicists are trying to take up the slack by building detectors to look for the dark matter as it streams through Earth.




- Particles of dark matter, though reluctant to interact with ordinary atoms, should still do so occasionally. When such a particle ricochets off an atomic nucleus, the nucleus recoils, hits surrounding atoms and releases energy in the form of heat or light.
- The real trick is to distinguish this energy release from the effects of more prosaic processes, such as radioactive decay. Such effects may account for the only reported detection of dark matter to date.

DON DIXON (*preceding pages*); SLIM FILMS (*this page*)

# COMPOSITION OF THE UNIVERSE

| MATERIAL | REPRESENTATIVE PARTICLES | TYPICAL PARTICLE MASS OR ENERGY (ELECTRON VOLTS) | NUMBER OF PARTICLES IN OBSERVED UNIVERSE | PROBABLE CONTRIBUTION TO MASS OF UNIVERSE | SAMPLE EVIDENCE |
|---|---|---|---|---|---|
| Ordinary ("baryonic") matter | Protons, electrons | $10^6$ to $10^9$ | $10^{78}$ | 5% | Direct observation, inference from element abundances |
| Radiation | Cosmic microwave background photons | $10^{-4}$ | $10^{87}$ | 0.005% | Microwave telescope observations |
| Hot dark matter | Neutrinos | $\leq 1$ | $10^{87}$ | 0.3% | Neutrino measurements, inference from cosmic structure |
| Cold dark matter | Supersymmetric particles? | $10^{11}$ | $10^{77}$ | 25% | Inference from galaxy dynamics |
| Dark energy | "Scalar" particles? | $10^{-33}$ (assuming dark energy comprises particles) | $10^{118}$ | 70% | Supernova observations of accelerated cosmic expansion |

ter. Those calculations have been corroborated by measurements of primordial hydrogen, helium and lithium in the universe.

Nor can more than a small fraction of the dark matter be neutrinos, a lightweight breed of particle that zips through space and is unattached to any atom. Neutrinos were once a prominent possibility for dark matter, and their role remains a matter of discussion, but experiments have found that they are probably too lightweight [see "Detecting Massive Neutrinos," by Edward Kearns, Takaaki Kajita and Yoji Totsuka; Scientific American, August 1999]. Moreover, they are "hot"—that is, in the early universe they were moving at a velocity comparable to the velocity of light. Hot particles were too fleet-footed to settle into observed cosmic structures.

The best fit to the astronomical observations involves "cold" dark matter, a term that refers to some undiscovered particle that, when it formed, moved sluggishly. Although cold dark matter has its own problems in explaining cosmic structures [see "The Life Cycle of Galaxies," by Guinevere Kauffmann and Frank van den Bosch; Scientific American, June 2002], most cosmologists consider these problems minor compared with the difficulties faced by alternative hypotheses. The current Standard Model of elementary particles contains no examples of particles that could serve as cold dark matter, but extensions of the Standard Model—developed for reasons quite separate from the needs of astronomy—offer many plausible candidates.

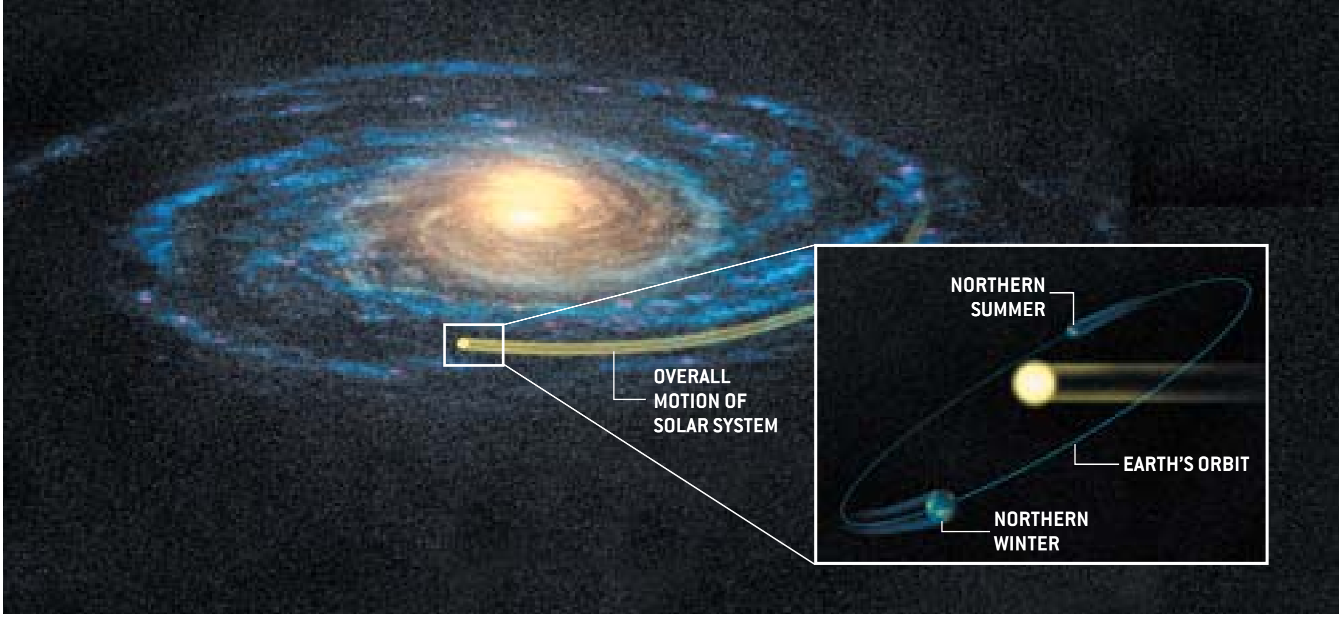
By far the most studied extension of this kind is supersymmetry, so I will concentrate on this theory. Supersymmetry is an attractive explanation for dark matter because it postulates a whole new family of particles—one "superpartner" for every known elementary particle. These new particles are all heavier (hence more sluggish) than known particles. Several are natural candidates for cold dark matter. The one that gets the most attention is the neutralino, which is an amalgam of the superpartners of the photon (which transmits the electromagnetic force), the *Z* boson (which transmits the so-called weak nuclear force) and perhaps other particle types. The name is somewhat unfortunate: "neutralino" sounds much like "neutrino," and the two particles indeed share various properties, but they are otherwise quite distinct.

Although the neutralino is heavy by normal standards, it is generally thought to be the lightest supersymmetric particle. If so, it has to be stable: if a superparticle is unstable, it must decay into two lighter superparticles, and the neutralino is already the lightest. As the name implies, the neutralino has zero charge, so it is unaffected by electromagnetic forces (such as those involving light). The hypothesized mass, stability and neutrality of the neutralino satisfy all the requirements of cold dark matter.

The big bang theory gives an estimate of the number of neutralinos that were created within the hot primordial plasma of the cosmos. The plasma was a chaotic soup of all types of particles. No individual particle survived for long. It would quickly collide with another particle, annihilating both but producing new particles in the process; those new particles soon collided with others, in a cycle of destruction and creation. But as the universe cooled down and thinned out, the collisions became less violent, and the process

# THE DARK WIND

LIKE MOTORCYCLISTS FEELING the wind in their face, we on planet Earth are being blasted by a head wind of dark matter. The dark matter is essentially a stagnant gas—particles move randomly but have no organized motion—and our solar system roars through this material at 220 kilometers a second. Within the solar system, Earth orbits at 30 kilometers a second. When the tilt of the orbit is taken into account, the head wind has a net velocity of 235 kilometers a second in the northern summer and 205 kilometers a second in winter. This variation distinguishes dark matter from noise, which does not change with the seasons.




ground to a halt. Particles condensed out one by one, beginning with those that tended to collide less often and proceeding to more collision-prone types.

## Shy but No Hermit

THE NEUTRALINO is a particularly collision-shy particle, so it froze out early on. At the time, the density of the universe was still very high, so a huge number of neutralinos were produced. In fact, based on the expected neutralino mass and its low tendency to collide, the total mass in neutralinos almost exactly matches the inferred mass of dark matter in the universe. This correspondence is a strong sign that neutralinos are indeed dark matter.

To detect dark matter, scientists need to know how it interacts with normal matter. Astronomers assume that it interacts only by means of gravitation, the weakest of all the known forces of nature. If that is really the case, physicists have no hope of ever detecting it. But the astronomers' assumption is probably just a convenient approximation—something that lets them describe cosmic structures without worrying about the detailed properties of the particles.

Theories of supersymmetry predict that the neutralino will interact by a force stronger than gravitation: the weak nuclear force. This is similar to the interaction that betrays neutrinos [see "The Search for Intermediate Vector Bosons," by David B. Cline, Carlo Rubbia and Simon van der Meer; SCIENTIFIC AMERICAN, March 1982]. The vast majority of neutralinos will slip through a slab of matter without interacting, but the occasional neutralino will hit an atomic nucleus. The unlucky particle will transfer a small amount of its energy to the nucleus.

The improbability and feebleness of the interaction are offset by the sheer number of particles. After all, dark matter is thought to dominate the galaxy. Being dark, it was never able to lose energy by emitting radiation, so it never could agglomerate into subgalactic clumps such as stars and planets. Instead it continues to suffuse interstellar space like a gas. Our solar system is orbiting around the center of the galaxy at 220 kilometers a second, so we are pushing through this gas at quite a clip [*see illustration above*]. Researchers estimate that a billion dark matter particles flow through every square meter every second.

Leszek Roszkowski and his team at the University of Lancaster in England recently carried out a complete calculation of the rates of neutralino interactions with normal matter. The rates are usually expressed as the number of events that would occur in a day in a sin-

THE AUTHOR

*DAVID B. CLINE* has now written seven articles for *Scientific American,* a new record for a researcher. Cline is professor of physics and astrophysics at the University of California, Los Angeles. His research has addressed the most important topics in particle physics: high-energy neutrinos, proton decay and the *W* and *Z* bosons, carriers of the weak nuclear force. More recently, his interests have turned to the search for dark matter. He works with the CMS detector at CERN near Geneva, which could one day produce dark matter.

DON DIXON

gle kilogram of normal matter. Depending on the theoretical details, the figures vary from 0.0001 to 0.1 event per kilogram a day. Current experiments are able to detect event rates in the high end of this range.

The main difficulty is no longer detector sensitivity but detector impurity. All materials on Earth, including the metal out of which the detectors are built, contain a trace amount of radioactive material such as uranium and thorium. The decay of this material produces particles that register much as dark matter would. Terrestrial radioactivity typically outpowers the putative neutralino signal by a factor of $10^6$. If the detectors are located aboveground, cosmic rays worsen the situation by an equal factor. To identify dark matter particles with any confidence, researchers must reduce both these unwanted backgrounds a millionfold.

## Turning the Other Cheek

PHYSICISTS THUS FACE two challenges: to detect the inherently weak interaction of dark matter with ordinary matter and to screen out confounding noise. To take the first challenge first, several properties of matter can be used to record the recoil of a nucleus that has been struck by a neutralino. Perhaps the simplest of all possible methods is just to look for the heating that will occur when the recoiling nucleus plows into the surrounding matter and gives up its kinetic energy, thereby raising the temperature of the material slightly. To detect this heating, the material must be at a very low temperature to start with. This is the principle of a cryogenic detector.

Cryogenic detectors such as those used by two leading search programs, the Cryogenic Dark Matter Search (CDMS) and Edelweiss, are designed to measure individual phonons, or quanta of heat, in a material. They operate at a temperature of about 25 millikelvins and use thermistors to record the temperature rise in the various parts of the apparatus. Individual detectors have a mass of a few hundred grams, and researchers can stack a large number of detectors to reach a total mass of a few kilograms or more, thereby boosting the signal. The latest incarnation of CDMS, located inside the Soudan Mine in Minnesota, is scheduled to start taking data later this year.

A second method watches for another effect of the recoiling nucleus: ionization. The nucleus knocks some electrons off surrounding atoms, resulting in excited ions known as excimers. Those ions eventually recapture an electron and return to normal. In some materials, mainly noble gas liquids such as xenon, the process triggers the emission of light, called scintillation light. This is how excimer lasers—those used in eye surgery—work. For liquid xenon, the light is very intense and lasts about 10 nanoseconds. A photomultiplier can amplify the signal to detectable levels.

In the early 1990s the ZEPLIN project—led by HanGuo Wang and me at U.C.L.A. and Pio Picchi of the University of Turin in Italy—developed two-phase liquid-xenon detectors. These instruments amplify the light by introducing a layer of gas threaded by an electric field; the field accelerates the electrons that get kicked off by recoiling nuclei, thereby turning a handful of particles into an avalanche. Eventually it should be possible

## LEADING SEARCHES FOR DARK MATTER

| PROJECT | LOCATION | START DATE | PRIMARY DETECTOR TYPE | PRIMARY DETECTOR MATERIAL | PRIMARY DETECTOR MASS (kg) | DISCRIMINATION DETECTOR TYPE(S) |
|---|---|---|---|---|---|---|
| UKDMC | Boulby, U.K. | 1997 | Scintillation | Sodium iodide | 5 | None |
| DAMA | Gran Sasso, Italy | 1998 | Scintillation | Sodium iodide | 100 | None |
| ROSEBUD | Canfranc, Spain | 1999 | Cryogenic | Aluminum oxide | 0.05 | Thermal |
| PICASSO | Sudbury, Canada | 2000 | Liquid droplets | Freon | 0.001 | None |
| SIMPLE | Rustrel, France | 2001 | Liquid droplets | Freon | 0.001 | None |
| DRIFT | Boulby, U.K. | 2001 | Ionization | Carbon disulfide gas | 0.16 | Directional |
| Edelweiss | Frejus, France | 2001 | Cryogenic | Germanium | 1.3 | Ionization, thermal |
| ZEPLIN I | Boulby, U.K. | 2001 | Scintillation | Liquid xenon | 4 | Timing |
| CDMS II | Soudan, Minn., U.S. | 2003 | Cryogenic | Silicon, germanium | 7 | Ionization, thermal |
| ZEPLIN II | Boulby, U.K. | 2003 | Scintillation | Liquid xenon | 30 | Ionization, scintillation |
| CRESST II | Gran Sasso, Italy | 2004 | Cryogenic | Calcium tungsten oxide | 10 | Scintillation, thermal |

to construct a 10-metric-ton liquid-xenon detector, which should be sensitive to the neutralinos even if their interactivity is very low.

The xenon need not be in liquid form. Some detectors use it in gaseous form. Although the gas has a lower density than the liquid does, gas more readily reveals the trail left by the recoiling nucleus. The trail points back to the direction of the incoming dark matter, allowing a further check that a galactic neutralino is responsible. Detectors of this type are being developed for the Boulby underground laboratories in England.

Xenon is convenient because it has no natural long-lived radioactive isotopes (thus reducing the background noise) and is readily available in the atmosphere (after purification to remove radioactive krypton left over from nuclear bomb tests). But it is not the only material that scintillates. DAMA, an experiment being conducted at the Gran Sasso Laboratory near Rome, uses sodium iodide. With a mass of 100 kilograms, DAMA is the largest detector in the world.

## Telling the Difference

THREE STEPS are generally taken to cope with the other great challenge, overcoming the background noise from natural radioactivity and cosmic rays. First, researchers screen out cosmic rays by placing detectors deep underground and enclosing them in special shields. Second, they purify the detector material to reduce radioactive contamination. Third, they build special instruments to look for the telltale signs that distinguish dark matter from other particles.

Even when the first two steps are taken, they are not enough. Therefore, new dark matter detectors all take the third step, employing some form of event discrimination. The first line of defense is to look for an annual variation of the signal. The flux of dark matter should be higher

## TWO TYPES OF DARK MATTER DETECTORS

### SCINTILLATION DETECTOR

ZEPLIN II project (*also below*)

**Principle:**
Looks for slight pulses of light triggered by dark matter passing through, in this case, liquid xenon

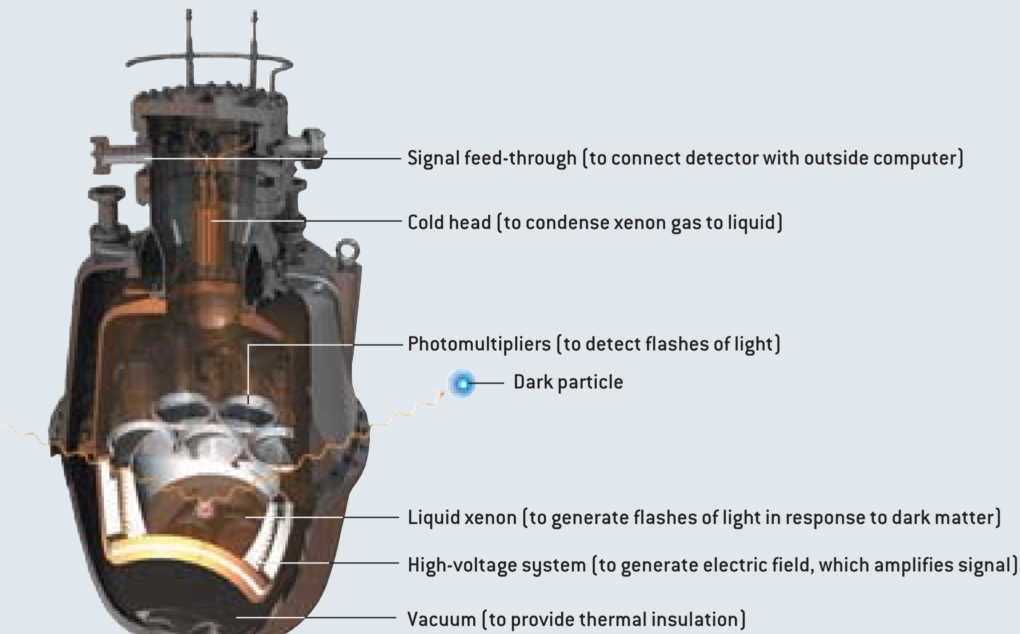
**Advantages:**
- Measurement of shape of pulse, potentially distinguishing dark matter from ordinary matter
- Measurement of multiple particle properties

### CRYOGENIC DETECTOR

CDMS II project

**Principle:**
Looks for slight pulses of heat generated by dark matter passing through a supercooled crystal

**Advantages:**
- Simplicity
- High sensitivity to low-energy particles
- Precise measurement of particle energy

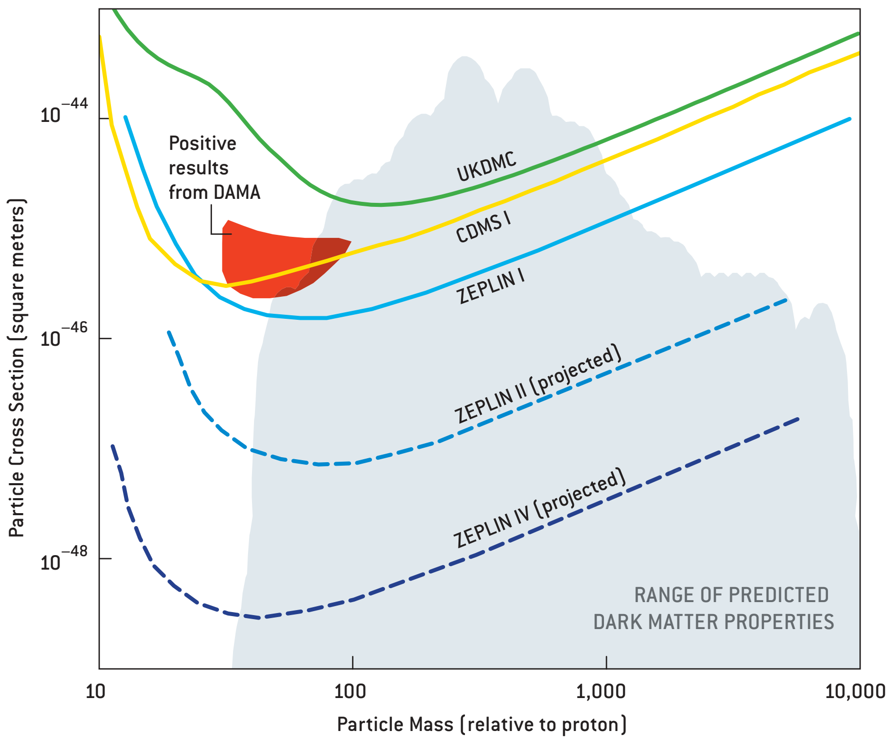



COURTESY OF DAVID B. CLINE; ROY PREECE *Dark Matter Group, Rutherford Appleton Laboratory* (*cutaway illustration*) in the northern summer, when Earth's orbital motion adds to the overall motion of the solar system through the galaxy, than in the northern winter, when Earth's motion subtracts from that of the solar system [*see illustration on page 54*]. The signal variation could be as high as a few percent.

The most advanced projects add a secondary detector, built using a different technology from that of the primary. The two detectors will respond to different types of particles in slightly different ways. For example, background particles tend to produce more ionization than a nucleus recoiling from a neutralino collision. By combining two detectors, this difference can be caught.

Using one or more of the above techniques, searches for dark matter signals started in earnest in the late 1980s. All but one have been null to date, which is not surprising, because they have only recently achieved the requisite sensitivity and noise tolerance. The lone exception is DAMA. Four years ago this project reported an observation of annual variation, which created excitement and skepticism in equal measure [see "Revenge of the WIMPs," by George Musser; News & Analysis, SCIENTIFIC AMERICAN, March 1999]. The problem was that DAMA does not use multiple detectors to discriminate between signal and noise. Three other experiments that do use multiple detectors have since cast doubt on DAMA's claims. Edelweiss, ZEPLIN I and CDMS I observed nothing in much of the range of parameters that DAMA had probed. The CDMS I team claimed a confidence level of 98 percent for the null result. If independent projects continue to come up empty-handed, the DAMA researchers will have to attribute their signal to radioactive processes or other noise.

The new generation of detectors should be able to rule neutralinos conclusively in or out. If they do not find anything, then supersymmetry must not be the solution that nature has chosen for the dark matter problem. Theorists would have to turn to other ideas, however distasteful that may now seem. But if the detectors do register and verify a signal, it would go down as one of the great accomplishments of the 21st century. The discovery of 25 percent of the universe (leaving only the dark energy unexplained) would obviously be the most spectacular implication. Other valuable information would follow. If detectors can spot particles of dark matter, particle accelerators such as CERN's Large Hadron Collider near Geneva might be able to re-create them and conduct controlled experiments. The confirmation of supersymmetry would imply a vast number of new particles waiting to be discovered and would lend support to string theory, in which supersymmetry plays an integral role. The greatest mystery in modern astrophysics may soon be solved. SA




DARK MATTER PROPERTIES are predicted by theory to fall somewhere within a certain range (*gray area*). The two properties shown here are the mass and the effective cross-sectional area, which is a measure of how likely it is that the dark matter particles will interact with ordinary matter. Detectors (*colored curves*) already probe a substantial part of this predicted range; the colored curves indicate the limit of their sensitivity. Most have found nothing, but one, known as DAMA, has seen hints of dark matter with a narrow band of possible properties (*red area*). Future detectors should be able to probe most of the predicted range, either proving the existence of dark matter or ruling it out.

JOHNNY JOHNSON; SOURCE: RICK GAITSKELL AND VUK MANDIC *University of California, Berkeley (dendera.berkeley.edu/plotter/entryform.html)*

## MORE TO EXPLORE


**Through a Universe Darkly: A Cosmic Tale of Ancient Ethers, Dark Matter, and the Fate of the Universe.** Marcia Bartusiak. HarperCollins, 1993.

**Supersymmetric Dark Matter.** Gerard Jungman, Marc Kamionkowski and Kim Griest in *Physics Reports,* Vol. 267, pages 195–373; March 1996. Available at **arXiv.org/abs/hep-ph/9506380**

**Just Six Numbers: The Deep Forces That Shape the Universe.** Martin J. Rees. Basic Books, 1999.

**Quintessence: The Mystery of the Missing Mass.** Lawrence M. Krauss. Basic Books, 2001.

**Sources and Detection of Dark Matter and Dark Energy in the Universe.** Edited by David B. Cline. Springer Verlag, 2001.

**WIMP Direct Detection Overview.** Yorck Ramachers. Invited review at Neutrino 2002 conference, Munich, Germany, May 25–30, 2002. **arXiv.org/abs/astro-ph/0211500**

Some Web sites on specific programs:

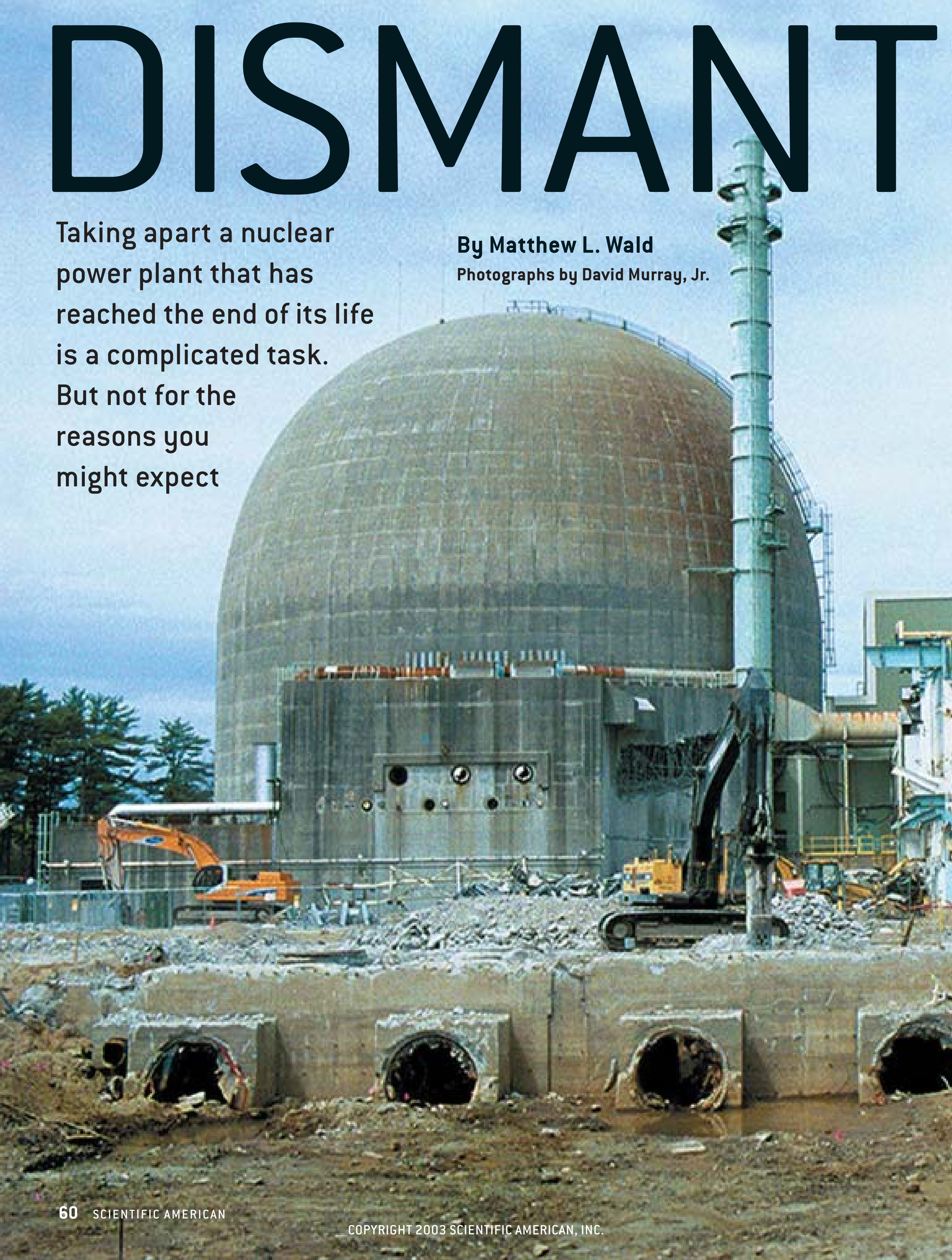
**www.physics.ucla.edu/wimps/default-main.html**
**cdms.berkeley.edu**
**www.lngs.infn.it/lngs/htexts/dama**
**hepwww.rl.ac.uk/ukdmc/ukdmc.html**
**avmp01.mppmu.mpg.de/cresst**

# DISMANT

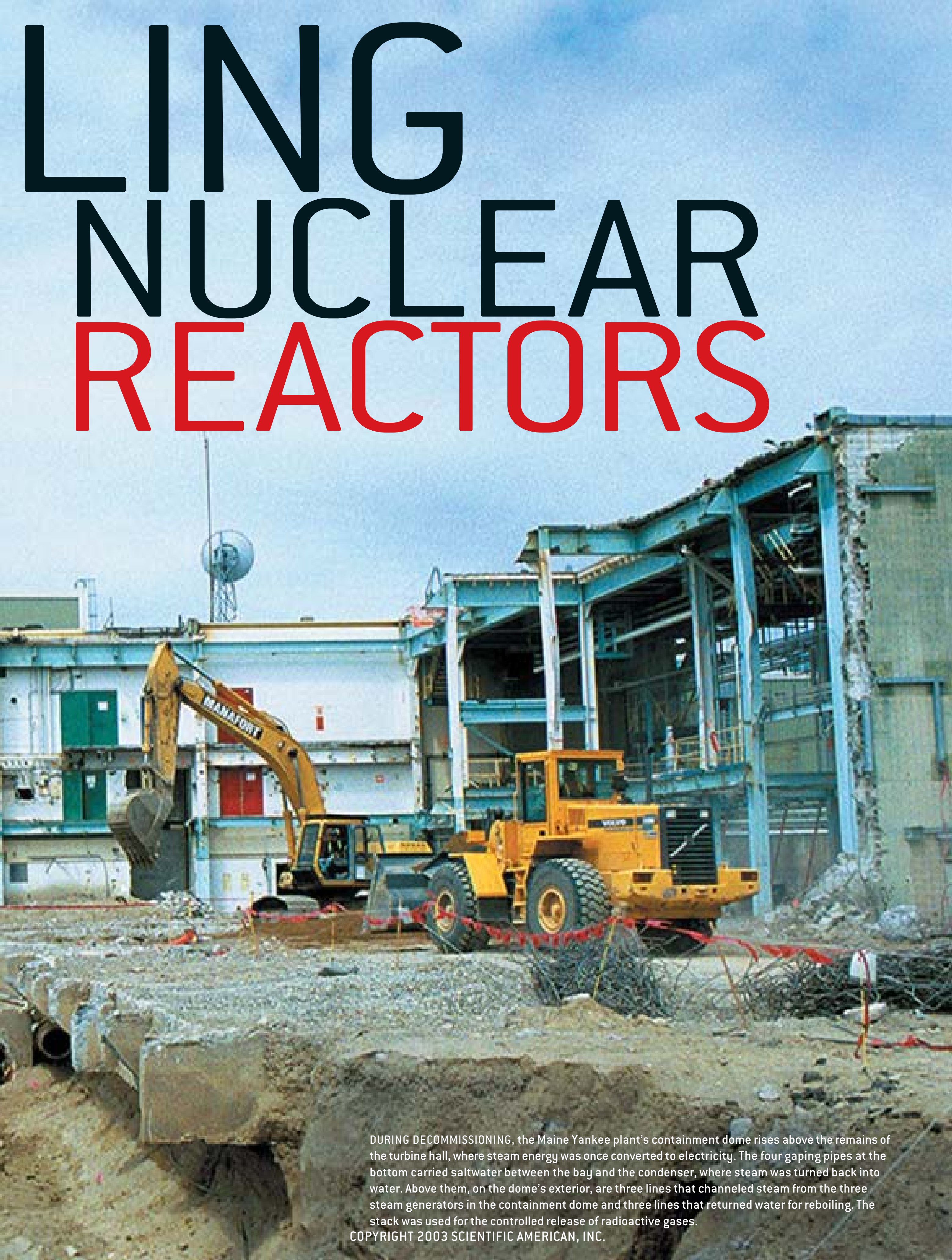
Taking apart a nuclear power plant that has reached the end of its life is a complicated task. But not for the reasons you might expect

**By Matthew L. Wald**

**Photographs by David Murray, Jr.**



# LING NUCLEAR REACTORS




DURING DECOMMISSIONING, the Maine Yankee plant's containment dome rises above the remains of the turbine hall, where steam energy was once converted to electricity. The four gaping pipes at the bottom carried saltwater between the bay and the condenser, where steam was turned back into water. Above them, on the dome's exterior, are three lines that channeled steam from the three steam generators in the containment dome and three lines that returned water for reboiling. The stack was used for the controlled release of radioactive gases.

**In a tidy office** in the city hall in Wiscasset, Me., right around the corner from the town clerk, Judy Foss touts the virtues of an 820-acre industrial site that she plans to have available for redevelopment soon. It offers easy access by road, rail and barge and has plenty of cooling water. It is already on the high-voltage electric grid. It is just a mile from the municipal airport, the local government is stable, and the natives are friendly.

There is a catch, though. It's radioactive. And parts of it will stay that way until at least 2023 and probably a lot longer.

The site, 40 miles northeast of Portland, is the home of Maine Yankee, one of the first large commercial nuclear power–generating stations built in this country and one of the first to close. It will also be among the first of this group to be decommissioned, an unglamorous task that was not fully thought through during the era when plants were being constructed.

Foss, a consultant, was brought in to find a replacement for the Maine Yankee plant, which, like nearly all power reactors, was the keystone of its local economy. When the plant was running, from 1972 until the end of 1996, it paid 90 percent of Wiscasset's property taxes and provided most of the high-paying jobs. Vital as such sites generally are to their host communities, Maine Yankee, as a pioneer in decommissioning, is particularly crucial to the nuclear industry's hopes for revival. No new technologies need to be developed to make decommissioning work. But the public and policy makers have scientific questions to weigh, including how much engineering work needs to be done and how clean is clean enough. (Whereas other countries rely more heavily on nuclear power, the American program is older, and thus decommissioning is more advanced here.)

The U.S. has 123 large commercial-scale power reactors that have ever operated, including the 103 currently open. Several companies that run them have talked about building new ones, a notion that has garnered recent national attention [see "Next-Generation Nuclear Power," by James A. Lake, Ralph G. Bennett and John F. Kotek; Scientific American, January 2002]. If the industry is not, in fact, dead (a debatable point, because no plants have been ordered since 1973 except those that were later canceled), then among the hurdles that must be overcome before building new plants is successfully decommissioning the old ones. The industry has to show that the acreage that once housed a plant is not a permanent industrial sacrifice zone and that it can be returned to the clean, "green-field" status essential for most kinds of redevelopment.

## Overview/*Plant Disassembly*

- The U.S. has 103 commercial nuclear power plants in operation, many of them the keystones of their local economies. Now owners are making plans for their eventual closure and decommissioning—a complex task not fully considered during the era they were built.
- The successful return of these sites to "green-field" status for unrestricted usage is considered imperative for the revival of the nuclear industry; the public will not accept the building of new plants if the status of closed ones cannot be resolved.
- Maine Yankee, one of the first large commercial nuclear plants to be built, provides a case study for the technical, environmental and economic complexities of decommissioning. Around the country, among the still unsettled questions: How clean is clean enough?

## Decontamination in Action

As it turns out, "decommissioning" does not mean "neutralizing"; it means moving radioactive material from one place to another. At Maine Yankee, that means 233 million pounds of waste, of which 150 million pounds is concrete. A little more than half the waste, 130 million pounds, is radioactive. Younger plants have 50 percent more generating capacity than older ones, and their debris volume will be somewhat larger.

There was a plan to sharply cut the amount of waste to be moved around. Originally, Maine Yankee's owners wanted to "rubbleize" the concrete and dump it into the building's foundation, then pour in more concrete to make a monolith. But local law blocks such burials of nuclear waste without a statewide referendum. (The Nuclear Regulatory Commission, or NRC, still considers on-site burial a useful option, but so far no civilian facility has tried it.) So instead the plant is literally going away, at a rate of about a trainload a week. In doing so, it is demonstrating both the pitfalls and the ease of decommissioning.

At the site, on a saltwater peninsula south of town where herons nest on power pylons, giant earth-moving equipment has torn up the nonnuclear buildings and loaded the concrete and metal onto railcars. The open gondolas are headed for nuclear dumps in South Carolina or Utah or for a nonnuclear landfill for construction debris in Niagara County, New York.

The anatomy of the plant is laid out a bit like that of a frog being dissected in a high school biology lab. During this visit the massive containment dome stands at the edge of a tangle of wreckage that used to be the turbine hall, where the energy in nuclear-heated steam was converted into torque for an electric generator. The path through which the reactor's product once traveled is plainly visible. Three pipes, each about the size of a water main, emerge from the containment building wall. They conveyed 500-degree-Fahrenheit steam to the turbines at more than 1,000 pounds per square inch of pressure. Underneath each pipe is a larger one that carried water back again for reheating. These were once monitored intensely for signs of radioactive contamination or fluctuations in temperature or flow. Now they sit open to the breeze, waiting their turn to move into the gondolas.

The dome is a tougher challenge. It is a typical containment for a large nuclear plant, big enough to enclose a high school gymnasium. It is four feet thick at the bottom, tapering to two feet at the top, with concentric layers of steel reinforcing bars. It weighs about 62 million pounds.

# Where the Plants and Dumps Are

LARGE COMMERCIAL nuclear power reactors (*blue*) operate mainly in the North and East. Shut-down plants (*red*) will eventually be dismantled, and their low-level radioactive waste could be sent to dumps in Barnwell, S.C., or Clive, Utah; the federal Hanford nuclear reservation in Washington State has also been used for some decommissionings. Assuming that approval and construction of the proposed high-level waste facility at Yucca Mountain (*orange*) in Nevada stay on schedule, it won't open before 2010.


*Browns Ferry 1 is licensed to operate but is not currently running.

LAURIE GRACE

To get the major components out of the dome, workers used a diamond saw. The concrete on the outside surface of the dome has the texture of a driveway. But where blocks have been removed, it feels as smooth as a lacquered coffee table. "Making the first few cuts into a nuclear-related safety system was very difficult to do, knowing it would never come back," says Michael J. Meisner, the chief nuclear officer on the project. In what was designed to be airtight even at 50 pounds per square inch of overpressure, a rough plywood door, fastened shut with a padlock, gives a little in the occasional breezes.

Although it seems counterintuitive, one of the easiest tasks thus far has been removing the main nuclear components, such as the reactor vessel and the three steam generators at the heart of the plant. They were taken out whole. In the case of the reactor vessel, a giant carbon-steel pot with a stainless-steel liner, the "internals"—the metal frame that held the core and channeled the water on its serpentine path—were chopped up with water jets and cutting tools. The work was done by remote control and underwater. (Tellingly, the American reactor industry did not survive the full life cycle of the first big plants; a French company, Framatome ANP, provided the technology for slicing apart the big metal components.)

Then the reactor core was filled with cement, or "grouted" in industry parlance, to reduce the possibility of parts loosening in coming centuries. The vessel was lifted out in preparation for a barge trip to a low-level-waste dump in Barnwell, S.C. Less active material goes to Envirocare in Clive, Utah, about 85 miles west of Salt Lake City. A third dump, on the federal government's Hanford nuclear reservation in south-central Washington State, has also been used for some decommissionings. The environmental benefit to moving the material is that it is easier to guard and monitor in a central location.

The internals will eventually go wherever the fuel—uranium pellets encased in pencil-thin rods—goes. In theory, that will be Yucca Mountain, in Nevada, where the Department of Energy hopes to build a nuclear waste repository. In any case, the internals will wait in four giant steel-and-concrete casks, alongside 60 other casks filled with spent fuel.

These, on a six-acre plot, form the new Independent Spent Fuel Storage Installation. The ISFSI, one of the newer acronyms to enter the nuclear lexicon, is similar to those springing up at plants around the country. Maine Yankee's has earthen berms around the 18-foot-high canisters, an electrified fence, closed-circuit cameras and a solid-looking guard building. If the Energy Department sticks to its latest schedule for finishing Yucca Mountain and accepting waste, which would be remarkable, the plot here will be in use for about 20 years. But it is expected to be far longer.

# Dissection of a Plant

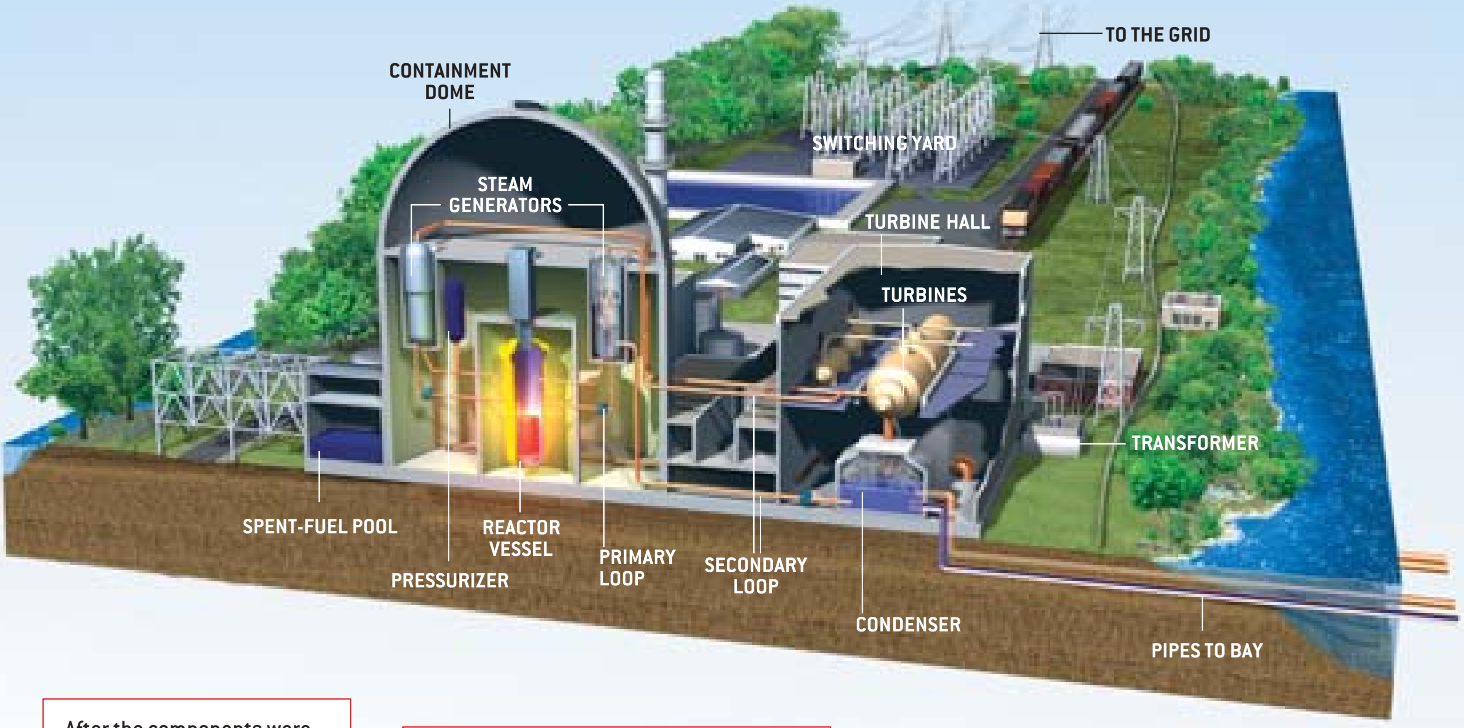
SOME 233 MILLION POUNDS of waste at Maine Yankee will be trucked to three dumps, depending on the level of radioactivity. More than half the material—130 million pounds—is radioactive. (For clarity, aspects of the plant's actual design and layout are modified in this illustration.)

MAINE YANKEE before its close in 1996.

A hole was cut in the wall of the containment dome to allow for removal of the components. The pressurizer and three steam generators (for simplicity, two are shown) were shipped intact to a dump at Barnwell, S.C.

Spent-fuel rods containing uranium pellets are being removed to dry casks for temporary on-site storage (which may last decades, until a central facility opens). The "internals"—the metal frame that held the core and channeled water throughout the plant—will ultimately fill four of 64 casks at Maine Yankee.

The surface of the concrete around the reactor vessel was "scabbled," or blasted away, to remove the top, contaminated layer.



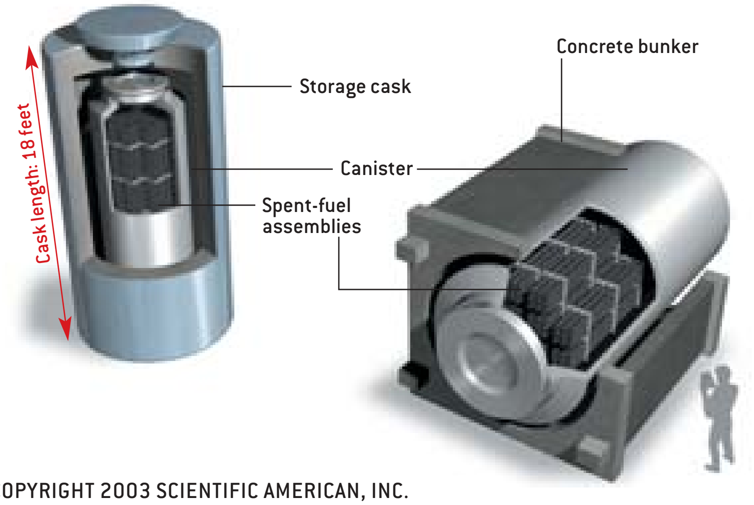

After the components were removed, the reactor vessel was "grouted," or filled with concrete, and prepared for shipment to Barnwell.

The primary loops were chemically washed to remove radioactive deposits. (Maine Yankee had three piping loops; for simplicity, two are shown.)

Low-level waste goes to Envirocare in Clive, Utah. Nonradioactive material is being sent to a landfill for construction debris in New York State.

## ON-SITE STORAGE

WITH NO CENTRAL FACILITY yet available for high-level radioactive materials, commercial nuclear power plants are opening Independent Spent Fuel Storage Installations to house giant casks of their waste. At some plants these steel-and-concrete containers rest horizontally (*far right*), but at Maine Yankee the casks are upright, under earthen berms, on a six-acre plot.




COURTESY OF MAINE YANKEE (*photograph*); DAVID FIERSTEIN (*top illustration*); DON FOLEY (*bottom illustration*)

In fact, although the NRC refuses to certify the casks indefinitely, it is not clear what would make them unsafe to use over the next 100 years or more, except global sea-level rise or, perhaps, terrorism. Critics say the casks are vulnerable to attack. Some have suggested sheltering the canisters in the dome, but the owners counter that it is too small. Nuclear experts argue that breaking the canisters would be difficult and that the material inside, already at a low-enough temperature that it does not require mechanical cooling, is not prone to aerosolizing and spreading over large distances. The NRC says it believes the casks are safe, but in September 2002 the agency imposed new security rules on them; the rules are secret.

## How Clean Is "Clean"?

THE FUEL IS AN OBVIOUS PROBLEM. Much of the rest of the plant presents a more subtle one. Technicians made 14,300 measurements, a little more than half in areas where they did not expect to find contamination. On the other hand, certain parts were barely tested, such as the reactor cooling system, the emergency core cooling system, and the chemical volume and control system; these were presumed to be dirty. Some sampling was done by running a vehicle over the land at speeds lower than five miles an hour. Many samples were sent to off-site labs for more sensitive analysis than was possible using Geiger-Mueller detectors.

The residual radiation permitted by state and federal regulations was so low that plant managers concluded that they would have to determine what normal background was, lest they end up removing radionuclides that would have been present had the plant never been built. (For instance, one major source of background radiation is fallout from atmospheric nuclear tests, mostly cesium 137.) So they went to the headquarters of one of Maine Yankee's owners, the Central Maine Power Company in Augusta, and sampled for beta activity on painted and unpainted concrete, ceramic tile, and asphalt.

While trying to discount natural background sources, managers also looked for the unnatural ones. As part of an agreement with a local environmental group, Friends of the Coast, they invited former workers back to Maine Yankee to discuss locations where materials had been dumped or spilled. The General Accounting Office (GAO), the investigative arm of Congress, lists this opportunity as a factor favoring prompt decommissioning.

Pressurized water reactors like Maine Yankee have multiple layers to hold in radioactive materials, but they always escape and turn up in odd places. In Maine Yankee's case, that included cobalt 60 on the employees' baseball field. (Decommissioning managers think it was brought there with snow plowed from the area immediately around the plant.)

A power reactor makes two kinds of radioactive materials. The dominant type is fission products. As nuclear plants run, they split uranium, which emits so little radiation that technicians handle raw fuel in nothing more than cotton gloves. But uranium splits into a dozen major kinds of fragments, which in turn decay into others. The fragments, and many of the decay products, are highly unstable. They readily give off energy—in the form of a gamma ray, an alpha or beta particle, or sometimes a gamma ray and a particle—to return to equilibrium. The fuel begins as a ceramic pellet wrapped in a metal tube and bathed in ordinary water. But in operation the ceramic fractures; at several plants, including Maine Yankee, the tubing leaked, allowing fission products to enter the cooling water. Many of these radioactive particles "plate out" on the interior of the vessel or on the piping.

In the pressurized-water design, the water that circulates past the fuel runs through giant heat exchangers, called steam generators, streaming inside thin-walled metal pipes, while clean water on the outside is boiled into steam, which then flows to the turbine. At Maine Yankee, those tubes leaked, too. And as is common at industrial plants, contaminated water was sometimes spilled into drains.

To cope with these fission products, plant technicians washed the piping with chemicals, lowering the radiation in the primary coolant loops fivefold. For surface-contaminated concrete, workers turned to "scabbling," or blasting away the first quarter- to half-inch; dust was vacuumed out and went through a high-efficiency particulate air, or HEPA, filtration system.

Even if the tubes or the fuel had never leaked, there is a second kind of contamination: activation products, atoms that are struck by neutrons from the fissioning uranium, absorb the neutron and become unstable, or radioactive, instead of splitting. Technicians found evidence of activation products up to two feet deep into concrete. Over the years of operation, the reactor internals are generally so transformed by neutron irradiation that they must be treated as high-level waste.

According to the NRC, one of the dominant activation products and a major source of radioactivity aside from the fuel is cobalt 60. It is produced by the interaction of neutrons and cobalt 59 or nickel, both components of various metal alloys. There is a saving grace to cobalt 60: its half-life, or the period that it takes half the material to give off its particles and gamma rays and transmute itself to nonradioactive nickel 60, is just 5.27 years. In theory, workers could simply wait it out; in 21 years, $^{15}/_{16}$ of the cobalt 60 would be gone.

But at Maine Yankee and many other plants, the impetus is to move ahead. One reason is cost, which tends to increase with time. Another is a characteristic of nuclear projects that own-

**THE FUEL IS AN OBVIOUS PROBLEM. MUCH OF THE REST OF THE PLANT PRESENTS A MORE SUBTLE ONE.**

ers have learned to fear: changing rules. Just as shifting regulations caused major delays in plant construction, they could lead to delays in tearing them down. A related concern is whether low-level waste repositories will be available when the time comes. If one or more of the three now in operation in the U.S. were to shut and not enough new ones were to open, prices could rise steeply or disposal could become unavailable. Disposal costs today already can run $600 per cubic foot.

In fact, rule changes have already occurred since the shutdown of Maine Yankee, and the regulatory challenges have grown. In 1997 the challenge was to meet the NRC's standard for unrestricted release of a property, but new rules are stricter.

The NRC standard is "as low as reasonably achievable" but no more than 25 millirem a year in additional radiation (above the background exposure in that area) to the average member of a critical, or vulnerable, group. The Environmental Protection Agency has a standard for sites that are chemically contaminated, based on a one-in-a-million chance of an additional cancer. It works out to 15 millirem per year, with no more than four millirem of that amount coming from groundwater.

THE AUTHOR

*MATTHEW L. WALD* is a reporter at the *New York Times,* where he has been covering nuclear topics since 1979. He has written extensively about reactor construction and operation, production of materials for nuclear weapons, military and civilian waste management, and the economics of power generation. He has visited 22 of the nuclear power plants in North America, as well as three research reactors, two military reactors, three nuclear waste burial grounds and the proposed high-level-waste repository at Yucca Mountain in Nevada. His current assignment is in Washington, D.C., where he also covers transportation safety and other technical subjects.

LATTICEWORK of 24 pigeonholes holds 12-foot-long radioactive fuel assemblies (*above*). The assemblies are shrouded in 2.5-inch-thick steel and set in a concrete silo 28.5 inches thick and 19 feet high (*right*).

The millirem is an odd unit to get a handle on. It is not directly a unit of radiation but one of biological damage. It derives from the roentgen, a measure of the ionizing power of gamma rays. But the three dominant types of radiation—alpha, beta and gamma—differ in their biological potency; the rem, which is short for "roentgen equivalent man," integrates the three into a single number.

The NRC asserts that its standard is sufficiently protective. For the moment, it is the federal standard. But it is also rapidly losing relevance. That is because the ultimate arbiters of health and safety, the states, are stepping in. In 2000 the Maine legislature cut the amount to 10 millirem, with no more than four from groundwater. Massachusetts, New York and New Jersey took similar steps, although so far the last two states do not have any reactors ready for full decommissioning.

The number is a key parameter because cleanup becomes more complicated as standards tighten. When it comes to radiation, it seems, almost no standard is stringent enough.

Some people think the Maine law sets a bad precedent. "What we ought to do is set standards for cleanup based on sound science and protection of health and safety," says Marvin S. Fertel, a senior vice president of the Nuclear Energy Institute, the industry's trade association. "The Maine standard goes well below it, and it's not a good use of societal resources."

James D. Werner, who was the Energy Department's director of long-term stewardship during the Clinton administration, observes that nuclear cleanup requirements are debated "in a world of ideologues. On one hand, you have people saying, 'It's so safe you can put it in your Wheaties,' " he expounds. "And there are others saying, 'My baby is going to die,' or at least, 'My investors will be nervous.' There is bad karma associated with these sites. These are emotional, not rational, responses. We'd be in bad shape if people had these responses to gas pipelines or electric cables."

A less technical evaluation, but one in better touch with the public's mood, comes from John W. O'Connell, the Wiscasset interim town manager: "I think the only acceptable level is zero."

Arguably, 25 millirem and 10 millirem are effectively the same: to use a technical term, zip. Worse, the significance of even 25 millirem is largely unknown. The idea that this amount has a health effect is part of a crucial but unproved assumption about radiation exposure—that unlike many chemical hazards, there is no threshold below which it is harmless. In fact, the mathematical model used to draw up safety regulations assumes that a given increment of exposure, 10,000 person-rem of collective dose, will cause one to eight fatal cancers no matter how applied. The 10,000 person-rem could be the result of exposing 10,000 people to one rem each, or 100,000 people to a tenth of a rem each, or a million people to a hundredth of a rem each. This is in contrast to individual dose; without medical treatment, a dose of about 350 rem will kill half of those exposed in what the regulators call "prompt death," as opposed to the "latent cancer fatalities" from collective doses.

On the other hand, health physicists argue that no effects have been demonstrated below 10 rem. Acute effects, such as nausea and hair loss, do not turn up until an individual has absorbed tens of rem.

There are some other yardsticks. For example, the federal government estimates that the average American's annual dose from all sources, including cosmic rays, radon gas and medical x-rays, is about 360 millirem. That would mean that 25 millirem from a decommissioned nuclear reactor is nearly an additional one-month dose every year. A resident of Wiscasset, which is at sea level, would get roughly the same extra increment of radiation by moving to Denver, which, at 5,260 feet above sea level, is less shielded by the atmosphere from cosmic rays. (The difference in natural background radiation is one reason that the limit on radiation exposure is set in terms of *additional* dose from a given human activity, not total dose. Otherwise, a strict standard could make living in Denver illegal.) Los Alamos National Laboratory estimates that cosmic radiation at sea level is 25 to 30 millirem a year; at an elevation of about 9,000 feet, it is 90 millirem.

In contrast to the 25-millirem maximum from decommissioned reactors, operating nuclear plants are allowed to expose people who live near them to 100 millirem a year, although actual exposures are far lower. Nuclear plant workers are limited to five rem a year, although operators aim for a maximum of two rem a year, and most employees get far less.

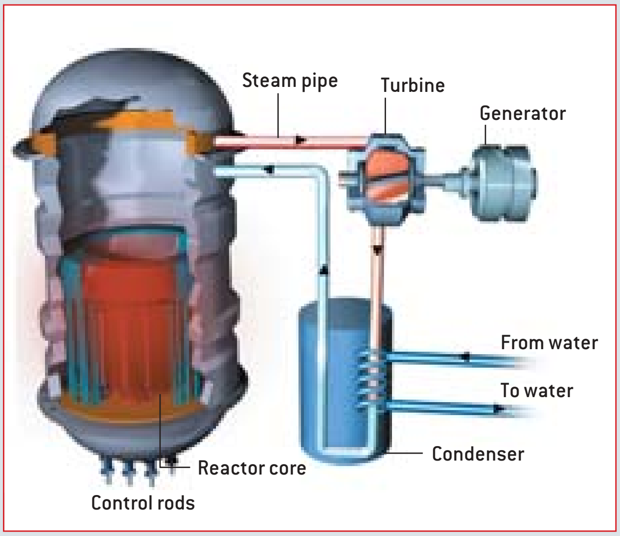
In addition, to reduce public exposure to radiation through the process of decommissioning, workers will soak up more of the dosage. The Maine Yankee project has a "budget" for worker exposure, 1,115 person-rem over the course of the work, for on-site activity. That compares with 440 person-rem in the year of the reactor's last refueling outage.

Whereas the 25-millirem figure may seem low, it would be hard for the average person to get that much. The NRC assumes that the most likely person to absorb such a dose is a farmer growing food on the site and irrigating the crops with a well drilled into the most contaminated spot.

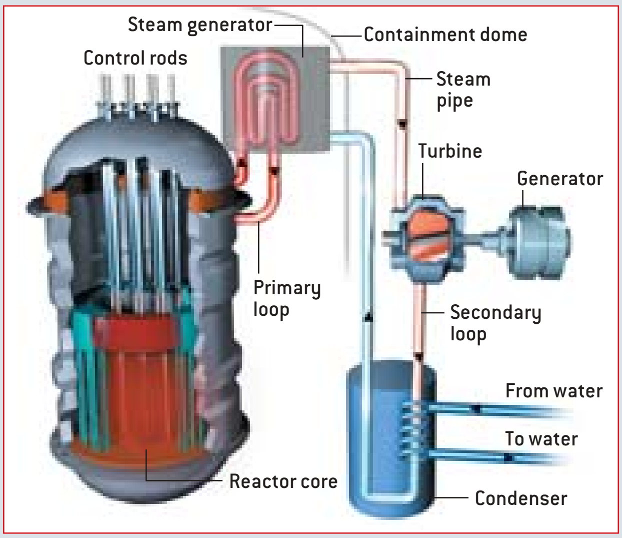
But farming would horrify Foss, the redevelopment consultant, because agriculture would not pay much in taxes and the site is too valuable as industrial real estate. In fact, Maine has few people who grow all their own food. A person who worked at the site eight hours a day, 250 days a year, eating food grown elsewhere and drinking town water, would arguably have barely any additional exposure at all, probably less during that year than a passenger receives on a transpolar airplane flight. Still, the guiding principle of unrestricted release is that the land should be in good shape for any conceivable use.

# Boiling or Pressurized

TWO TYPES OF REACTORS operate in the U.S. Pressurized water reactors account for 69 of the total 103 reactors; the rest are boiling water reactors.




BOILING WATER REACTOR boils water in the reactor and uses the steam to spin a turbine, just as a coal plant uses steam to do so. But the steam from the reactor is slightly radioactive. This design is slightly more fuel-efficient, which planners thought would be a consideration when the reactors were conceived; now, however, uranium is inexpensive.




PRESSURIZED WATER REACTOR heats water in the reactor and runs it through a heat exchanger, called a steam generator. The reactor water flows through thousands of thin-walled tubes. Outside of these tubes, clean, nonradioactive water is boiled into steam for the turbine. Thus, the radioactive water is designed to remain in the reactor building and not enter the turbine hall (unless the steam generator leaks, which happened at Maine Yankee and also at other plants).

The standard is so strict that checking for compliance becomes a technical problem. "You can't measure it; you have to model it," says Eric T. Howes, director of public and government affairs at the Maine Yankee plant. Radiation is customarily gauged in energy emissions per hour; to determine emissions per year in millirem, or thousandths of a rem, requires measuring hourly emissions in millionths of a rem.

Adding to the complexity is that each isotope will persist for a different length of time. For example, among the most prevalent at the time of shutdown was cobalt 60, with its five-year half-life. Later, cesium 137, with a half-life of 30.2 years, will be the major concern. Eventually the remaining radioactive sources will be the trace amounts of isotopes that have half-lives in the thousands of years.

## Paying the Tab

MANAGERS REPEATEDLY DECLINED to say how much extra it cost to meet the tougher Maine standard, as if the idea made them uncomfortable. But the General Accounting Office says Maine Yankee calculates the extra cost to be between $25 million and $30 million. In January 2002 Maine Yankee put the total decommissioning cost at $635 million. Low-level waste burial was $81.5 million of that amount; packaging and shipping accounted for another $26.8 million. Expenses at other plants should be in the same range. These are prodigious numbers compared with the $231 million that the plant cost to build in the 1960s and 1970s.

The Electric Power Research Institute estimates that for a plant that operates for 40 years, the cost of decommissioning will run 0.2 cent per kilowatt-hour produced in that period. Consumers today generally pay eight or nine cents for that much electricity, making it small by their standards, but the number is large for a company deciding what kind of plant to build.

The cost of decommissioning didn't always matter so much. It was a communal obligation, and the only issue was intergenerational: whether enough would be collected from a utility's captive customers for decommissioning or whether utilities would have to charge future users, not yet born when the benefits of the plant were enjoyed.

Now generating stations change ownership repeatedly, and somebody is going to be last. The GAO complained in a December 2001 report that the NRC was not paying enough attention to the financial qualifications of those entities buying plants. The NRC replied that it was, although some of the owners were not the entities to which it had granted operating licenses, as the builders had been. But the financial landscape has clearly changed; among the owners of today's plants is Enron, which acquired a majority interest in the defunct Trojan reactor when it bought an Oregon utility, Portland General Electric.

In the end, money was not a problem at Maine Yankee, because the Federal Energy Regulatory Commission allowed the owners to bill the former customers.

At many plants, it is difficult to say when a shutdown will eventually occur—one of the other remaining questions that will influence the fate of aging reactors. The plants were originally

DON FOLEY

licensed for 40 years from the issuance of a construction permit. The building of some dragged on so long that the NRC agreed to move up the start of the clock, to the time when operations actually began. Then it began offering 20-year license extensions. Most of the 103 plants running seem likely to apply.

Still, the economic life of old reactors is uncertain. They resemble older cars, worth an oil change but not a new transmission. Maine Yankee was retired because problems with its wiring and steam generators were becoming obvious. A sister plant, Yankee Rowe in Massachusetts, suffered from embrittlement of its reactor vessel. This condition, caused by years of neutron bombardment, makes the reactor vulnerable to thermal shock—that is, it could crack if the emergency core cooling system dumped in cold water. The extent of embrittlement at Yankee Rowe was not known, but the owners—a coalition of utilities that overlap with the owners of Maine Yankee—decided that it was not worth the price to find out.

Even those plants with 20-year life extensions will probably not run until the last day of their licenses. Capital improvements required for continued operation in the past few years would have to earn back their cost in a very short period of time.

The extent of decommissioning required is also uncertain. There are less drastic options than a return to green-field status. For example, when Northern States Power closed the Pathfinder reactor in Sioux Falls, S.D., an early plant less than one tenth the size of Maine Yankee, it installed a conventional boiler powered first by coal and later by natural gas, and ran the turbine that way. Public Service Company of Colorado did the same with the Fort St. Vrain reactor, putting in natural gas turbines and using their waste heat to make steam to turn the old nuclear turbine. In both cases, only the nuclear components were removed.

Indian Point 1 in New York State, Millstone 1 in Connecticut, Dresden 1 in Illinois, and Peach Bottom 1 in Pennsylvania, among others, all adjacent to reactors that are still operating, were simply defueled, closed up and left to sit; they'll be decommissioned later. So was Three Mile Island 2, the reactor near Harrisburg, Pa., that melted down its core in March 1979. Maine Yankee is not alone in decontamination, though. Yankee Rowe is undergoing the same process, as is Connecticut Yankee. The Shoreham reactor on Long Island, N.Y., which ran for only a few days, has been cleaned out, but many of its structures are still standing.

Another uncertainty is how much of the debris will require disposal. The NRC announced on November 6, 2002, that it would develop a rule for recycling contaminated metal. Proponents say that slightly radioactive metal would be fine for rebar encased in concrete; others worry that it could turn up in the braces on children's teeth or in pants zippers. When the Energy Department tried to salvage nickel and other metals from its nuclear plants in the mid-1990s, public outrage was so great that the program was ended in 2000.

And the final cost will depend in part on how long the industry waits for permanent disposal of high-level nuclear fuel. Until that is resolved, there will be one large patch of concrete on the Maine coast where snow will not stick; the on-site storage ISFSI casks generate up to 17 kilowatts each, about as much as a dozen handheld hair dryers. Inside them is a latticework of 24 pigeonholes (each long enough for a 12-foot-long fuel assembly), vacuumed dry and welded shut in a steel wrapper 2.5 inches thick, set in a concrete silo 28.5 inches thick. They suggest an industrial-age Stonehenge, although their builders fervently hope no one will forget what they are for. Filling the casks began last August and will last well into 2003. When that job is finished, workers can tear down the spent fuel pool, the last remaining working system of the old plant.

Throughout the debate about decommissioning in Maine, opponents cut the owners no breaks, requiring a painstaking, expensive process. But the owners have demonstrated that, technologically speaking, this hill is not too high to climb.

Most of all, decommissioning standards have proved to be a response to uncertainty. One concern, looming large in the public's mind, is the effect of small amounts of radiation. But this site, and others around the country, will be cleaned to a standard so that, whatever the future conclusion about the effect, there is little left to deliver a dose. SA

**THERE WILL BE ONE LARGE PATCH OF CONCRETE ON THE MAINE COAST WHERE SNOW WILL NOT STICK.**



## MORE TO EXPLORE

Maine Yankee License Termination Plan: **www.maineyankee.com**

Multi-Agency Radiation Survey and Site Investigation Manual, the federal standard for measuring environmental contamination: **www.epa.gov/radiation/marssim** (includes FAQs and other introductory material as well as the manual itself)

World Nuclear Association listing of decommissioning status: **www.world-nuclear.org/wgs/decom/portal_atoz.htm**

U.S. Nuclear Regulatory Commission FAQ on Decommissioning, NUREG 1628: **www.nrc.gov/reactors/decommissioning/faq.html**

General Accounting Office report: *Nuclear Health and Safety: Consensus on Acceptable Radiation Risk to the Public Is Lacking,* RCED-94-190: **www.gao.gov**

*The bone decay of osteoporosis can cripple, but an improved understanding of how the body builds and loses bone is leading to ever better prevention and treatment options*

# RESTORING AGING BONES

By Clifford J. Rosen

Late last year a new patient, 72-year-old Maxine LaLiberte, limped into my office. She said she had always been very active. She baby-sat frequently for her nine grandchildren and had been looking forward to a long-planned cross-country motor home trip with her husband. But now the excruciating pain between her shoulder blades was curtailing her movements and making her feel old.

I was all too familiar with those symptoms in people my patient's age. Even without examining her, I was reasonably sure that one or more of her vertebrae had fractured as a result of osteoporosis, a disorder characterized by bone loss so severe that fractures occur spontaneously or from even minor bumps.

Osteoporosis afflicts about 10 million Americans, especially women past menopause. Fully half of all postmenopausal women will incur an osteoporosis-related fracture during their lives. Fortunately, the outlook for people with osteoporosis has never been better. Drugs are now available that can restore lost bone and thereby greatly reduce the risk of additional breaks. Furthermore, recent insights into the cellular and molecular bases of osteoporosis have generated exciting ideas for new and even more effective therapies.

Just a decade ago therapeutic options for osteoporosis consisted mainly of calcium supplements, painkillers and, for women past menopause, estrogen replacement therapy—helpful treatments, but imperfect. Estrogen replacement therapy, for instance, increases the risk for heart attack, stroke, breast cancer and

NEW TREATMENTS and preventives for osteoporosis are allowing women—and men—to avoid its worst consequences.

OSTEOPOROTIC SPINE (*left*) shows the bone thinning and collapsed vertebrae characteristic of the disease. In contrast, the vertebrae of a normal spine (*right*) are dense and uniform.

blood clots. Today, in contrast, pharmacies stock several drugs that reduce the likelihood of new fractures by as much as 70 percent in the first year of treatment.

Similarly dramatic improvements have taken place in diagnosis. Not long ago a fracture often was the only tip-off that someone had osteoporosis. But physicians are now using a sophisticated in-office tool called dual-energy x-ray absorptiometry (DEXA) to measure bone mineral density at sites especially susceptible to fracture. DEXA is allowing doctors to diagnose osteoporosis much earlier—in time to initiate drug treatment that can keep bones intact and prevent fractures from occurring. In addition, DEXA can be a useful screening tool to predict the likelihood of future breaks at any site [*see box on opposite page*].

Recent research has also yielded a new appreciation for heredity's role in osteoporosis. The disorder was long considered a "traumatic" condition, in which decades of skeletal wear and tear culminate in fractures and pain. Genetic investigations have now revealed, however, that genes influence bone density and, hence, the risk of fractures. These studies indicate that genetic differences account for up to 70 percent of human variability in bone mass, although such factors as diet and exercise play a part, too. Apparently, many different genes influence propensity. As specific osteoporosis-promoting gene variants are found, they could form the basis for tests to detect susceptibility and could also lead to drugs able to counteract their effects.

## Reversing Silent Thievery

THE NEED FOR better preventive and therapeutic options is urgent. Osteoporosis, which literally means "porous bones," is the underlying cause of virtually all broken bones in people older than 65. The vertebrae, hips and wrists are particularly susceptible to osteoporotic fractures. These broken bones can cause chronic, disabling pain and—in the case of the hip—often usher in a series of events that can lead to death: of the 275,000 older Americans who suffer a broken hip every year, 20 percent die within a year of the episode from blood clots, infections or undernutrition. In addition to the 10 million Americans with existing osteoporosis, another 18 million have low bone mass (osteopenia), a condition that does not qualify as osteoporosis but heightens their risk for eventually developing the disorder.

Medicines introduced in the past 10 years are designed to alleviate the suffering of osteoporosis by interfering with a process known as bone remodeling, or turnover. Seemingly inert when viewed from the outside, bone is a living tissue that ceaselessly destroys and rebuilds itself throughout adult life. This remodeling essentially replaces the entire skeleton every 10 years—dissolving, or resorbing, old bone and completely replacing it with new. Remodeling undoubtedly serves some useful functions, such as freeing calcium from bone for use by various tissues and repairing microfractures. But defective remodeling underlies the development of osteoporosis.

During childhood and adolescence, bone formation proceeds at a faster rate than resorption, causing bone density to increase until young adults attain their peak bone mass at around age 18. Density stays constant throughout young adulthood as bone formation and resorption proceed at the same rate. But around age 40, everyone begins to experience some age-related bone thinning as resorption begins to outpace bone formation. For several reasons, however, the risk of osteoporosis is much greater in women, who account for 80 percent of cases.

The average woman attains a peak bone mass that is generally about 5 percent below that of a man's, so women have a bit less bone density "in the bank" when age-related bone loss begins. In addition, women lose an important bone protector—estrogen—at menopause. As

## Overview/*Osteoporosis*

- Bones are constantly being dissolved and remade throughout life. Osteoporosis results when bone-degrading cells, called osteoclasts, are more active than bone-building cells, called osteoblasts.
- Novel treatments for osteoporosis depend on blocking the activity of osteoclasts or killing them.

ILLUSTRATION BY MELISSA SZALKOWSKI; GCa *Photo Researchers, Inc.* (*left spine*), CORBIS (*right spine*) (*preceding pages*); ROBERT M. LEVIN *Boston Medical Center* (*this page*) a result, bone loss in women can increase sharply for some four to seven years after the shutoff of estrogen at menopause.

Two types of bone cells carry out remodeling—bone-forming osteoblasts and large, bone-resorbing osteoclasts [*see illustration on next page*]. Both cell types come together in three milllion to four million remodeling sites, termed basic multicellular units (BMUs) of bone remodeling, that are scattered throughout the skeleton. Remodeling always occurs in the same sequence: a rapid (two- to three-week) bone resorption phase followed by a slower (two- to three-month) bone formation phase.

Resorption begins when the osteoclasts attach to a microscopic section of bone surface and release substances that degrade the structural parts of bone—calcium, other minerals and the protein collagen. This degrading activity forms an indentation in bone called a resorption pit, after which the osteoclasts disappear, probably as a consequence of programmed cell death (also called apoptosis, or cell suicide). Remodeling's bone formation phase begins when osteoblasts—perhaps attracted by growth factors released during bone resorption—converge on the resorption pit, filling it with new bone by synthesizing and secreting collagen and other bone proteins. Calcium, phosphorus and other minerals then crystallize around the collagen matrix to form hydroxyapatite, the hard, mineralized part of bone that accounts for 90 percent of its mass.

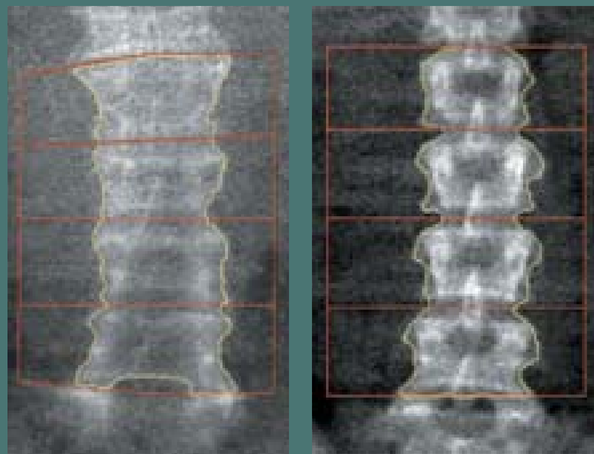
Until late last year, all drugs approved for treating osteoporosis were considered antiresorptives, because they slow resorption more than they promote formation (although in truth, anything that affects one process also affects the other to some degree). Drugs of one antiresorptive class in particular—the bisphosphonates—have transformed osteoporosis treatment over the past decade and are now the first choice for both men and women with osteoporosis. These oral agents slow bone remodeling by attaching readily to the mineral part of bone, where they sit in wait for osteoclasts to bind to the bone's surface. Once that happens, the bisphosphonates diffuse into the osteoclasts and induce those cells to self-destruct.

Large-scale, randomized clinical trials have shown unequivocally that the most potent bisphosphonates—alendronate (Fosamax) and risedronate (Actonel)—not only prevent further bone loss but can also increase bone density in most patients by 5 to 10 percent over three years. That bone buildup may seem modest, but it is enough to reduce the risk of spine, hip and wrist fractures by as much as 50 percent at three years, with more significant fracture reduction evident in the first year of therapy. The bisphosphonates need to be taken just once a week and seem exceptionally safe: aside from heartburn, side effects are rare. These drugs have been in use for only a decade, however, so their long-term safety beyond 10 years remains to be demonstrated.

## Seeking New Drug Targets

MOTIVATED IN PART by a desire for more effective osteoporosis drugs, scientists are now intensively studying how bone remodeling is regulated so that those controls can be manipulated to en-

## TO SCREEN OR NOT TO SCREEN?



SPINAL SCANS made with dual-energy x-ray absorptiometry (DEXA) are used to diagnose osteoporosis. Bone in the lumbar (lower) spine of someone with osteoporosis (*left*) is much less dense than that in the spine of a healthy individual (*right*). The vertebrae have also begun to collapse, shifting the spine out of alignment (*indicated by red lines*).

FAYE LIQUE *Maine Center for Osteoporosis Research and Education*

SHOULD OLDER WOMEN be screened to see if they are at risk for osteoporotic fractures? Ever since tools for measuring bone mineral density became available to doctors, this question has elicited intense controversy.

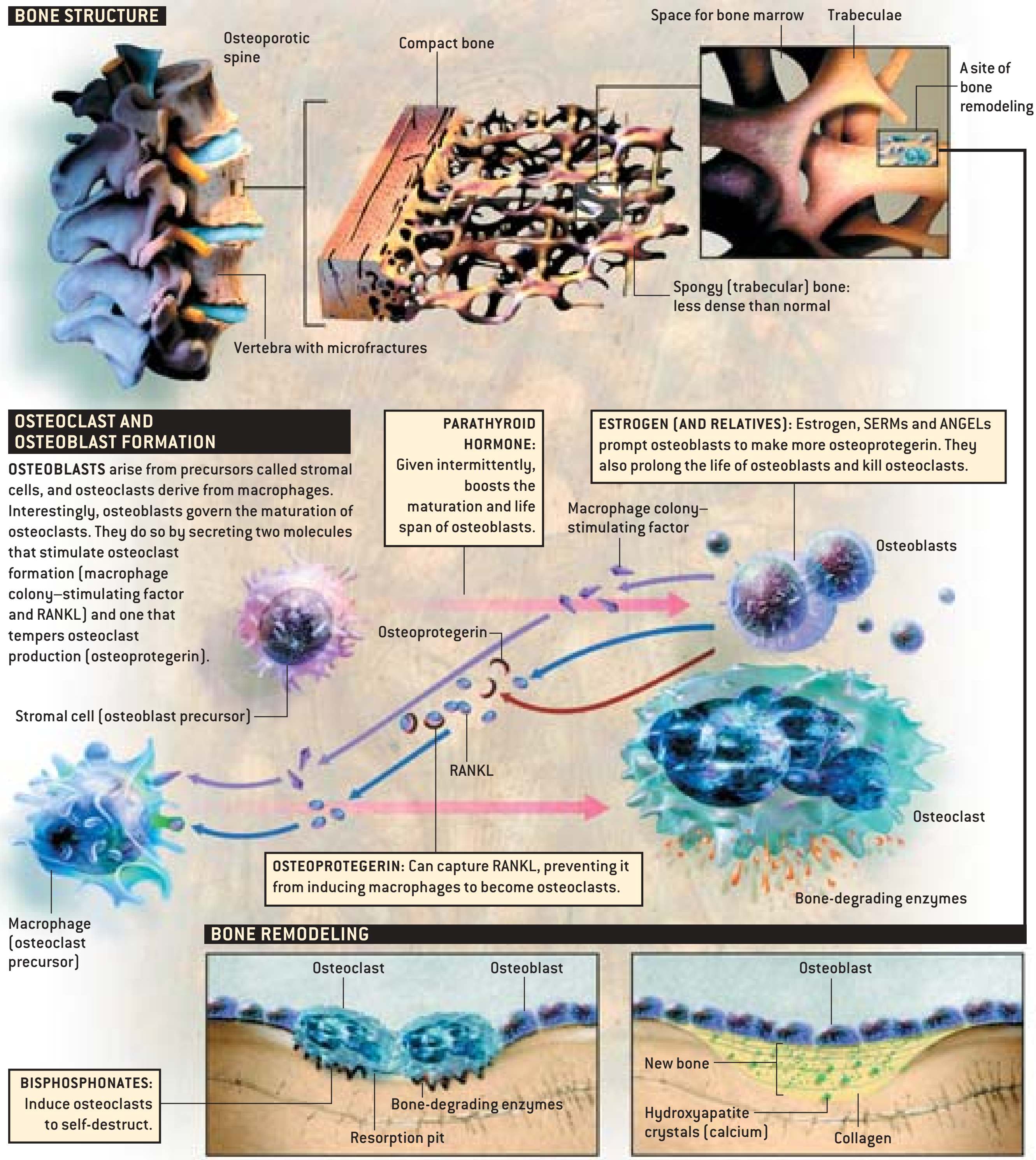
Studies show that density measurements—of the hip or spine, for example—can reliably predict a person's risk for a fracture at that site. The "gold standard" for measuring bone mineral density is a technology called dual-energy x-ray absorptiometry (DEXA), which uses x-rays but involves very little radiation exposure. DEXA diagnoses osteoporosis when it finds that the measure of density is much lower than the average for healthy young women at the spine, hip or wrist (2.5 or more standard deviations from the mean).

DEXA not only tells a woman whether she has osteoporosis; it can predict her risk for fracture at that site over the next several years—potentially useful knowledge, because new drugs can rebuild bone density and prevent fractures before they occur. Yet critics of screening note that mineral density is just one of many factors (including exercise, nutrition, genetics and bone quality) that influence a woman's fracture risk. In addition, critics say, women worried about low scores might be scared into taking drugs, such as estrogen, that might produce dangerous side effects.

Last September the U.S. Preventive Services Task Force came down firmly on the side of screening, recommending for the first time that all women aged 65 and older have their bone density measured at least once to assess their risk of fracture. In support of its recommendation, the task force emphasized that the risk for osteoporosis "increases steadily and substantially with age." Compared with women aged 50 to 54, the task force wrote, the odds of having osteoporosis are 5.9 times higher in women aged 65 to 69 and 14.3-fold higher in women aged 75 to 79. *—C.J.R.*

# OSTEOPOROSIS AND TARGETS FOR THERAPY

THE BODY CONTINUOUSLY renews, or remodels, the bones throughout life using two types of cells: osteoclasts, which destroy old bone, and osteoblasts, which make new bone. Osteoporosis results when the normal balance between the activity of osteoclasts and osteoblasts becomes disrupted, tipping the scales in favor of bone destruction. Various drugs are now on the market or under development (*gold boxes*) to treat osteoporosis by decreasing the action of osteoclasts or boosting that of osteoblasts.




**RESORPTION:** Osteoclasts invade the bone surface and secrete bone-dissolving enzymes, which carve out cavities (resorption pits) to release calcium.

**FORMATION:** Osteoblasts fill in the cavities by building new bone. Osteoporosis occurs when osteoclasts carve too deeply or when osteoblasts fail to fill enough new bone.

KEITH KASNOT

courage bone formation. In the past two years they have made progress in teasing out the features that regulate osteoclastogenesis—the birth and maturation of osteoclasts, the bone-dissolving cells.

Osteoblasts and osteoclasts both arise through the differentiation of predecessor cells in bone marrow (which also houses the body's blood-producing cells). So-called stromal cells mature into osteoblasts, and macrophages (a type of white blood cell) differentiate into osteoclasts. Recently biologists have learned that stromal cells and their offspring, the osteoblasts, govern the production of the bone-degrading osteoclasts; they do so by secreting three different signaling molecules—two that promote osteoclast development and one that suppresses it.

Early on, for instance, osteoblasts secrete a signaling molecule called macrophage colony–stimulating factor that binds to a receptor on macrophages, inducing them to multiply. A second chemical, RANKL, secreted by osteoblasts, binds to a different receptor on macrophages, inducing the cells to differentiate into osteoclasts. The third osteoblast product, however, osteoprotegerin, can block osteoclast formation by acting as a decoy receptor—latching onto RANKL and preventing it from coming into contact with its intended receptor on macrophages.

In theory, anything that interferes with osteoclast formation—and thus with bone resorption—should enhance bone density. Research involving one intervention based on the new molecular understanding—delivery of osteoprotegerin—is ongoing. In human trials, injections of the molecule have slowed the rate of bone resorption by at least 60 percent. Biologists have also identified nearly a dozen other chemical signals involved in coordinating bone formation and resorption—among them estrogen, parathyroid hormone and insulinlike growth factor-1. Study of these substances has suggested additional strategies for preventing and treating osteoporosis.

Circulating estrogen exerts its differing influences in the body by teaming up with estrogen receptors present in various tissues, including the uterus, breast, colon, muscle and bone. Doctors have known for 50 years that estrogen helps to preserve bone density, but the molecular mechanisms have long been a mystery. It is now clear that one of estrogen's functions is to interfere with the creation of osteoclasts.

More specifically, estrogen binds to osteoblasts in bone and induces them to increase their output of osteoprotegerin and to suppress their RANKL production—a combination of signals that suppresses osteoclast formation, keeping bone loss in check. The reduction of estrogen that accompanies menopause thus contributes to bone loss largely by removing an important brake on osteoclast formation and activity. In addition, estrogen appears to prolong the lives of osteoblasts while simultaneously promoting the suicide of osteoclasts. So the decline of estrogen at menopause hits women with a triple whammy: shorter-lived osteoblasts must contend with more osteoclasts that have longer life spans.

Until last year, physicians routinely urged their female patients to take hormone replacement therapy (usually estrogen combined with progestin, a form of progesterone) at menopause, not only to protect against osteoporosis but to ward off other age-related health problems for which estrogen was considered useful, including heart disease and dementia. The health benefits of hormone replacement therapy were thought to outweigh any possible dangers.

So women and their doctors were stunned last July when medical authorities overseeing the federally sponsored Women's Health Initiative determined that hormone replacement therapy caused small increases in breast cancer, heart attack, stroke and blood clots and that the risks of the therapy outweighed its modest benefits, which included small decreases in the risks for hip fractures and colon cancer. Three months later, after reviewing results from this and similar studies, the influential U.S. Preventive Services Task Force recommended against the use of combined estrogen and progestin therapy for preventing cardiovascular disease and other chronic conditions, such as osteoporosis in postmenopausal women. For now, the best estrogen alternatives for bone health are the bisphosphonates. In a meta-analysis that our group recently completed, combining data from many studies, the bisphosphonates proved slightly better than estrogen therapy at increasing bone mineral density and preventing fractures.

Drugs known as selective estrogen receptor modulators (SERMs) may also be useful for the long-term treatment of women fearful about breast cancer. SERMs act like estrogen in some tissues (bone, for example) while at the same time blocking estrogen's effects in other tissues, such as the breast. So far the only SERM approved for the treatment and prevention of osteoporosis is raloxifene (Evista), but others are being tested. Raloxifene is not as effective as estrogen in increasing bone mineral density and preventing fractures, and it can cause hot flashes; however, studies involving women being treated for osteoporosis have found that raloxifene reduced their risk for breast cancer.

## Controlling the Controllers

BUT AN EVEN BETTER ANSWER may be on the way. In a few years, scientists may begin human testing of synthetic estrogens that offer all of estrogen's bone benefits and none of the risks—and help men as well as women. Work on those agents began in response to a radical hypothesis proposed a few years ago by Stavros C. Manolagas of the University of Arkansas for Medical Sciences.

Manolagas proposed that estrogen exerts its effects on cells in two separate ways. One is the well-established mechanism by which estrogen influences *all* its target tissues in females, reproductive

THE AUTHOR

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## BLAME IT ON EVOLUTION

MILLIONS OF YEARS AGO our ancestors emerged from the sea and evolved into land mammals that confronted a serious problem: how to satisfy their calcium needs, now that absorbing calcium from seawater was no longer an option.

Humans and other mammals evolved an ingenious solution to the calcium challenge, relying on our own skeletons—where 99 percent of bodily calcium resides—as calcium "banks." In a process known as calcium homeostasis, the mineral is deposited into or withdrawn from the skeleton so that blood levels are kept within the narrow range essential for nerve conduction, blood clotting, muscle contraction and other vital physiological functions. Unfortunately, this process is at the root of osteoporosis, because it calls for sacrificing the skeleton if that is what it takes to maintain adequate blood calcium levels.

The regulatory system at the heart of calcium homeostasis features parathyroid hormone (PTH), vitamin D and ingested calcium. When the parathyroid gland (located near the thyroid gland in the neck) senses a dip in circulating calcium levels, it secretes PTH—a hormone that works in several ways to boost blood calcium levels. PTH powerfully influences osteoporosis by inducing bone-degrading cells (osteoclasts) to dissolve bone and release calcium into the blood. The hormone also stimulates the kidneys to return calcium to the blood instead of excreting it and induces the small intestine to absorb calcium more efficiently from food—a feat that PTH accomplishes indirectly, by increasing the body's production of vitamin D.

Some 90 percent of the average person's vitamin D is synthesized in the skin using energy from the sun's ultraviolet rays (we also get some vitamin D from foods such as fatty fish and vitamin D–fortified dairy products). In an ongoing chemical reaction that progresses from the skin to the liver to the kidney, PTH helps to transform vitamin D3 (the vitamin D precursor made when ultraviolet rays strike the skin's epidermis) into vitamin D's most active form. Vitamin D acts directly on the small intestine, boosting its absorption of calcium from food so that more of the mineral is available for physiological functions and for building bones.

A falloff in vitamin D curtails the amount of calcium absorbed from food and causes blood calcium levels to decline, prompting the parathyroid gland to secrete more PTH to raise levels of active vitamin D. People with consistently low levels of the vitamin tend to have chronic elevations in serum PTH, a condition known as secondary hyperparathyroidism. The elevated PTH level manages to maintain vitamin D and calcium at close to normal levels but also accelerates the bone resorption that leads to osteoporosis in many people.

Recent surveys have found that low serum vitamin D levels are surprisingly common, especially among people living in northern latitudes, where sun exposure is limited. In studies involving older women, vitamin D supplements have been found effective in returning vitamin levels to normal and in preventing bone loss. I recommend that women older than 65 living in northern latitudes take 400 International Units (IU) of vitamin D daily, plus an additional 400 IU during the winter months, when bone densities tend to fall and fracture rates rise.

Ingesting sufficient quantities of calcium (1,000 to 1,500 milligrams per day) is equally important. Studies indicate that the best time for an adequate calcium intake is not later in life but during childhood and adolescence, when peak bone mass is being built. The same holds true for exercise, which is often recommended for keeping older bones healthy. When combined with adequate calcium intake, exercise—particularly jogging and other forms of weight-bearing exercise—helps to slow bone loss and may even increase bone density in older people. But studies involving young athletes strongly suggest that regular exercise—like calcium intake—exerts its major bone-building effect during youth. The higher the bone mass one attains as a young adult, the lower one's risk for developing osteoporosis later in life. *—C.J.R.*

GETTY IMAGES (*glass of milk*); JONELLE WEAVER *Getty Images* (*cheese*); FRANÇOISE SAUZE *Photo Researchers, Inc.* (*calcium pills*); INC. JANEART *Getty Images* (*woman walking*)

BONE-BUILDING ESSENTIALS include foods rich in calcium and vitamin D—such as fortified milk and cheese—or vitamin and mineral supplements. Weight-bearing exercise also keeps bones strong and healthy.

and nonreproductive alike: After estrogen crosses a cell's outer membrane and cytoplasm, it enters the nucleus and binds to its receptor. This estrogen/receptor duo (along with other nuclear proteins known as co-activators) directly interacts with specific sequences of DNA to induce certain genes to give rise to specific proteins needed for cellular activities.

But this "genotropic" pathway (so named because of estrogen's direct contact with genes) could not explain all of estrogen's numerous effects on cells. So Manolagas hypothesized that estrogen also acts through a different mechanism that influences bone and other nonreproductive tissues in both males and females and has no effect on reproductive tissues.

In this scenario, estrogen still binds to receptors in cells, but then the hormone and its receptor induce cellular changes by acting on kinases, enzymes that reside outside the nucleus, in the cytoplasm. (In the case of bone tissue, these kinases exist in the cytoplasm of osteoblasts and osteoclasts.) The activated kinases then migrate to the nucleus, where they help to regulate the expression of genes.

Manolagas and his colleagues synthesized an estrogenlike hormone, dubbed estren, designed to act exclusively through the nongenotropic pathway. Last October in *Science,* Manolagas and his team reported on mouse studies comparing estren with estrogen. Estren was even more effective than estrogen in rebuilding bone in female mice whose ovaries had been removed to simulate menopause. Just as important, estren did not increase the weight of mice uteri, confirming the drug's lack of effect on reproductive tissue. Similar results were observed in male mice: estren proved just as good as testosterone in rebuilding lost bone in mice whose testes had been removed, and, unlike testosterone, it had no effect on the weight of seminal vesicles in male mice.

The findings indicate that estren could become the first of a new class of osteoporosis drugs that Manolagas has named ANGELS (activators of nongenomic estrogenlike signaling). These agents might work even better than estrogen in building bone without causing estrogen's unwanted effects on reproductive tissue, such as uterine and breast cancer.

## In the Driver's Seat

MUCH AS ESTROGEN defends against bone loss by limiting osteoclast development, parathyroid hormone (PTH) can be considered the engine that "drives" osteoporosis, because it promotes the action of osteoclasts. PTH triggers osteoclast formation indirectly, by binding to osteoblasts and prompting them to increase RANKL output and decrease osteoprotegerin production—precisely opposite to the way estrogen regulates RANKL and osteoprotegerin to block osteoclast formation and preserve bone. Paradoxically, however, the notoriously "resorptive" PTH was recently approved as the first bone-building agent, as opposed to the antiresorptives, and some data suggest that it could be the best of all osteoporosis treatments.

Although the body's own PTH promotes bone loss when elevated over long periods, intermittent injections turn out to elicit quite a different response. The first inkling that PTH could build bone emerged in 1928, when researchers noted that PTH injections increased bone density in dogs. But the finding was ignored until the 1970s, when researchers at Massachusetts General Hospital and at the University of Cambridge began independently experimenting with delivering natural, and later recombinant, PTH. Over the past 25 years, experiments in humans have shown that intermittently administered PTH has an amazing ability to increase bone density (especially in the vertebrae), enhance the structural integrity of bone, and prevent fractures in both men and postmenopausal women. Typically, daily PTH injections result in bone-density increases of 8 to 10 percent after one year, with the risk of fracture reduced by an impressive 60 percent. Injectable PTH, under the brand name Forteo, was approved in late 2002 by the U.S. Food and Drug Administration for the treatment and prevention of osteoporosis in both men and women.

Why does the body's own PTH cause bone thinning, whereas PTH "pulses" have a bone-building effect? The intermittent doses seem to direct osteoblast precursors to mature into osteoblasts while simultaneously preventing established osteoblasts from dying, resulting in much greater numbers of bone-forming osteoblasts that function for longer periods. One particular molecule activated by intermittent PTH treatment is insulinlike growth factor-1 (IGF-1), which stimulates stromal cells to differentiate into bone-forming osteoblasts. It also circulates in high concentrations in the blood. Healthy adults have wide differences in their serum IGF-1 levels—and these can have important implications for bone density. For example, an evaluation of women in the Framingham Heart Study found that women in the highest quartile for serum IGF-1 had the highest bone density in the spine, hip and wrist.

Although diet has some influence over IGF-1 (malnutrition can cause steep declines), levels of IGF-1 are largely genetically determined. Over the past decade my laboratory in Bar Harbor, Me., has studied the genetic regulation of IGF-1 using two strains of mice that exhibit major differences in bone mineral density. Our research has shown that 60 percent or more of IGF-1 is genetically determined—a significant finding, because emerging evidence suggests that the "high normal" IGF-1 levels that protect against osteoporosis also correlate with an increased risk for breast cancer, prostate cancer and, perhaps, colon cancer. In the future, measuring IGF-1 levels in people may serve as a useful risk predictor, with high levels indicating a low risk for osteoporosis but an elevated risk for certain types of cancer.

In the end, the DEXA scan of Maxine's spine confirmed my suspicions. She had suffered a recent fracture of her eighth thoracic (T8) vertebra, near her shoulder blades, and her vertebral bone mineral density was more than 2.5 standard deviations below that of a 35-year-old woman. Either finding alone was sufficient for a diagnosis of osteoporosis, yet her prognosis was good. I told her that the back pain would diminish over the next several weeks. And I prescribed a bisphosphonate drug that would restore 5 to 10 percent of her bone density and reduce by 70 percent the likelihood that she would experience a fracture within the next year. The news cheered her. With more grandchildren on the way, her baby-sitting responsibilities were about to increase. SA

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*New broadcasting technologies are challenging the restrictions on the viewing of American television shows and films in other countries*

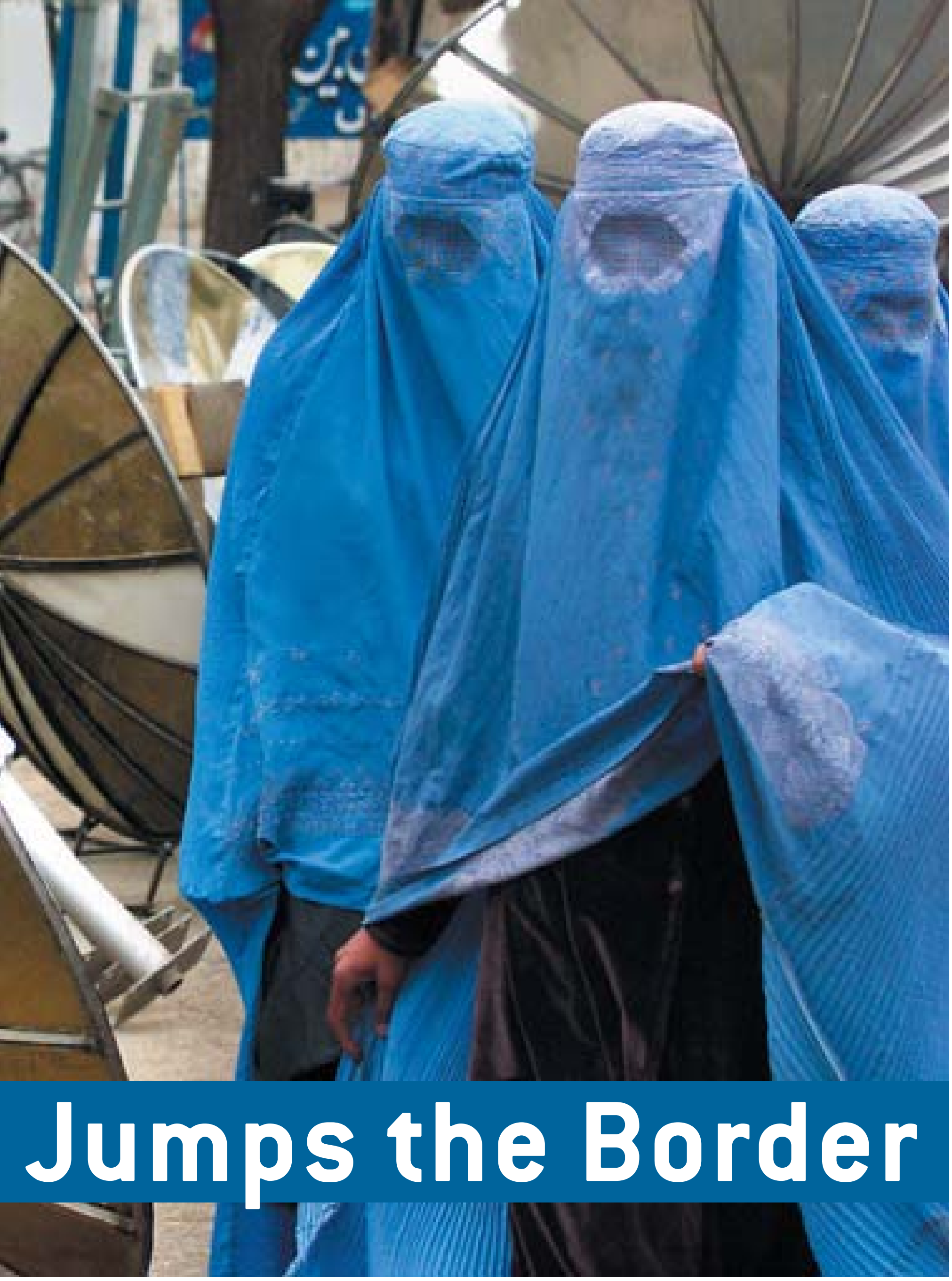
ENRIC MARTI *AP Photo*

# DIGITAL ENTERTAINMENT

## By Harvey B. Feigenbaum

Popular culture has become one of America's biggest exports. Every year the U.S. sells more than $60 billion worth of music, books, movies, television programs and computer software to consumers abroad. And this estimate does not even include the revenues made by illegal copying and other forms of piracy. In Europe or Canada, one need only flick on the television, buy a compact disc or browse the entertainment section of a newspaper to see the ubiquity of American culture.

Over the past few decades many governments around the world have viewed this trend with alarm. Fearing the loss of their national idioms and folkways, France, South Korea, Australia, Canada and other countries have adopted policies to protect their producers of music, books, magazines, films and television shows. Some of the most effective techniques for preserving cultural diversity involve quotas that limit the number of U.S.-produced films and programs that can be shown on television. In 1989 the European Union issued its Television Without Frontiers directive, which required member states to reserve, "where practicable," most of their television schedules for European programming. Some E.U. states go even further: in



# Jumps the Border

AFGHAN WOMEN in Kabul pass a shop selling satellite dishes.

France, for example, at least 60 percent of broadcast time must be European programming, and 40 percent must be French. In Australia, at least 55 percent of the schedule from 6 A.M. to midnight is set aside for Australian shows and films. In South Korea, foreign programming is limited to no more than 20 percent of over-the-air broadcasts (television signals transmitted by antennas rather than by cable). The Canadian government reserves 60 percent of over-the-air broadcast time for Canadian programming.

But new technologies for distributing movies and television shows now threaten to overwhelm these national barriers. Satellite broadcasters in Europe and Asia are already offering subscribers an unregulated mix of programming dominated by American shows. The widely anticipated introduction of video-on-demand—programming libraries that allow consumers to choose their favorite shows and films—will make another crack in the quota system. And people worldwide may someday be able to avoid quotas altogether by watching movies and television transmitted over the Internet.

So will these new technologies further expand the reach of American popular culture? The answer is not so simple. The advent of digital video has slashed the cost of making a film or television show, allowing low-budget production companies in Europe and Asia to compete more effectively with their Hollywood counterparts. And even if U.S. movies and programs are shown on more screens, it is not clear that non-American cultures will be put at risk. The cultural impact of film and television may well be exaggerated.

## The Technological Threat

THE FIRST TECHNOLOGY to confront broadcast quotas was direct broadcasting by satellite (DBS). Widely available in Europe and some parts of Asia, DBS allows consumers to receive programming through a satellite dish not much larger than a dinner plate. Much of this programming is American because license fees for U.S. television shows are typically one third to one tenth of those for shows produced elsewhere. (American shows benefit from the size of the domestic market: a popular U.S. show is first sold to a network, then to local TV channels as reruns and then to networks in other countries. Because the shows are sold many times over, the producers can charge lower license fees.) In Europe, companies such as Turner Network Television and the Cartoon Network run their programs with multiple sound tracks, permitting broadcasts in several languages.

The European Union permits national enforcement of quotas that have been legitimized by its Television Without Frontiers directive, and European courts have extended national quota legislation to satellite broadcasting. But in reality, there is very little a country can do to prevent DBS transmissions that do not respect quotas, especially if the DBS company is not based in an E.U. state. The only option would be to jam the satellite signals, which might well trigger diplomatic objections. In any case, the European Court of Justice has ruled that E.U. states cannot take "excessive measures" to block transborder television reception.

A newer threat to quotas is video-on-demand, which is made possible by the use of digital video. In conventional analog television, a broadcaster must transmit 30 frames a second for each channel. But digital video converts the pictures into data, and engineers have come up with ingenious ways to compress this data stream. Because not all the elements of a television picture move, only the changing pixels need to be transmitted. Reducing the size of each video transmission greatly increases the carrying capacity of the broadcaster's bandwidth—that is, the number of shows that can be delivered via cable to customers. Thus, digital compression enables cable services to offer an extensive library of films and television programs, which viewers can request at any time.

U.S. companies have been developing video-on-demand systems for years, and now the technology is catching on in Europe and Asia, with services being introduced in Portugal, Sweden and Hong Kong. The technology pokes a hole in the quota system because it is based strictly on viewer choice. Television watchers are unlikely to give much consideration to national quotas when deciding which films or shows they would like to see. Sylvie Perras, a former adviser in the French ministry of culture, predicts that over the next 10 years the growth of video-on-demand will severely diminish the effectiveness of quotas.

The ultimate blow to broadcast quotas would be the transmission of video over the Internet, but this technology is not quite ready for prime time. Hollywood studios are now experimenting with Internet distribution of movies, and such a system could eventually allow consumers to pick a full-length film from a Web library and download it. Because the amount of data needed to reconstitute a two-hour-long film is huge, the downloading would probably take several hours: you would request the movie in the morning, and it would be available by evening. The consumer would need enough memory in a home computer, digital television or digital set-top box to hold the movie until it was ready for viewing. Also, the studios would have to develop encryption codes and digital safeguards to prevent unauthorized copying.

A simpler solution may be video streaming, a technology that could let users watch a movie or television show on the Internet without downloading it. Video streaming is already employed in familiar software packages such as RealPlayer, but current applications typically have very small screens, fuzzy pictures and jerky movements. Over time, as more consumers get high-bandwidth Internet connections, the quality of Web video will probably improve. But Internet-based broadcasting has a fundamental economic problem as well. The costs of conventional broadcasting are fixed, so profitability increases with the size of the audience. In video streaming, though, each additional viewer increases the cost of delivering the entertainment, thereby decreasing profits. Hollywood still has high hopes for video streaming, but the technology has not advanced enough to pose an immediate threat to national quotas yet.

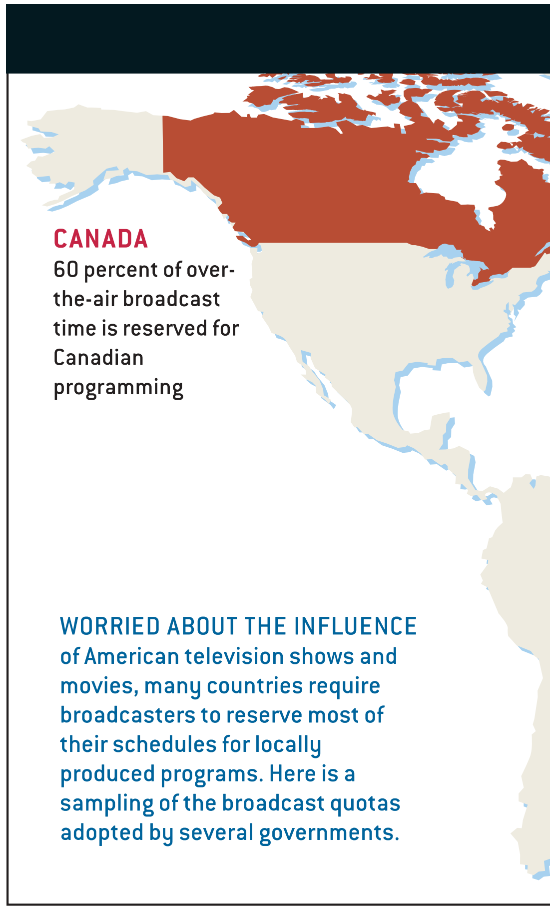
## Digital Guerrillas

ALTHOUGH THE FUTURE of broadcast quotas does not look good, the digital revolution may have other effects that could hold back the onslaught of American entertainment. Perhaps most important, digital video cameras and computer-based editing have dramatically reduced the cost of making feature films, documentaries and television shows. Lower costs allow producers in other countries to charge lower license fees, helping them to compete with American-made shows in the highly fragmented cable and DBS markets. Given the choice, foreign viewers usually prefer shows made in their own countries; in fact, when U.S. studios recently raised their license fees for some prime-time shows, European broadcasters replaced them with homegrown programs.

Conventional analog video cannot match the resolution and quality of 35-millimeter film, but the newest digital video cameras provide approximately the same resolution as a 35mm camera and a greater depth of field. This development has put filmmaking within the means of many more independent producers, who no longer have to pay for film stock and processing (which are of-

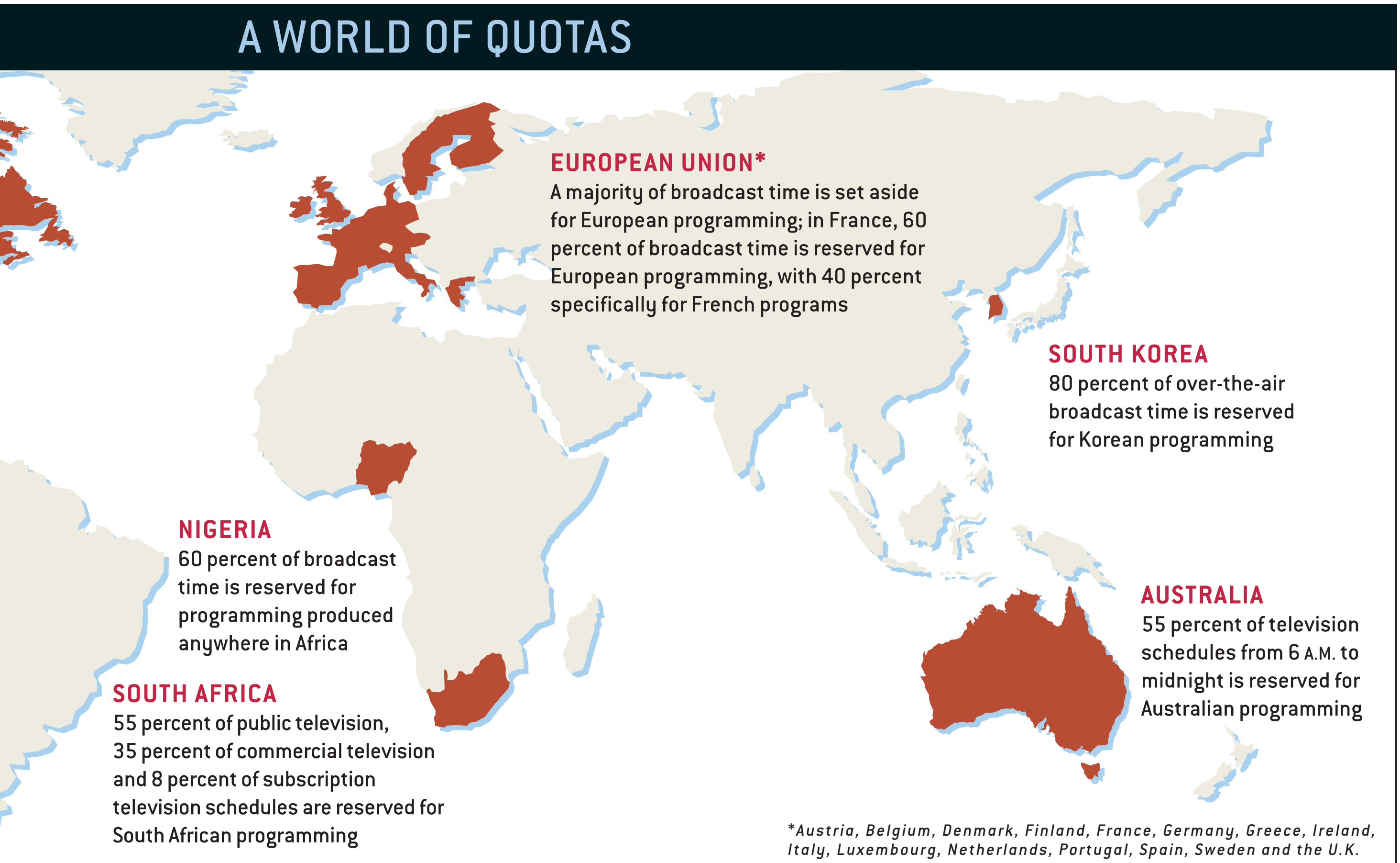
## Overview/*Technology vs. Diversity*

- Fearing the loss of their cultural distinctiveness, many countries have adopted broadcast quotas that limit the amount of American programming that can be shown on television. But new technologies such as satellite broadcasting, video-on-demand and Internet video threaten to make these quotas obsolete.
- At the same time, the advent of digital video cameras, computer-based editing and digital projection may lower the cost of making films and television shows, allowing producers in other countries to better compete with Hollywood studios.
- Governments that are worried about the influence of American entertainment may have to consider replacing quotas with carefully targeted subsidies.




WORRIED ABOUT THE INFLUENCE of American television shows and movies, many countries require broadcasters to reserve most of their schedules for locally produced programs. Here is a sampling of the broadcast quotas adopted by several governments.

JOYCE PENDOLA




ten among the biggest expenses of a low-budget movie). What is more, the drop in cost can lead to an improvement in quality. A typical shooting ratio for low-budget filmmakers is 3 to 1—one foot of film used for every three feet shot. But a director with a digital camera does not have to worry about wasting film, so the shooting ratio can climb as high as 50 to 1. Also, the director can use more than one camera for a scene and then choose the video with the best angle. In a conventional shoot, using more than one camera is a luxury even major studios often cannot afford.

Innovations in postproduction have reduced costs, too. Digital video can be edited on a computer, a much less expensive and onerous process than cutting a film negative [see "Moviemaking in Transition," by Peter Broderick; Scientific American, November 2000]. And a desktop computer can create spectacular special effects that would cost millions of dollars if made by a Hollywood production house. Although not every movie can look like *Lord of the Rings*, computerized effects are now within the means of filmmakers everywhere.

The digitizing of video may also help remove one of the principal stumbling blocks for European and Asian filmmakers: the difficulty of getting their movies shown in theaters. In the U.K., for example, the biggest film distribution companies are controlled by American firms that have a vested interest in distributing Hollywood films rather than British ones. As a result, it is almost impossible to view a British film in the U.K. unless it is a comedy. In France, too, the local distribution companies are not big enough to compete effectively with the American-owned firms. Although France has a thriving film industry, about 60 percent of the box office receipts in that country are from American movies.

One of the reasons for American dominance of film distribution is economic. Making a film print and shipping copies to theaters can cost as much as $3 million for a movie in wide release. But digital video can be transmitted by satellite directly to theaters, then downloaded and shown. Although digital projectors now cost about five times as much as conventional film projectors, the technology should become less expensive over time. As distribution costs fall, cin-

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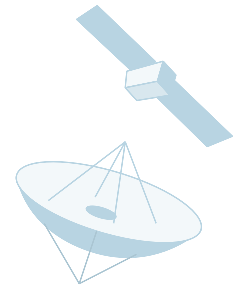
## ENTERTAINMENT TECHNOLOGIES AND CULTURAL DIVERSITY

SOME NEW ENTERTAINMENT TECHNOLOGIES will most likely weaken the effect of broadcast quotas, allowing American television shows and movies to be seen more widely in other countries. But other technologies may foster cultural diversity by stimulating television and film production around the world.

### TECHNOLOGIES THAT WEAKEN BROADCAST QUOTAS



#### SATELLITE BROADCASTING

The programming beamed by satellites directly to viewers is often dominated by American shows. Governments may find it difficult to regulate these broadcasts.



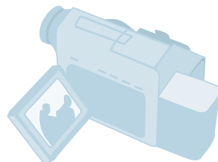
#### VIDEO-ON-DEMAND

Digital compression allows broadcasters to offer an extensive selection of movies and shows. Viewers will be free to choose American programs over locally produced offerings.

#### INTERNET VIDEO

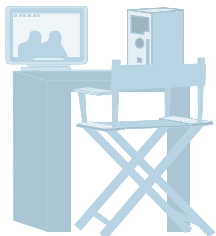
Anyone with an Internet connection may eventually be able to download American films and shows, or view them in real time using video-streaming technology.

### TECHNOLOGIES THAT STIMULATE TV AND FILM PRODUCTION



#### DIGITAL VIDEO CAMERAS

New digital video cameras make it easier and cheaper to create movies and television shows, enabling independent producers to compete better with Hollywood studios.



#### COMPUTER-BASED EDITING

Editing digital video is much cheaper than splicing film. And postproduction editors can also use computers to generate high-quality special effects.



#### DIGITAL PROJECTION

Independent producers may be able to slash their distribution costs by digitally transmitting their movies to theaters instead of sending film reels.

JOYCE PENDOLA

ema multiplexes all over the world will be able to show more low-budget films made outside of Hollywood.

## Subsidies, Not Quotas

OF COURSE, HOLLYWOOD studios will also reap many of the benefits of digital video. It is conceivable that digital production and distribution will simply make it easier to deliver American movies and television shows around the globe. But does the worldwide export of American entertainment actually threaten non-American cultures? Although much ink has been spilled on the subject of "cultural imperialism," sociologists have been unable to prove that such a phenomenon is actually occurring [*see box on opposite page* ]. It is undeniable, however, that American entertainment has at least *some* impact on other societies, even if it is only providing them with a new set of cultural references. If it is the mission of the state to preserve national culture and identity, then the declining effectiveness of broadcast quotas is an appropriate matter for government attention.

One possible step is for countries to replace quotas with subsidies for their producers of films and television shows. The question, though, is what kind of subsidies should be granted and to whom. In the past, European producers have counted on aid from the European Union's Media and Media II programs. More recently, the E.U. has introduced Media Plus, which has focused on subsidies for distribution and marketing. In addition, individual countries have their own subsidies. In France, broadcast networks must give 3 percent of their revenues to subsidize film production, and Canal Plus—France's biggest pay-television operator—must give 9 percent. The downside of subsidies is that European filmmakers produce many films that never find an audience. You cannot protect cultural diversity by subsidizing films that no one wants to see.

Some countries have adopted policies to minimize this problem. In Australia, for example, film projects must demonstrate a "marketplace attachment" to receive subsidies from that country's Film Finance Corporation. This means, essentially, that the film must already have a distributor lined up. Another option is to subsidize the infrastructure of the local television and film industry—production facilities and training, for instance—instead of individual projects. Australia has just taken this approach by building a new film studio in Melbourne. This strategy also creates assets that attract “runaway production,” which occurs when U.S. studios make films overseas to take advantage of lower labor costs. The American films provide work for Australian actors and crew members, enabling them to pursue local projects as well. The disadvantage of such a system is that local filmmakers are crowded out of high-priced facilities aimed at the U.S. market and are outbid in the competition for local talent.

It may be time to consider policy innovations for television and film subsidies. Because the entertainment industry is inherently risky, perhaps new financial instruments aimed at offsetting risk might be useful. For example, a European or Asian country could create a secondary market for film and television investments and an agency that plays a role similar to that of America’s Fannie Mae in the secondary mortgage market. Of course, film and television projects are much riskier than real estate, so the analogy is deceptive. A secondary market for the entertainment industry would be closer, perhaps, to the reinsurance market of Lloyd’s of London or, frankly, to a secondary market in junk bonds. Such a mechanism might bolster entertainment companies that do not have the deep pockets of the Hollywood studios.

Furthermore, governments in smaller countries could focus their subsidies on the new technologies that are fostering low-budget films and television shows—digital production, postproduction and distribution. This strategy would have a beneficial side effect: people trained in the techniques of digital video could apply those skills to making computer games and other multimedia software.

Government aid to film and television, however, need not be justified in solely economic terms. Although it is true that the entertainment industry produces high-paying jobs and relatively little damage to the environment, it would still be valuable even if it were not so lucrative or nonpolluting. Culture, after all, is its own reward. SA

## The Anxiety of Influence

Although many foreign governments are worried about the dominance of American entertainment, it is very difficult to determine how much films like *Titanic* or television shows like *Baywatch* are influencing other cultures. One of the most fascinating studies on this subject was conducted in the late 1980s by Elihu Katz and Tamar Liebes of Hebrew University in Jerusalem. Katz and Liebes assembled focus groups consisting of people of various nationalities, including Americans, Arabs, Russians and Japanese, and had them all watch the same episode of *Dallas,* the extremely popular American television show. Afterward the participants talked about the episode in their native languages.

Katz and Liebes found that all the focus groups discussed the same general themes—success, honor, family relations, sex roles and so on—leading the researchers to conclude that the show “may indeed set agendas for thinking and talking.” The different groups, however, perceived the program in radically different ways, often interpreting the episode from their own cultural perspectives. The Arabs saw “moral degeneracy,” whereas the Russians saw “rotten capitalism.” Only the Americans discussed the business relations of the characters. Members of the Arab group even misread the show’s story, to make it more compatible with their mores: they assumed that a married female character had fled to her father’s house, when she had actually moved into the house of her former lover and *his* father.

The study suggests that American television may not have as much influence as commonly believed, because its messages are viewed through the filter of the receiving culture. Other sociologists have disputed this conclusion, however, noting that years of television watching could have effects that would not be seen using Katz and Liebes’s methods. *—H.B.F.*

A SCENE from *Dallas*

EVERETT COLLECTION

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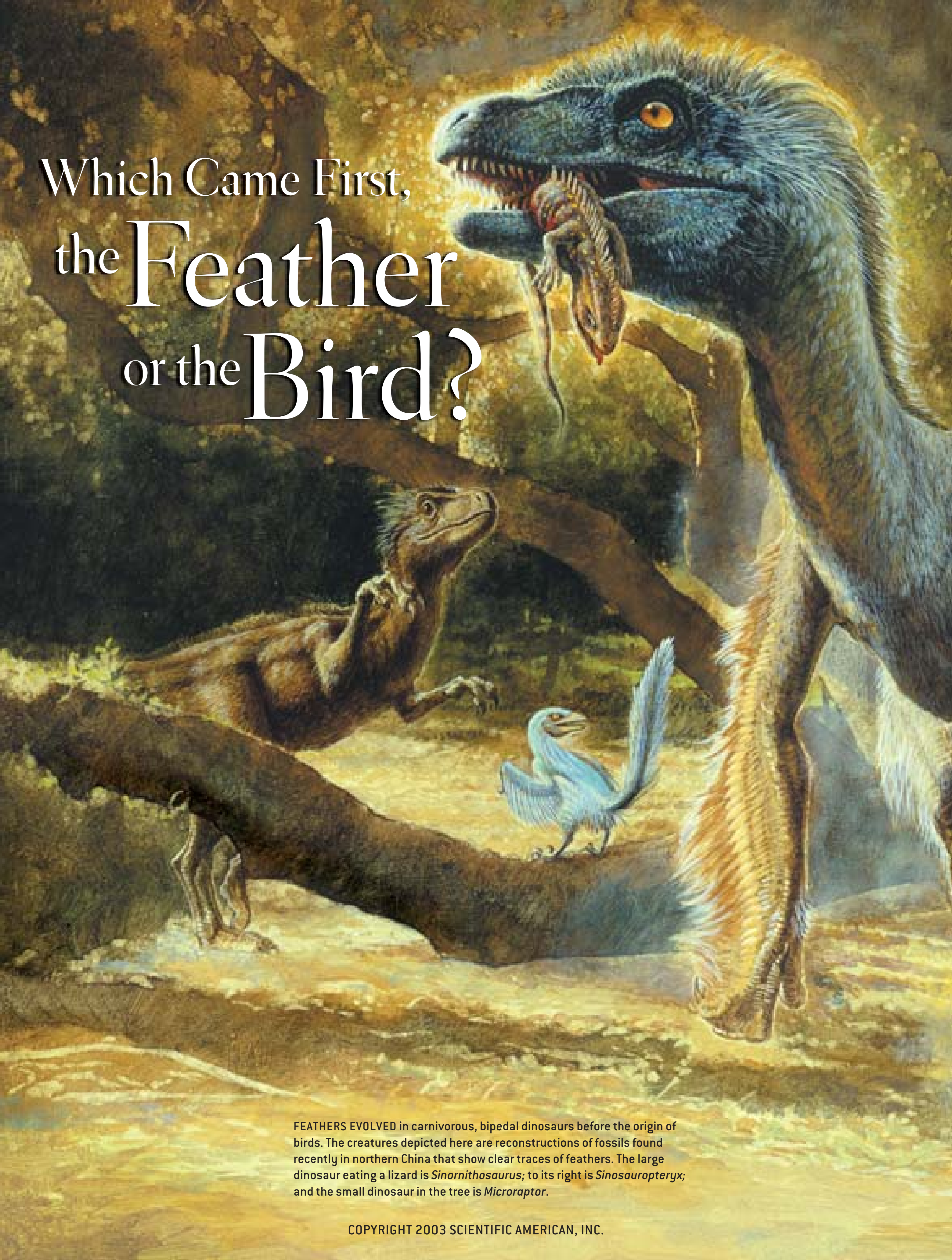
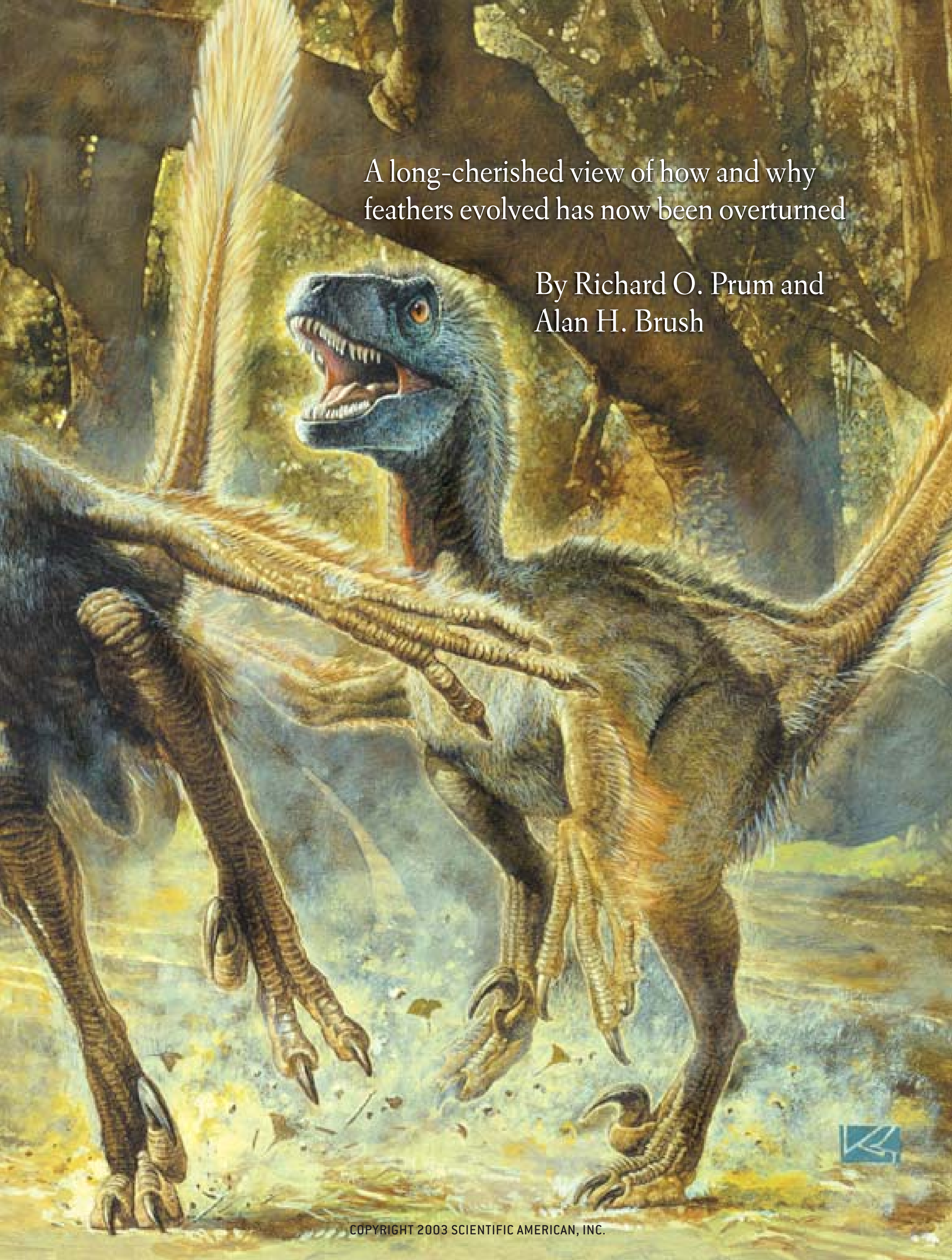
**The Future for Local Content? Options for Emerging Technologies.** Ben Goldsmith, Julian Thomas, Tom O’Regan and Stuart Cunningham. Australian Broadcasting Authority, 2001. Available at **www.aba.gov.au/tv/research/projects/local_cont.htm**

# Which Came First, the Feather or the Bird?



FEATHERS EVOLVED in carnivorous, bipedal dinosaurs before the origin of birds. The creatures depicted here are reconstructions of fossils found recently in northern China that show clear traces of feathers. The large dinosaur eating a lizard is *Sinornithosaurus;* to its right is *Sinosauropteryx;* and the small dinosaur in the tree is *Microraptor*.



A long-cherished view of how and why feathers evolved has now been overturned

By Richard O. Prum and Alan H. Brush

Hair, scales, fur, feathers. Of all the body coverings nature has designed, feathers are the most various and the most mysterious. How did these incredibly strong, wonderfully lightweight, amazingly intricate appendages evolve? Where did they come from? Only in the past five years have we begun to answer this question. Several lines of research have recently converged on a remarkable conclusion: the feather evolved in dinosaurs before the appearance of birds.

The origin of feathers is a specific instance of the much more general question of the origin of evolutionary novelties—structures that have no clear antecedents in ancestral animals and no clear related structures (homologues) in contemporary relatives. Although evolutionary theory provides a robust explanation for the appearance of minor variations in the size and shape of creatures and their component parts, it does not yet give as much guidance for understanding the emergence of entirely new structures, including digits, limbs, eyes and feathers.

Progress in solving the particularly puzzling origin of feathers has also been hampered by what now appear to be false leads, such as the assumption that the primitive feather evolved by elongation and division of the reptilian scale, and speculations that feathers evolved for a specific function, such as flight. A lack of primitive fossil feathers hindered progress as well. For many years the earliest bird fossil has been *Archaeopteryx lithographica,* which lived in the late Jurassic period (about 148 million years ago). But *Archaeopteryx* offers no new insights on how feathers evolved, because its own feathers are nearly indistinguishable from those of today's birds.

Very recent contributions from several fields have put these traditional problems to rest. First, biologists have begun to find new evidence for the idea that developmental processes—the complex mechanisms by which an individual organism grows to its full size and form—can provide a window into the evolution of a species' anatomy. This idea has been reborn as the field of evolutionary developmental biology, or "evo-devo." It has given us a powerful tool for probing the origin of feathers. Second, paleontologists have unearthed a trove of feathered dinosaurs in China. These animals have a diversity of primitive feathers that are not as highly evolved as those of today's birds or even *Archaeopteryx*. They give us critical clues about the structure, function and evolution of modern birds' intricate appendages.

Together these advances have produced a highly detailed and revolutionary picture: feathers originated and diversified in carnivorous, bipedal theropod dinosaurs before the origin of birds or the origin of flight.

## Overview/*Feather Evolution*

- The way a single feather develops on an individual bird can provide a window into how feathers evolved over the inaccessible stretches of prehistoric time. The use of development to elucidate evolution has spawned a new field: evolutionary developmental biology, or "evo-devo" for short.
- According to the developmental theory of feather origin, feathers evolved in a series of stages. Each stage built on an evolutionary novelty in how feathers grow that then served as the basis for the next innovation.
- Support for the theory comes from diverse areas of biology and paleontology. Perhaps the most exciting evidence comes from recent spectacular fossil finds of feathered dinosaurs that exhibit feathers at the various stages predicted by the theory.

## The Totally Tubular Feather

THIS SURPRISING PICTURE was pieced together thanks in large measure to a new appreciation of exactly what a feather is and how it develops in modern birds. Like hair, nails and scales, feathers are integumentary appendages—skin organs that form by controlled proliferation of cells in the epidermis, or outer skin layer, that produce the keratin proteins. A typical feather features a main shaft, called the rachis [*see box on opposite page*]. Fused to the rachis are a series of branches, or barbs. In a fractal-like reflection of the branched rachis and barbs, the barbs themselves are also branched: a series of paired filaments called barbules are fused to the main shaft of the barb, the ramus. At the base of the feather, the rachis expands to form the hollow tubular calamus, or quill, which inserts into a follicle in the skin. A bird's feathers are replaced periodically during its life through molt—the growth of new feathers from the same follicles.

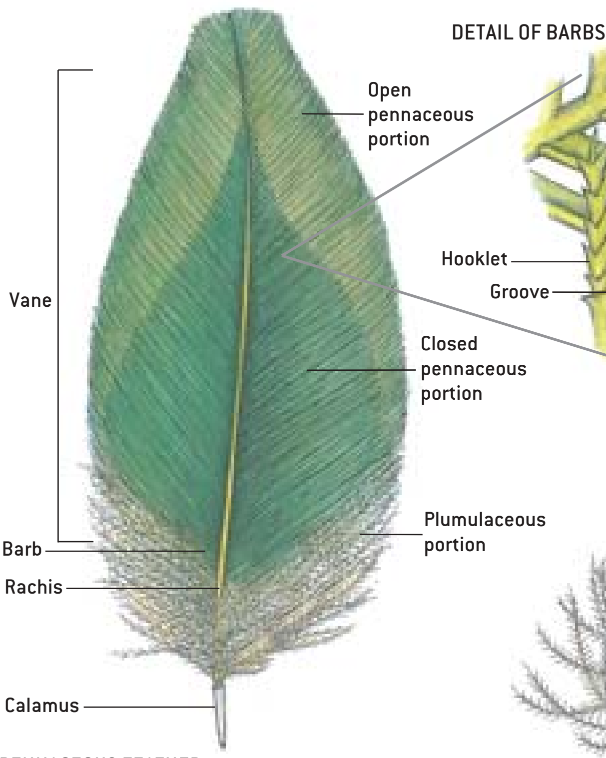
Variations in the shape and microscopic structure of the barbs, barbules and rachis create an astounding range of feathers. But despite this diversity, most feathers fall into two structural classes. A typical pennaceous feather has a prominent rachis and barbs that create a planar vane. The barbs in the vane are locked together by pairs of specialized barbules. The barbules that extend toward the tip of the feather have a series of tiny hooklets that interlock with grooves in the neighboring barbules. Pennaceous feathers cover the bodies of birds, and their tightly closed vanes create the aerodynamic surfaces of the wings and tail. In dramatic contrast to pennaceous feathers, a plumulaceous, or downy, feather has only a rudimentary rachis and a jumbled tuft of barbs with long barbules. The long, tangled barbules give these feathers their marvelous properties of lightweight thermal insulation and comfortable loft. Feathers can have a pennaceous vane and a plumulaceous base.

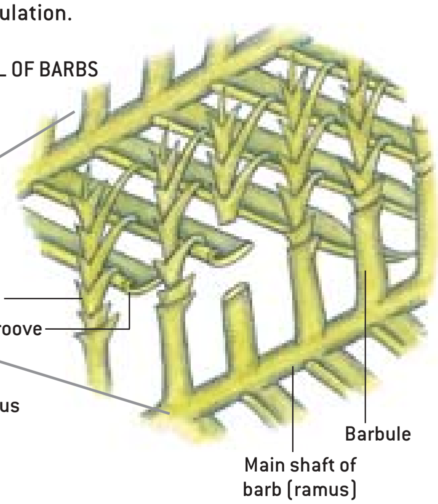
In essence, all feathers are variations on a tube produced by proliferating epidermis with the nourishing dermal pulp in the center. And even though a feather is branched like a tree, it grows from its base like a hair. How do feathers accomplish this?

KAZUHIKO SANO (*preceding pages*)

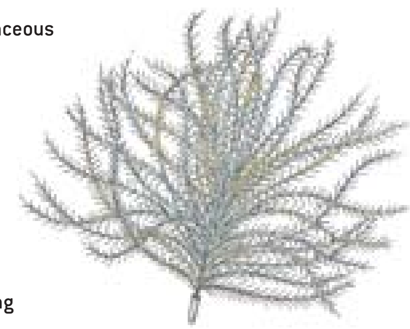
# THE NATURE OF FEATHERS

FEATHERS DISPLAY AN AMAZING DIVERSITY, and they serve almost as wide a range of functions, from courtship to camouflage to flight. Variations in the shapes of a feather's components—the barbs, barbules and rachis—create this diversity. Most feathers, however, fall into two basic types. The pennaceous is the iconic feather of a quill pen or a bird's wing. The plumulaceous, or downy, feather has soft, tangled plumes that provide lightweight insulation.




PENNACEOUS FEATHER
Paired barbs fused to the central rachis create the defining vane of a pennaceous feather. In the closed pennaceous portion of the vane, tiny hooklets on one barbule interlock with grooves in the neighboring barbule (*detail* and *middle micrograph*) to form a tight, coherent surface. In the open pennaceous portion, the barbules do not hook together. Closed pennaceous feathers are essential for avian flight.



PLUMULACEOUS (DOWNY) FEATHER
A plumulaceous feather has no vane. It is characterized by a rudimentary rachis and a jumbled tuft of barbs with elongated barbules.

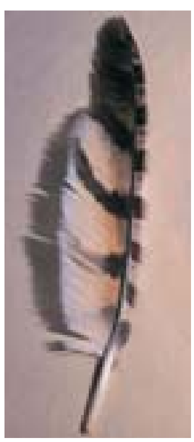
Open pennaceous vane

Closed pennaceous vane

Plumulaceous (downy) feather

DOWNY FEATHER
Fluffy structure provides insulation.

CONTOUR FEATHER
Planar vane helps form the outline of the body.



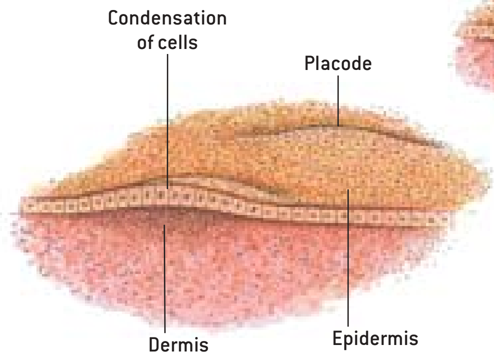
FLIGHT FEATHER
Asymmetrical vane creates aerodynamic forces.

PINFEATHERS
Newly emerged, incompletely developed feathers are visible on two species of cockatoo.

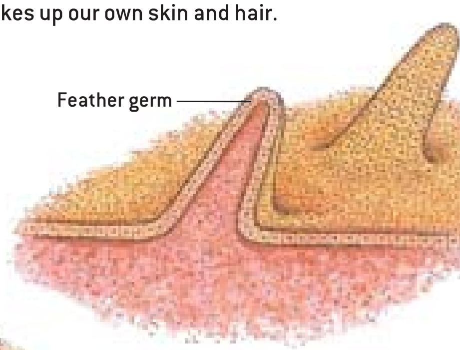
ILLUSTRATIONS BY PATRICIA J. WYNNE; MICROGRAPHS BY TIM LEE QUINN; FEATHER PHOTOGRAPHS BY TINA WEST; COCKATOOS PHOTOGRAPH BY GAIL J. WORTH *Aves International*

## HOW FEATHERS GROW

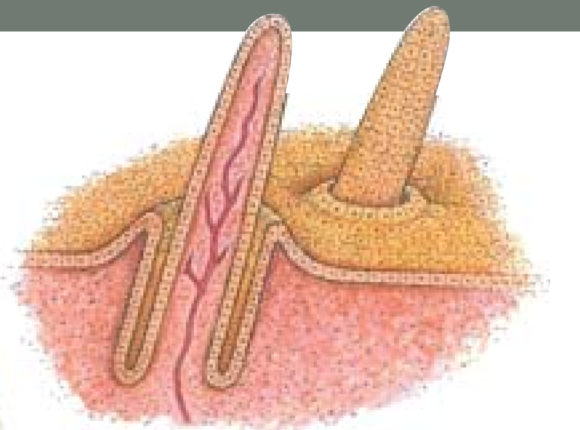
**AS IN HAIR, NAILS AND SCALES,** feathers grow by proliferation and differentiation of keratinocytes. These keratin-producing cells in the epidermis, or outer skin layer, achieve their purpose in life when they die, leaving behind a mass of deposited keratin. Keratins are filaments of proteins that polymerize to form solid structures. Feathers are made of beta-keratins, which are unique to reptiles, including birds. The outer covering of the growing feather, called the sheath, is made of the softer alpha-keratin, which is found in all vertebrates and makes up our own skin and hair.




Feather growth begins with the placode—a thickening of the epidermis over a condensation of cells in the dermis.

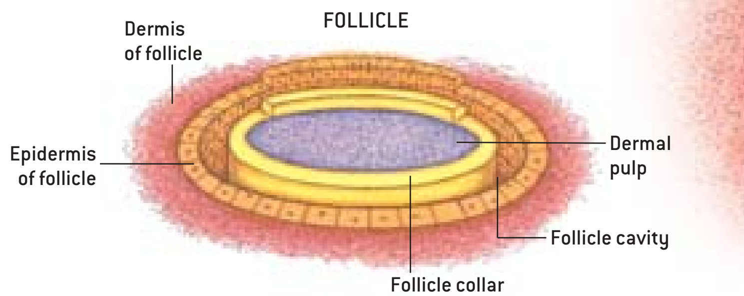



The placode then forms a unique elongated tube, the feather germ.



Proliferation of cells in a ring around the feather germ creates the follicle (*detail below*), the organ that generates the feather. At the base of the follicle, in the follicle collar, the continuing production of keratinoctyes forces older cells up and out, eventually creating the entire, tubular feather.

FOLLICLE




Feather growth begins with a thickening of the epidermis called the placode, which elongates into a tube—the feather germ [*see illustration above*]. Proliferation of cells in a ring around the feather germ creates a cylindrical depression, the follicle, at its base. The growth of keratin cells, or keratinocytes, in the epidermis of the follicle—the follicle "collar"—forces older cells up and out, eventually creating the entire feather in an elaborate choreography that is one of the wonders of nature.

As part of that choreography, the follicle collar divides into a series of longitudinal ridges—barb ridges—that create the separate barbs. In a pennaceous feather, the barbs grow helically around the tubular feather germ and fuse on one side to form the rachis. Simultaneously, new barb ridges form on the other side of the tube. In a plumulaceous feather, barb ridges grow straight without any helical movement. In both types of feather, the barbules that extend from the barb ramus grow from a single layer of cells, called the barbule plate, on the periphery of the barb ridge.

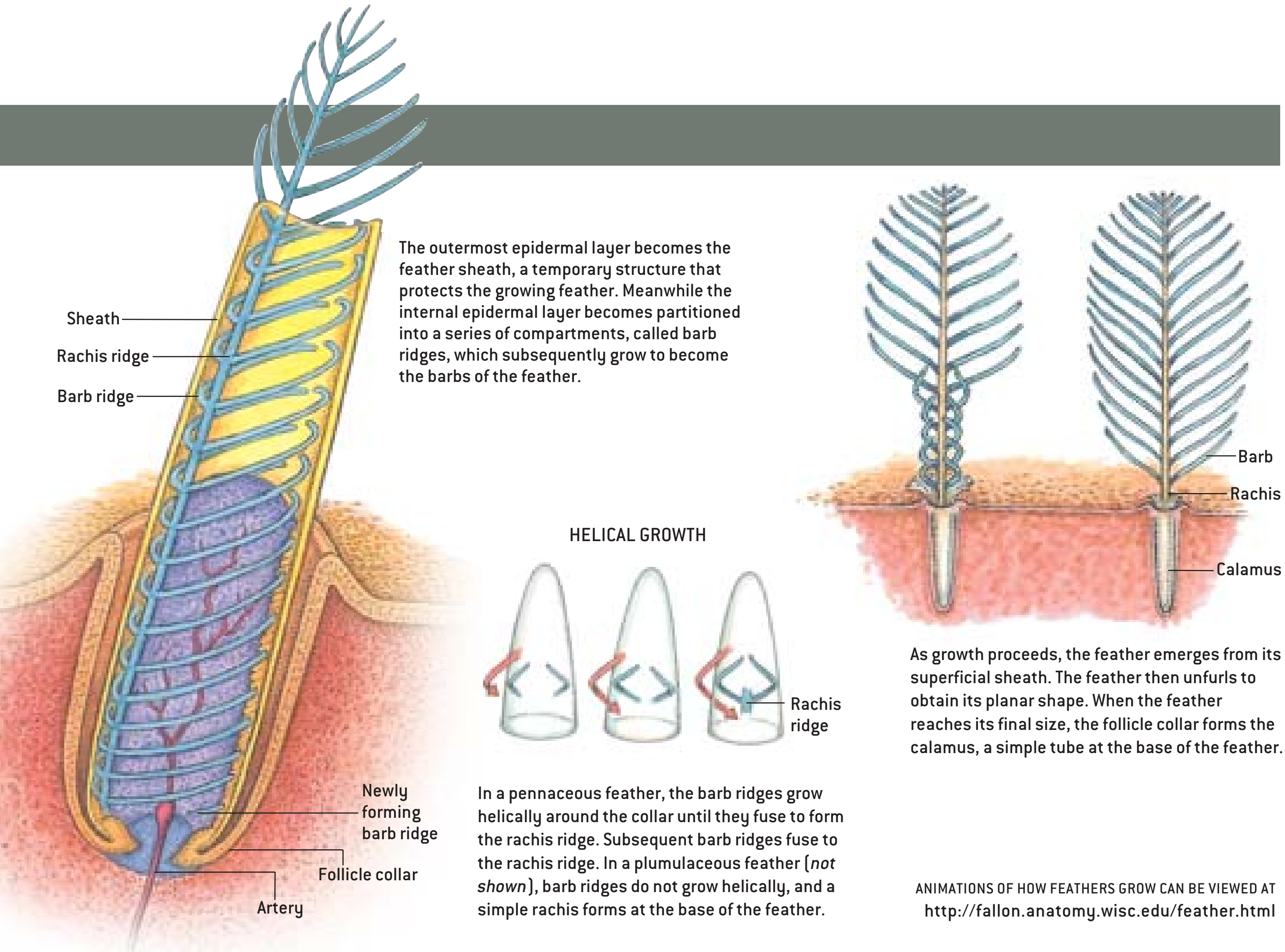
### Evo-Devo Comes to the Feather

TOGETHER WITH VARIOUS COLLEAGUES, we think the process of feather development can be mined to reveal the probable nature of the primitive structures that were the evolutionary precursors of feathers. Our developmental theory proposes that feathers evolved through a series of transitional stages, each marked by a developmental evolutionary novelty, a new mechanism of growth. Advances at one stage provided the basis for the next innovation [*see box on pages 90 and 91*].

In 1999 we proposed the following evolutionary scheme. Stage 1 was the tubular elongation of the placode from a feather germ and follicle. This yielded the first feather—an unbranched, hollow cylinder. Then, in stage 2, the follicle collar, a ring of epidermal tissue, differentiated (specialized): the inner layer became the longitudinal barb ridges, and the outer layer became a protective sheath. This stage produced a tuft of barbs fused to the hollow cylinder, or calamus.

The model has two alternatives for the next stage—either the origin of helical growth of barb ridges and formation of the rachis (stage 3a) or the origin of the barbules (3b). The ambiguity about which came first arises because feather development does not indicate clearly which event occurred before the other. A stage 3a follicle would produce a feather with a rachis and a series of simple barbs. A stage 3b follicle would generate a tuft of barbs with branched barbules. Regardless of which stage came first, the evolution of both these features, stage 3a+b, would yield the first double-branched feathers, exhibiting a rachis, barbs and barbules. Because barbules were still undifferentiated at this stage, a feather would be open pennaceous—that is, its vane would not form a tight, coherent surface in which the barbules are locked together.

PATRICIA J. WYNNE




The outermost epidermal layer becomes the feather sheath, a temporary structure that protects the growing feather. Meanwhile the internal epidermal layer becomes partitioned into a series of compartments, called barb ridges, which subsequently grow to become the barbs of the feather.

In a pennaceous feather, the barb ridges grow helically around the collar until they fuse to form the rachis ridge. Subsequent barb ridges fuse to the rachis ridge. In a plumulaceous feather (*not shown*), barb ridges do not grow helically, and a simple rachis forms at the base of the feather.

As growth proceeds, the feather emerges from its superficial sheath. The feather then unfurls to obtain its planar shape. When the feather reaches its final size, the follicle collar forms the calamus, a simple tube at the base of the feather.

ANIMATIONS OF HOW FEATHERS GROW CAN BE VIEWED AT http://fallon.anatomy.wisc.edu/feather.html

In stage 4 the capacity to grow differentiated barbules evolved. This advance enabled a stage 4 follicle to produce hooklets at the ends of barbules that could attach to the grooved barbules of the adjacent barbs and create a pennaceous feather with a closed vane. Only after stage 4 could additional feather variations evolve, including the many specializations we see at stage 5, such as the asymmetrical vane of a flight feather.

## The Supporting Cast

INSPIRATION FOR THE THEORY came from the hierarchical nature of feather development itself. The model hypothesizes, for example, that a simple tubular feather preceded the evolution of barbs because barbs are created by the differentiation of the tube into barb ridges. Likewise, a plumulaceous tuft of barbs evolved before the pennaceous feather with a rachis because the rachis is formed by the fusion of barb ridges. Similar logic underlies each of the hypothesized stages of the developmental model.

Support for the theory comes in part from the diversity of feathers among modern birds, which sport feathers representing every stage of the model. Obviously, these feathers are recent, evolutionarily derived simplifications that merely revert back to the stages that arise during evolution, because complex feather diversity (through stage 5) must have evolved before *Archaeopteryx*. These modern feathers demonstrate that all the hypothesized stages are within the developmental capacity of feather follicles. Thus, the developmental theory of feather evolution does not require any purely theoretical structures to explain the origin of all feather diversity.

Support also comes from exciting new molecular findings that have confirmed the first three stages of the evo-devo model. Recent technological advances allow us to peer inside cells and identify whether specific genes are expressed (turned on so that they can give rise to the products they encode). Several laboratories have combined these methods with experimental techniques that investigate the functions of the proteins made when their genes are expressed during feather development. Matthew Harris and John F. Fallon of the University of

THE AUTHORS

*RICHARD O. PRUM* and *ALAN H. BRUSH* share a passion for feather biology. Prum, who started bird-watching at the age of 10, is now associate professor of ecology and evolutionary biology at the University of Kansas and curator of ornithology at the Natural History Museum and Biodiversity Research Center there. His research has focused on avian phylogeny, avian courtship and breeding systems, the physics of structural colors, and the evolution of feathers. He has conducted field studies in Central and South America, Madagascar and New Guinea. Brush is emeritus professor of ecology and evolutionary biology at the University of Connecticut. He has worked on feather pigment and keratin biochemistry and the evolution of feather novelties. He was editor of *The Auk*.

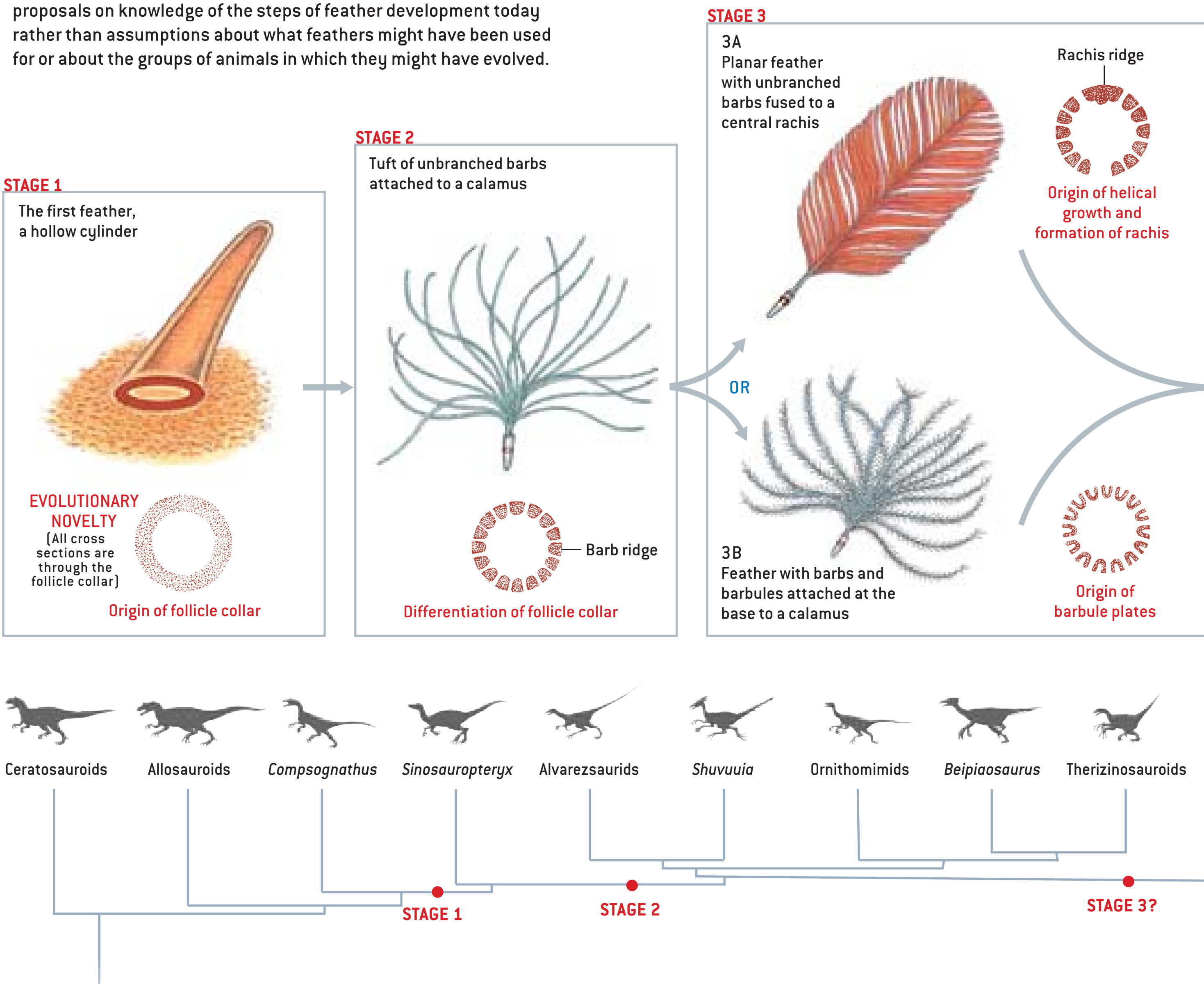
Wisconsin–Madison and one of us (Prum) have studied two important pattern formation genes—*sonic hedgehog* (*Shh*) and *bone morphogenetic protein 2* (*Bmp2*). These genes play a crucial role in the growth of vertebrate limbs, digits, and integumentary appendages such as hair, teeth and nails. We found that Shh and Bmp2 proteins work as a modular pair of signaling molecules that, like a general-purpose electronic component, is reused repeatedly throughout feather development. The Shh protein induces cell proliferation, and the Bmp2 protein regulates the extent of proliferation and fosters cell differentiation.

The expression of Shh and Bmp2 begins in the feather placode, where the pair of proteins is produced in a polarized anterior-posterior pattern. Next, Shh and Bmp2 are both expressed at the tip of the tubular feather germ during its initial elongation and, following that, in the epithelium that separates the forming barb ridges, establishing a pattern for the growth of the ridges. Then in pennaceous feathers, the Shh and Bmp2

## EVO-DEVO AND THE FEATHER

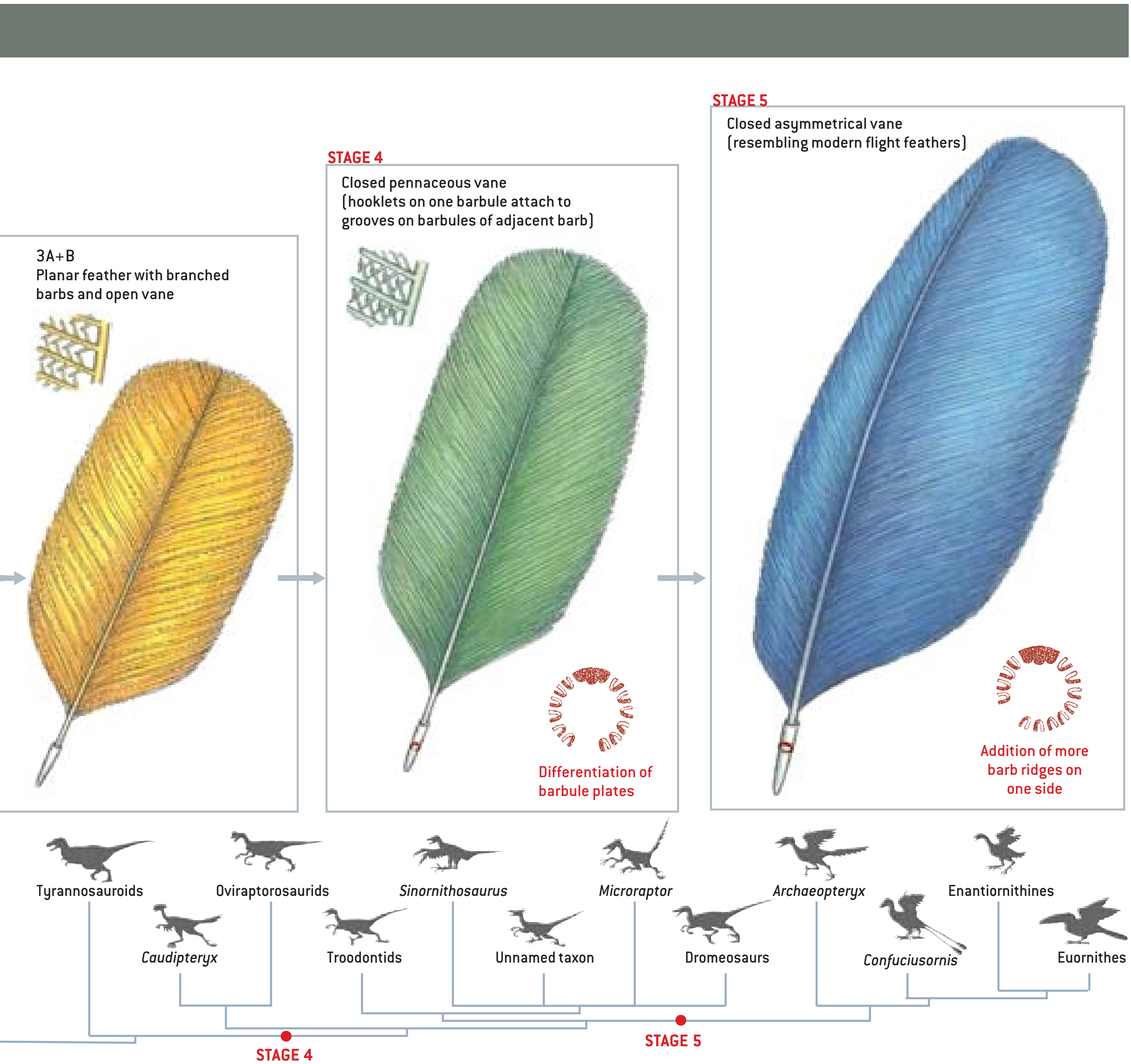
THE AUTHORS' THEORY of feather origin grew out of the realization that the mechanisms of development can help explain the evolution of novel features—a field dubbed evo-devo. The model proposes that the unique characteristics of feathers evolved through a series of evolutionary novelties in how they grow, each of which was essential for the appearance of the next stage. Thus, the theory bases its proposals on knowledge of the steps of feather development today rather than assumptions about what feathers might have been used for or about the groups of animals in which they might have evolved.

New fossil discoveries from Liaoning, China, provide the first insights into which theropod dinosaurs evolved the feathers of each hypothesized stage. Based on the similarities between the primitive feather predictions of the model and the shapes of the fossil skin appendages, the authors suggest that each stage evolved in a particular group of dinosaurs.



signaling lays down a pattern for helical growth of barb ridges and rachis formation, whereas in plumulaceous feathers the Shh and Bmp2 signals create a simpler pattern of barb growth. Each stage in the development of a feather has a distinct pattern of Shh and Bmp2 signaling. Again and again the two proteins perform critical tasks as the feather unfolds to its final form.

These molecular data confirm that feather development is composed of a series of hierarchical stages in which subsequent events are mechanistically dependent on earlier stages. For example, the evolution of longitudinal stripes in Shh-Bmp2 expression is contingent on the prior development of an elongate tubular feather germ. Likewise, the variations in Shh-Bmp2 patterning during pennaceous feather growth are contingent on the prior establishment of the longitudinal stripes. Thus, the molecular data are beautifully consistent with the scenario that feathers evolved from an elongate hollow tube (stage 1), to a downy tuft of barbs (stage 2), to a pennaceous structure (stage 3a).




PATRICIA J. WYNNE

## The Stars of the Drama

NEW CONCEPTUAL THEORIES have spurred our thinking, and state-of-the-art laboratory techniques have enabled us to eavesdrop on the cell as it gives life and shape to a feather. But plain old-fashioned detective work in fossil-rich quarries in northern China has turned up the most spectacular evidence for the developmental theory. Chinese, American and Canadian paleontologists working in Liaoning Province have unearthed a startling trove of fossils in the early Cretaceous Yixian formation (124 to 128 million years old). Excellent conditions in the formation have preserved an array of ancient organisms, including the earliest placental mammal, the earliest flowering plant, an explosion of ancient birds [see "The Origin of Birds and Their Flight," by Kevin Padian and Luis M. Chiappe; SCIENTIFIC AMERICAN, February 1998], and a diversity of theropod dinosaur fossils with sharp integumentary details. Various dinosaur fossils clearly show fully modern feathers and a variety of primitive feather structures. The conclusions are inescapable: feathers originated and evolved their essentially modern structure in a lineage of terrestrial, bipedal, carnivorous dinosaurs before the appearance of birds or flight.

The first feathered dinosaur found there, in 1997, was a chicken-size coelurosaur (*Sinosauropteryx*); it had small tubular and perhaps branched structures emerging from its skin. Next the paleontologists discovered a turkey-size oviraptoran dinosaur (*Caudipteryx*) that had beautifully preserved modern-looking pennaceous feathers on the tip of its tail and forelimbs. Some skeptics have claimed that *Caudipteryx* was merely an early flightless bird, but many phylogenetic analyses place it among the oviraptoran theropod dinosaurs. Subsequent discoveries at Liaoning have revealed pennaceous feathers on specimens of dromaeosaurs, the theropods, which are hypothesized to be most closely related to birds but which clearly are not birds. In all, investigators found fossil feathers from more than a dozen nonavian theropod dinosaurs, among them the ostrich-size therizinosaur *Beipiaosaurus* and a variety of dromaeosaurs, including *Microraptor* and *Sinornithosaurus*.

FOSSILS FOUND IN QUARRIES in Liaoning Province, China, over the past five years, such as this *Caudipteryx* forelimb, reveal feathered appendages. This dinosaur, which was roughly the size of a turkey, has excellently preserved pennaceous feathers on its tail as well as its forelimbs.

MICK ELLISON

The heterogeneity of the feathers found on these dinosaurs is striking and provides strong direct support for the developmental theory. The most primitive feathers known—those of *Sinosauropteryx*—are the simplest tubular structures and are remarkably like the predicted stage 1 of the developmental model. *Sinosauropteryx*, *Sinornithosaurus* and some other nonavian theropod specimens show open tufted structures that lack a rachis and are strikingly congruent with stage 2 of the model. There are also pennaceous feathers that obviously had differentiated barbules and coherent planar vanes, as in stage 4 of the model.

These fossils open a new chapter in the history of vertebrate skin. We now know that feathers first appeared in a group of theropod dinosaurs and diversified into essentially modern structural variety within other lineages of theropods before the origin of birds. Among the numerous feather-bearing dinosaurs, birds represent one particular group that evolved the ability to fly using the feathers of its specialized forelimbs and tail. *Caudipteryx*, *Protopteryx* and dromaeosaurs display a prominent "fan" of feathers at the tip of the tail, indicating that even some aspects of the plumage of modern birds evolved in theropods.

The consequence of these amazing fossil finds has been a simultaneous redefinition of what it means to be a bird and a reconsideration of the biology and life history of the theropod dinosaurs. Birds—the group that includes all species descended from the most recent common ancestor of *Archaeopteryx* and modern birds—used to be recognized as the flying, feathered vertebrates. Now we must acknowledge that birds are a group of the feathered theropod dinosaurs that evolved the capacity of powered flight. New fossil discoveries have continued to close the gap between birds and dinosaurs and ultimately make it more difficult even to define birds. Conversely, many of the most charismatic and culturally iconic dinosaurs, such as *Tyrannosaurus* and *Velociraptor*, are very likely to have had feathered skin but were not birds.

## A Fresh Look

THANKS TO THE DIVIDENDS provided by the recent findings, researchers can now reassess the various earlier hypotheses about the origin of feathers. The new evidence from developmental biology is particularly damaging to the classical the-

## DINOSAUR OR BIRD? THE GAP NARROWS

AS THIS ISSUE of *Scientific American* went to press, researchers announced a startling new find in China: a dinosaur with asymmetrical feathers, the only kind of feathers useful for flight, on its arms and legs. Before this discovery, scientists had thought that birds were the only creatures that possessed asymmetrical feathers. In fact, such feathers were one of the few unique characteristics that distinguished the avian descendants from their dinosaur forebears. Now it appears that even flight feathers, not merely feathers per se, existed before birds.

Writing in the January 23 issue of *Nature,* Xing Xu, Zhonghe Zhou and their colleagues from the Institute of Vertebrate Paleontology and Paleoanthropology of the Chinese Academy of Sciences report that a newly discovered species of *Microraptor* had modern-looking asymmetrical flight feathers creating front and hind "wings." Moreover, the feathers are more asymmetrical toward the end of the limb, just as occurs on the modern bird wing.

Debate on the origin of bird flight has focused on two competing hypotheses: flight evolved from the trees through an intermediate gliding stage or flight evolved from the ground through a powered running stage. Both have good supporting evidence, but Xu and his colleagues say the new *Microraptor* find furnishes additional support for the arboreal hypothesis because together the forelimb and leg feathers could have served as a "perfect airfoil." Substantial questions remain of course, among them, How did *Microraptor* actually use its four "wings"? *—The Editors*

NEWLY DISCOVERED *Microraptor gui*

XING XU

ory that feathers evolved from elongate scales. According to this scenario, scales became feathers by first elongating, then growing fringed edges, and finally producing hooked and grooved barbules. As we have seen, however, feathers are tubes; the two planar sides of the vane—in other words, the front and the back—are created by the inside and outside of the tube only after the feather unfolds from its cylindrical sheath. In contrast, the two planar sides of a scale develop from the top and bottom of the initial epidermal outgrowth that forms the scale.

The fresh evidence also puts to rest the popular and enduring theory that feathers evolved primarily or originally for flight. Only highly evolved feather shapes—namely, the asymmetrical feather with a closed vane, which did not occur until stage 5—could have been used for flight. Proposing that feathers evolved for flight now appears to be like hypothesizing that fingers evolved to play the piano. Rather feathers were "exapted" for their aerodynamic function only after the evolution of substantial developmental and structural complexity. That is, they evolved for some other purpose and were then exploited for a different use.

Numerous other proposed early functions of feathers remain plausible, including insulation, water repellency, courtship, camouflage and defense. Even with the wealth of new paleontological data, though, it seems unlikely that we will ever gain sufficient insight into the biology and natural history of the specific lineage in which feathers evolved to distinguish among these hypotheses. Instead our theory underscores that feathers evolved by a series of developmental innovations, each of which may have evolved for a different original function. We do know, however, that feathers emerged only after a tubular feather germ and follicle formed in the skin of some species. Hence, the first feather evolved because the first tubular appendage that grew out of the skin provided some kind of survival advantage.

Creationists and other evolutionary skeptics have long pointed to feathers as a favorite example of the insufficiency of evolutionary theory. There were no transitional forms between scales and feathers, they have argued. Further, they asked why natural selection for flight would first divide an elongate scale and then evolve an elaborate new mechanism to weave it back together. Now, in an ironic about-face, feathers offer a sterling example of how we can best study the origin of an evolutionary novelty: focus on understanding those features that are truly new and examine how they form during development in modern organisms. This new paradigm in evolutionary biology is certain to penetrate many more mysteries. Let our minds take wing. SA

### MORE TO EXPLORE


**Development and Evolutionary Origin of Feathers.** Richard O. Prum in *Journal of Experimental Zoology (Molecular and Developmental Evolution),* Vol. 285, No. 4, pages 291–306; December 15, 1999.

**Evolving a Protofeather and Feather Diversity.** Alan H. Brush in *American Zoologist,* Vol. 40, No. 4, pages 631–639; 2000.

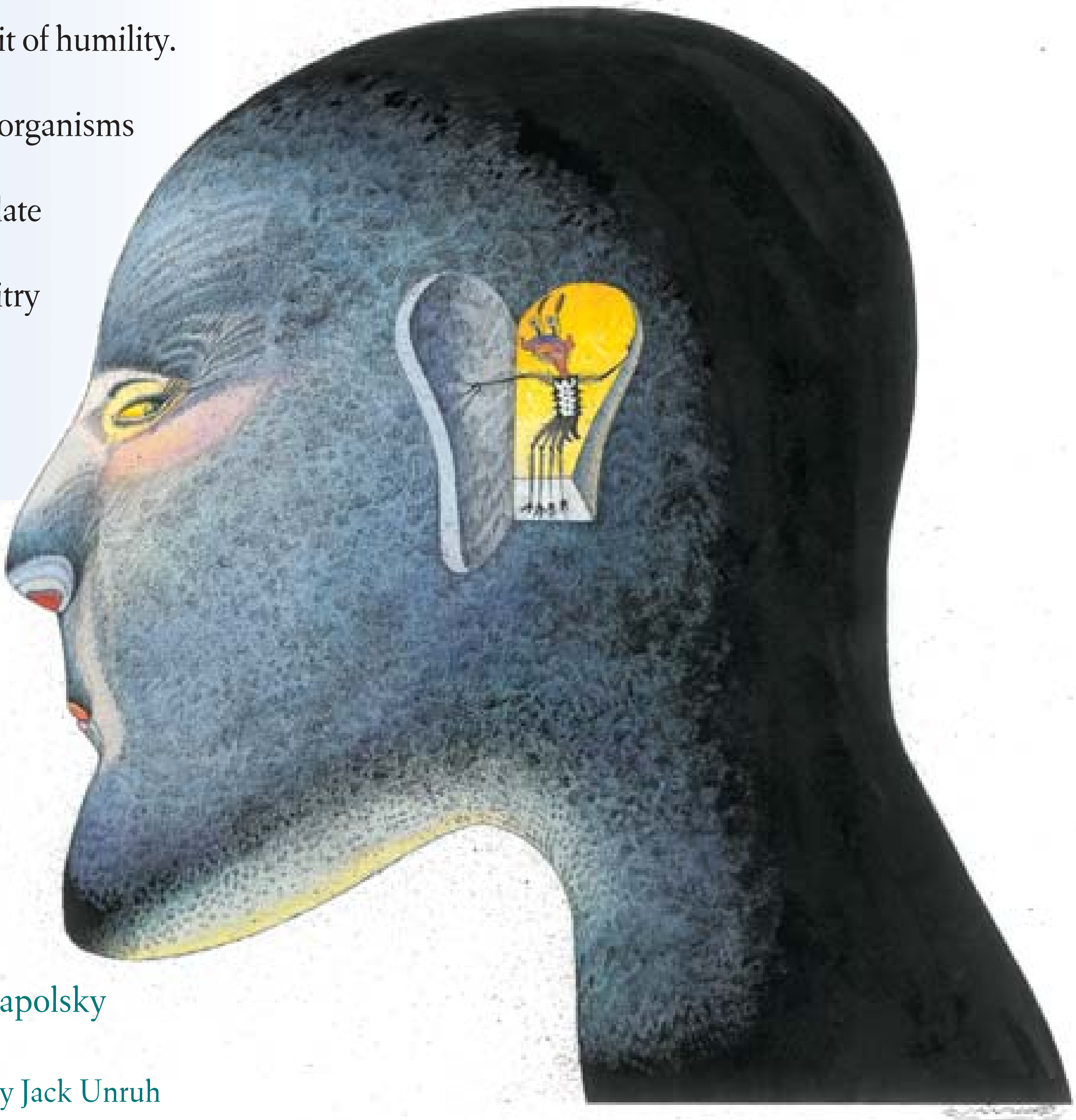
**Rapid Communication: Shh-Bmp2 Signaling Module and the Evolutionary Origin and Diversification of Feathers.** Matthew P. Harris, John F. Fallon and Richard O. Prum in *Journal of Experimental Zoology,* Vol. 294, No. 2, pages 160–176; August 15, 2002.

**The Evolutionary Origin and Diversification of Feathers.** Richard O. Prum and Alan H. Brush in *Quarterly Review of Biology,* Vol. 77, No. 3, pages 261–295; September 2002.

ESSAY

# Bugs in the Brain

Time for a bit of humility. Some microorganisms can manipulate neural circuitry better than we can



By Robert Sapolsky

Illustrations by Jack Unruh

Like most scientists, I attend professional meetings every now and then, one of them being the annual meeting of the Society for Neuroscience, an organization of most of the earth's brain researchers. This is one of the more intellectually assaulting experiences you can imagine. About 28,000 of us science nerds jam into a single convention center. After a while, this togetherness can make you feel pretty nutty: for an entire week, go into any restaurant, elevator or bathroom, and the folks standing next to you will be having some animated discussion about squid axons. The process of finding out about the science itself is no easier. The meeting has 14,000 lectures and posters, a completely overwhelming amount of information. Of the subset of those posters that are essential for you to check, a bunch remain inaccessible because of the enthusiastic crowds in front of them, one turns out to be in a language you don't even recognize, and another inevitably reports every experiment you planned to do for the next five years. Amid it all lurks the shared realization that despite zillions of us slaving away at the subject, we still know squat about how the brain works.

My own low point at the conference came one afternoon as I sat on the steps of the convention center, bludgeoned by information and a general sense of ignorance. My eyes focused on a stagnant, murky puddle of water by the curb, and I realized that some microscopic bug festering in there probably knew more about the brain than all of us neuroscientists combined.

My demoralized insight stemmed from a recent extraordinary paper about how certain parasites control the brain of their host. Most of us know that bacteria, protozoa and viruses have astonishingly sophisticated ways of using animal bodies for their own purposes. They hijack our cells, our energy and our lifestyles so they can thrive. But in many ways, the most dazzling and fiendish thing that such parasites have evolved—and the subject that occupied my musings that day—is their ability to change a host's behavior for their own ends. Some textbook examples involve ectoparasites, organisms that colonize the surface of the body. For instance, certain mites of the genus *Antennophorus* ride on the backs of ants and, by stroking an ant's mouthparts, can trigger a reflex that culminates in the ant's disgorging food for the mite to feed on. A species of pinworm of the genus *Syphacia* lays eggs on a rodent's skin, the eggs secrete a substance that causes itchiness, the rodent grooms the itchy spot with its teeth, the eggs get ingested in the process, and once inside the rodent they happily hatch.

*I realized that some microscopic bug festering in that puddle knew more about the brain than all of us neuroscientists combined.*

These behavioral changes are essentially brought about by annoying a host into acting in a way beneficial to the interlopers. But some parasites actually alter the function of the nervous system itself. Sometimes they achieve this change indirectly, by manipulating hormones that affect the nervous system. There are barnacles (*Sacculina granifera*), a form of crustacean, found in Australia that attach to male sand crabs and secrete a feminizing hormone that induces maternal behavior. The zombified crabs then migrate out to sea with brooding females and make depressions in the sand ideal for dispersing larvae. The males, naturally, won't be releasing any. But the barnacles will. And if a barnacle infects a female crab, it induces the same behavior—after atrophying the female's ovaries, a practice called parasitic castration.

Bizarre as these cases are, at least the organisms stay outside the brain. Yet a few do manage to get inside. These are microscopic ones, mostly viruses rather than relatively gargantuan creatures like mites, pinworms and barnacles. Once one of these tiny parasites is inside the brain, it remains fairly sheltered from immune attack, and it can go to work diverting neural machinery to its own advantage.

The rabies virus is one such parasite. Although the actions of this virus have been recognized for centuries, no one I know of has framed them in the neurobiological manner I'm about to. There are lots of ways rabies could have evolved to move between hosts. The virus didn't have to go anywhere near the brain. It could have devised a trick similar to the one employed by the agents that cause nose colds—namely, to irritate nasal-passage nerve endings, causing the host to sneeze and spritz viral replicates all over, say, the person sitting in front of him or her at the movies. Or the virus could have induced an insatiable desire to lick someone or some animal, thereby passing on virus shed into the saliva. Instead, as we all know, rabies can cause its host to become aggressive so the virus can jump into another host via saliva that gets into the wounds.

Just think about this. Scads of neurobiologists study the neural basis of aggression: the pathways of the brain that are involved, the relevant neurotransmitters, the interactions between genes and environment, modulation by hormones, and so on. Aggression has spawned conferences, doctoral theses, petty academic squabbles, nasty tenure disputes, the works. Yet all along, the rabies virus has "known" just which neurons to infect to make a victim rabid. And as far as I am aware, no neuroscientist has studied rabies specifically to understand the neurobiology of aggression.

Despite how impressive these viral effects are, there

THE AUTHOR

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is still room for improvement. That is because of the parasite's nonspecificity. If you are a rabid animal, you might bite one of the few creatures that rabies does not replicate well in, such as a rabbit. So although the behavioral effects of infecting the brain are quite dazzling, if the parasite's impact is too broad, it can wind up in a dead-end host.

Which brings us to a beautifully specific case of brain control and the paper I mentioned earlier, by Manuel Berdoy and his colleagues at the University of Oxford. Berdoy and his associates study a parasite called *Toxoplasma gondii*. In a toxoplasmic utopia, life consists of a two-host sequence involving rodents and cats. The protozoan gets ingested by a rodent, in which it forms cysts throughout the body, particularly in the brain. The rodent gets eaten by a cat, in which the toxoplasma organism reproduces. The cat sheds the parasite in its feces, which, in one of those circles of life, is nibbled by rodents. The whole scenario hinges on specificity: cats are the only species in which toxoplasma can sexually reproduce and be shed. Thus, toxoplasma wouldn't want its carrier rodent to get picked off by a hawk or its cat feces ingested by a dung beetle. Mind you, the parasite can infect all sorts of other species; it simply has to wind up in a cat if it wants to spread to a new host.

This potential to infect other species is the reason all those "what to do during pregnancy" books recommend banning the cat and its litter box from the house and warn pregnant women against gardening if there are cats wandering about. If toxoplasma from cat feces gets into a pregnant woman, it can get into the fetus, potentially causing neurological damage. Well-informed pregnant women get skittish around cats. Toxoplasma-infected rodents, however, have the opposite reaction. The parasite's extraordinary trick has been to make rodents lose their skittishness.

All good rodents avoid cats—a behavior ethologists call a fixed-action pattern, in that the rodent doesn't develop the aversion because of trial and error (since there aren't likely to be many opportunities to learn from

one's errors around cats). Instead feline phobia is hardwired. And it is accomplished through olfaction in the form of pheromones, the chemical odorant signals that animals release. Rodents instinctually shy away from the smell of a cat—even rodents that have never seen a cat in their lives, rodents that are the descendants of hundreds of generations of lab animals. Except for those infected with toxoplasma. As Berdoy and his group have shown, those rodents selectively lose their aversion to, and fear of, cat pheromones.

Now, this is not some generic case of a parasite messing with the head of the intermediate host and making it scatterbrained and vulnerable. Everything else seems pretty intact in the rodents. The social status of the animal doesn't change in its dominance hierarchy. It is still interested in mating and thus, de facto, in the pheromones of the opposite sex. The infected rodents can still distinguish other odors. They simply don't recoil from cat pheromones. This is flabbergasting. This is akin to someone getting infected with a brain parasite that has no effect whatsoever on the person's thoughts, emotions, SAT scores or television preferences but, to complete its life cycle, generates an irresistible urge to go to the zoo, scale a fence and try to French-kiss the pissiest-looking polar bear. A parasite-induced fatal attraction, as Berdoy's team noted in the title of its paper.

***Well-informed pregnant women get skittish around cats. Toxoplasma-infected rodents, however, have the opposite reaction.***

Obviously, more research is needed. I say this not only because it is obligatory at this point in any article about science, but because this finding is just so intrinsically cool that someone has to figure out how it works. And because—permit me a Stephen Jay Gould moment—it provides ever more evidence that evolution is amazing. Amazing in ways that are counterintuitive. Many of us hold the deeply entrenched idea that evolution is directional and progressive: invertebrates are more primitive than vertebrates, mammals are the most evolved of vertebrates, primates are the genetically fanciest mammals, and so forth. Some of my best students consistently fall for that one, no matter how much I drone on in lectures. If you buy into that idea big-time, you're not just wrong, you're not all that many steps away from a philosophy that has humans directionally evolved as well, with the most evolved being northern Europeans with a taste for schnitzel and goose-stepping.

So remember, creatures are out there that can control brains. Microscopic and even larger organisms that have more power than Big Brother and, yes, even neuroscientists. My reflection on a curbside puddle brought me to the opposite conclusion that Narcissus reached in his watery reflection. We need phylogenetic humility. We are certainly not the most evolved species around, nor the least vulnerable. Nor the cleverest. SA


## MORE TO EXPLORE

**Borna Disease Virus Infection in Animals and Humans.** Jurgen A. Richt, Isolde Pfeuffer, Matthias Christ, Knut Frese, Karl Bechter and Sibylle Herzog in *Emerging Infectious Diseases,* Vol. 3, No. 3, pages 343–352; July–September 1997. Available at **www.cdc.gov/ncidod/eid/vol3no3/richt.htm**

**Fatal Attraction in Rats Infected with *Toxoplasma gondii.*** Manuel Berdoy, Joanne Webster and David Macdonald in *Proceedings of the Royal Society of London,* B 267, pages 1591–1594; August 7, 2000.

**Parasites and the Behavior of Animals.** Janice Moore. Oxford University Press, 2002.

**FINGERPRINT READERS**

# No Two Alike

**Passwords are a simple tool** for controlling access to computers, networks and online transactions, but wrongdoers can steal or guess them. Fingerprint readers offer greater security, because it is almost impossible to fake a human digit.

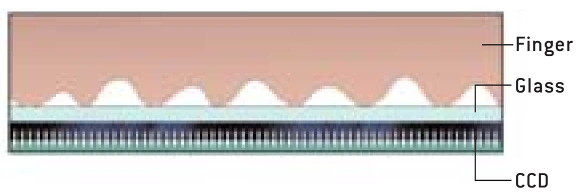
Two types of inexpensive readers have proliferated in recent years. Optical scanners, the first technology deployed, use an array of charge-coupled devices to take a digital image of a fingertip. So-called silicon, or solid-state, readers rely on tiny capacitors that sense a fingertip's topography. In both cases, in order to allow or deny access, software analyzes the geometric pattern of minutiae, such as the ridges and valleys that are unique to every finger, and compares it with patterns registered by legitimate users.

Technical improvements have reduced error rates and driven down cost, broadening appeal. False acceptance rates reach less than 25 in a million for the better devices, and false rejection rates are typically less than 3 percent, according to Naeem Zafar, president of Veridicom, a manufacturer in Sunnyvale, Calif. An accurate reader can now be had for $150 or less. (Law-enforcement agencies and motor vehicle registries use readers that cost $5,000 to $10,000 for nearly flawless identification.)

Easy software integration with popular operating systems has also improved acceptance, but the technology won't truly proliferate until dozens of vendors reach interoperability standards among themselves and with computer makers, says Kush Wadhwa, senior consultant at International Biometric Group in New York City, which provides technical and consulting services. Other applications could further widen the market, such as physical access control in corporations and prisons or the use of fingerprints as digital signatures for electronic commerce.

The greatest hurdle to overcome may be concerns about privacy; people worry that their imprints could be stored, copied or lifted. Technology can reduce this likelihood, but as with sending your credit-card information over the Internet, public confidence will ultimately depend on well-crafted policies and practices. *—Mark Fischetti*

**OPTICAL SCANNER** uses an array of thousands of charge-coupled devices, or CCDs, to take a digital gray-scale image of the ridges and valleys on a finger.




DANIELS & DANIELS

## DID YOU KNOW . . .

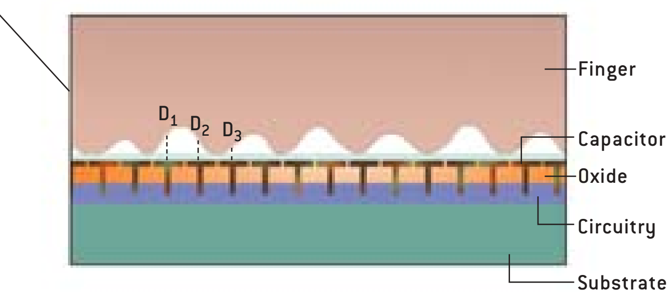
➤ MONEY AT YOUR FINGERTIPS: The market for fingerprint readers could grow dramatically if people allow their digits to be linked electronically to their bank accounts or credit cards. Then a person could withdraw money from an automatic teller machine by simply pressing a finger against a scanner in the screen. Similarly, he could pay for dinner at the counter, for gasoline at the pump or for groceries at the checkout aisle. Several school districts in Pennsylvania are testing scanners that let students pay for lunch at the touch of a finger.

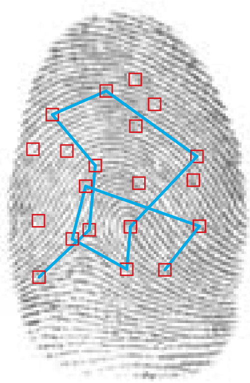
➤ IRIS'S IRIS: The complex pattern of tiny filaments in your iris is even more distinctive than your fingerprint. Recognition systems that capture this geometry achieve extremely low error rates. Few organizations have implemented this approach, though, because the iris scanners cost about twice as much as fingerprint readers and because users find it awkward to stare into a camera lens. Still, Virgin Atlantic and British Airways are experimenting with an iris ID system at Heathrow Airport that would allow frequent fliers to walk up to a scanner at customs checkpoints, bypassing lines for checking paper IDs.

➤ SMELLY ID: Biometrics engineers can identify you by some unusual traits: your face (distance from nose bottom to upper lip, angle of forehead); your voice (frequencies, cadence); your ear (geometry of outer ear features); your gait (changing angles among body parts during a stride); even your smell (vapors from pores).

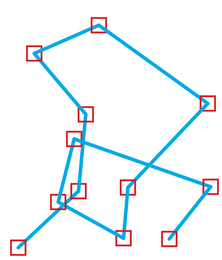

**EACH FINGER** has a particular, unchanging pattern of minutiae such as ridges, valleys and other details, all captured by a fingerprint scanner.

**SILICON SCANNER** charges an array of thousands of capacitor plates to a known value. The ridges and valleys of a finger draw off minute amounts of charge that vary with how far ($D_1$, $D_2$, $D_3$) each feature is from a given plate. Circuitry senses the charges drawn and translates each value to a distance. Software transforms the array of distances into a map of the fingerprint.



**SCANNERS RENDER** a fingerprint as a digital gray-scale image at up to 500 dots per inch. Software typically logs 10 to 40 minutiae (*inside the boxes*), then calculates the distances and angles between the key ones (*depicted by lines*), defining a template. Algorithms convert the geometric relations into a unique set of numbers that identifies the print and thus the person.



**ONCE A TEMPLATE** is enrolled in memory, software erases the actual fingerprint, to prevent copying or theft. When the person later places his finger on the scanner, only his template is calculated again; it is then compared with the stored one to determine whether a match exists.

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

# Follies and Foucault's Pendulum

SEEING SCIENCE PAST AND PRESENT IN TWO PARISIAN MUSEUMS BY MARGUERITE HOLLOWAY

**Seven workers in hard hats** and orange vests load wheelbarrows with bricks and run the loads along tracks to a red crane, where an operator pivots the machine, positioning the pulley. Slowly, the gray bricks fill in the yellow skeleton of the building. After 15 minutes or so, one of the workers decides his work is done. He leaves the bricks behind, ambles past the booth stationed near the entrance of the construction site, and starts tugging at his hat and vest. Suddenly, he remembers his parents and wildly looks around for them. Once they are well in hand, the worker, age four, heads off to repair a nearby car.

The City of Children, part of the City of Science and Industry (Cité des Sciences et de l'Industrie) complex in northeastern Paris, immerses kids ages three through 12 in the ways of invention and deduction. So engaging are many of the activities that some parents have to hold themselves back a bit. "Let them be," cautions a sign near the construction site. One father, seemingly smitten with the engineering possibilities, disregards the warning and gets a brick (foam) to the head when the crane (roughly his height) swings around.

Hands-on (but not always head-on) science and technology is the idea behind the City of Science and Industry, an enormous glass-and-steel structure next to the 86-acre Villette Park, similarly funky with its 35 bright-red follies (small, mostly nonfunctional structures that resemble deconstructed cubes). The center has temporary exhibitions and permanent interactive displays on almost every aspect of science and its applications, including math, space, computers, the environment and medicine. In addition, the complex contains a planetarium, an aquarium, a 3-D cinema, the Géode (a metal sphere that houses an IMAX theater) and the Cinaxe, another theater in which the seats move in conjunction with action in the film. In short, no one goes to the City

FUTURISTIC City of Science and Industry's Géode is 36 meters across. The shiny metal sphere stands in contrast to the dozens of angular red follies that dot the adjacent park.

ART ON FILE/CORBIS

EIGHTEENTH-CENTURY monastery, the Museum of Arts and Trades (*above*), is a repository for thousands of instruments and graphics portraying the history of science and industry, including developments in musical recording (*right*).

L. BOEGLY *Archipress*

of Science and Industry expecting to see everything. Many Parisians go periodically, visiting something different each time.

The City of Children is one of the most popular sections not only because it is so wonderfully done but because it feels finishable. There are two sides: one for kids ages three to five, another for ages five to 12. Each display explains the underlying principles but also lets children figure out the ideas for themselves. In the section for younger kids, for example, between the water playroom and the construction playground, is the "If I Were an Animal" room. Children compare their jumps to those of a frog, a hare and a grasshopper. They climb into models of a kangaroo's pocket, a bird's nest and a tortoise's shell, experiencing scale and life as another.

Adults have similar immersion experiences—sometimes with English and Spanish translation—on the upper floors. On a recent visit, the galleries were crowded with people, many of them in their 20s and 30s, deeply engaged by the exhibits. One group was entranced by the Pythagorean Theorem in action; they stood watching a yellow liquid empty out of two smaller squares (the squares of the shorter sides of the triangle) and fill the largest square (the square of the hypotenuse). In the sound section, another group of visitors paused in a "dead" section and explored the way sound was neutralized. And in the space division, people briefly experienced weightlessness between visits to displays on space stations and rocketry.

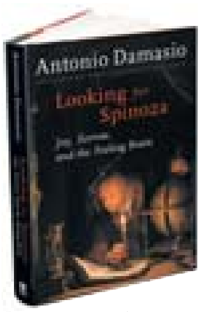
Iterations in the evolution of much of the science and technology described at the City of Science and Industry can be found several Métro stops to the south in a refurbished monastery. The Museum of Arts and Trades (Musée des Arts et Métiers) houses 80,000 scientific and industrial objects—it was conceived of in 1794 as a "depository for new and useful inventions." Among its most famous possessions is Jean Bernard Léon Foucault's pendulum, the one with which he showed that the earth rotates 360 degrees every 24 hours. Foucault's 1851 demonstration provided the first nonastronomical evidence of the planet's spin.

The first room of the collection, which seems like the wood-ribbed belly of a great galleon, contains beautiful water clocks, sextants, globes and early calculating machines. The museum then follows instrumentation forward in time—from chemist Antoine Lavoisier's 18th-century laboratory to a Cray computer and an electron microscope—and next into materials and various trades. There are early telephones, looms, knitting machines, architectural models, household devices, boats, music boxes and cars. The collection makes clear the artistry and beauty of instruments and machines. Hanging from the staircase just before the last hall is a lovely flying contraption designed by Clément Adler in the late 1800s. It looks like a bat, wings angular and pulled in. As in the City of Children, visitors see the animal world wrought large.

The City of Science and Industry, at 30 Avenue Corentin-Cariou, is open Tuesday through Saturday from 10 A.M. until 6 P.M. and until 7 P.M. on Sundays. The closest Métro stop is Porte de la Villette. Be aware that the ticket-purchasing process can be as overwhelming as the center itself, as there are separate tickets for most of the activities; if you can, figure out what you want to see before you arrive. The Museum of Arts and Trades is located at 60 Rue Réaumur, in the Third Arrondissement. The closest Métro stops are Arts et Métiers and Réaumur-Sébastopol. The museum is open every day except Monday and certain holidays from 10 A.M. until 6 P.M.; on Thursdays it is open until 9:30 P.M. SA

# The Neurologist and the Philosopher

A PROMINENT NEUROLOGIST TRACES MUCH OF WHAT MODERN NEUROSCIENCE IS LEARNING BACK TO A 17TH-CENTURY PHILOSOPHER **BY ERICA GOODE**




**LOOKING FOR SPINOZA: JOY, SORROW, AND THE FEELING BRAIN**
by Antonio Damasio
Harcourt, New York, 2003
($28)

**Returning to his hotel** in the Hague on a wet, wind-battered day in 1999, Antonio Damasio could not resist telling the doorman that he had just come from a visit to Spinoza's house. "You mean … the philosopher?" the doorman responded after a pause. "They don't speak much of him, these days."

In fact, for most people, the author of *The Ethics* and other tracts is little more than a dimly remembered figure from a college textbook. Damasio, a prominent neurologist and the author of two previous popular books on emotions and the brain, sets out to redress this state of affairs in *Looking for Spinoza: Joy, Sorrow, and the Feeling Brain*. Specifically, he would like to show that the philosopher, who took an active interest in the physics, astronomy and mathematics of his time, anticipated much of what neuroscientists are now learning about the human brain and, in particular, about the biological underpinnings of feelings and even consciousness itself.

The result is a volume that is by turns engaging and abstruse, elegant and disorganized, and that may prove daunting in some places to those without a passing acquaintance with neurophysiology. Blending the findings of recent studies and the case histories of brain-damaged patients, Damasio presents his own vision of how the thousands of small puzzle pieces that brain scientists are busily gathering might fit together. He speculates, for example, that feelings—joy, pain, well-being, sorrow—not only contribute to the survival of the species but impel humans toward ethical behavior and cooperative social organization. At the same time, in passages that deconstruct Spinoza's writings and discuss his life, he presses the philosopher's case.

It is no coincidence, Damasio believes, that Albert Einstein and other luminaries of the scientific world felt a kinship with Spinoza, a Dutch-born Jew of Portuguese descent, whose writings were deemed heretical and banned throughout Europe for almost a century after his death. The philosopher may have written mostly about religion and political structure, but he thought like a scientist.

For example, Damasio argues, in asserting that mind and body were inseparable, made "of the very same substance," Spinoza sensed that mental processes—thoughts, memories, emotions—were dependent on the neurophysiology of the brain, although he could know nothing of the chattering of neurons or the flow of neurotransmitters. Nevertheless, the philosopher, Damasio contends, intuited the role of feelings in paving the way for a conscious self. That role, in the neurologist's view, is gradually being supported by studies suggesting that certain brain areas are responsible for a constant monitoring of the body's overall state, registering the impact of events both external (an absence of food, the death of a loved one, a potential mugger on a street corner) and internal (an infection, the memory of a pleasant afternoon, embarrassment over a social misstep). What emerges from this global temperature reading are feelings, mental activity that stands apart from the raw data on which the reading itself is based. Spinoza, who stated that the "human mind is the very idea or knowledge of the human body," hinted at this concept, Damasio believes.

BARUCH SPINOZA, 1632–1677

FROM *LOOKING FOR SPINOZA*, DRAWN BY HANNA DAMASIO

"I am convinced that mental processes are grounded in the brain's mappings of the body, collections of neural patterns that portray responses to events that cause emotions and feelings," he writes. The push to maximize a sense of well-being and to avoid pain and other feelings may have evolved as a strategy to help the organism survive. Spinoza certainly endorses the notion that the best way to combat a negative feeling is to overpower it with a positive feeling based in reason, a recipe for well-being that the author spends the last part of the book considering.

Scientists who write books come in two varieties: those who are cautious, reluctant to stray beyond the data before them, and those who are bold and synthetic, using what is known as a spring-board for journeys into unproved theory. Damasio, whom some have accused of leaping ahead of what scientists actually know in order to construct convincing narratives, obviously belongs to the latter group. Some readers will fault him for it; others will see it as a strength. It is through such speculative leaps, after all, that understanding often advances.

Those who have read Damasio's popular works *Descartes' Error* and *The Feeling of What Happens* will find much that is already familiar. Still, *Looking for Spinoza* is compelling, in part because it so strongly conveys the feel of a personal expedition: the neurologist sifts through what is known about the philosopher's life as if pursuing a lost relative. How did he live? What did he read? Was he content during his exile from family and community?

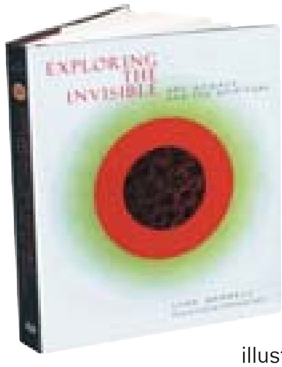
SPINOZA'S HOUSE in Rijnsburg, the Netherlands

Damasio finds some answers and imagines others. Spinoza, in the author's view, was admirable in his bravery, kind in his later years, and likable in many ways but unyielding and strange in others. He was remarkable in his ability to adapt his life to the consequences of his exile. "In his own terms he succeeded," Damasio writes. The neurologist clearly hopes to do the same. SA

*Erica Goode writes about human behavior for the* New York Times.

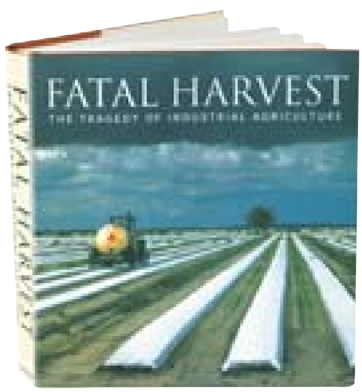
## THE EDITORS **RECOMMEND**

**EXPLORING THE INVISIBLE: ART, SCIENCE, AND THE SPIRITUAL**
*by Lynn Gamwell. Princeton University Press, Princeton, N.J., 2002 ($49.95)*
Scientific advances in the past two centuries have made many formerly invisible aspects of nature visible and have led most educated people in the West to a scientific worldview—a radical shift, Gamwell says. "This radical shift has long been recognized for its impact on science and culture; the purpose of this book is to demonstrate its infiltration into the visual arts and the resulting emergence of abstract art as part of the first wave of modern art in the late nineteenth century." Gamwell—director of the Art Museum at the State University of New York at Binghamton, curator of the Gallery of Art and Science at the New York Academy of Sciences, and adjunct professor of science at the School of Visual Arts in New York City—deals deftly with both the art and the science. With 364 illustrations and an unusual linkage of art and science, her book stimulates both the eye and the mind.




**THE KILLERS WITHIN: THE DEADLY RISE OF DRUG-RESISTANT BACTERIA**
*by Michael Shnayerson and Mark J. Plotkin. Little, Brown, New York, 2002 ($24.95)*
Commenting in 1969 on the success of antibiotics, U.S. Surgeon General William Stewart declared: "We can close the books on infectious diseases." Commenting three decades later on the rapid spread of bacterial resistance to antibiotics, U.S. Surgeon General David Satcher declared: "We are seeing a global resurgence of infectious diseases." Shnayerson and Plotkin (respectively, a staff writer at *Vanity Fair* and an ethnobotanist serving as president of the Amazon Conservation Team) recount what brought about the resurgence: "The principal cause was overuse—and misuse—of antibiotics." Poor infection control in hospitals and nursing homes is a contributing factor. Is there a way of stopping the march of the bugs? Maybe. The authors explore several possibilities but stop short of predicting that any of them will succeed.

**FATAL HARVEST: THE TRAGEDY OF INDUSTRIAL AGRICULTURE**
*edited by Andrew Kimbrell. Island Press, Washington, D.C., 2002 ($45)*
"We ... find ourselves in the midst of a historic battle over two very different visions of the future of food in the 21st century. A grassroots public movement for organic, ecological, and humane food is now challenging the decades-long hegemony of the corporate, industrial model." With 58 essays and more than 250 photographs, Kimbrell, director of the Center for Food Safety, aims to provide "a timely treasure trove of ammunition" for that movement. The ammunition includes a litany of environmental harms caused by industrial agriculture and a strategy for bringing about "the end of agribusiness."




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

FROM *LOOKING FOR SPINOZA*, DRAWN BY HANNA DAMASIO

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## FEATURED THIS MONTH

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### The Cultured Orangutan

**Researchers have observed** two dozen socially transmitted behaviors in orangutans. The findings could push the origin of culture back nearly seven million years, to the last common ancestor of orangutans and the African apes.

### Life on Earth Is Feeling the Heat

**Various species,** from frogs to flowering plants, have demonstrated changed behavior in response to increasing world temperatures over the past few decades. Two recent studies have concluded that these changes are not isolated events but instead represent a worldwide pattern, or "fingerprint," of global warming.

### Nicotine, Too, May Promote Cancer

**New research may provide** smokers with further impetus to kick the habit. Although tar has long been considered the carcinogenic agent in cigarettes, scientists have discovered that nicotine and compounds derived from it may also promote the development and progression of cancer.

### Wriggling Energy Source Powers Auroras

**Conventional theory holds** that large-scale currents flowing along the earth's magnetic field lines power the shimmering celestial shows known as auroras. Now researchers suggest that movement of the field lines themselves may help fuel the displays.

### Ask the Experts

**Why do computers crash?**

**Clay Shields,** professor of computer science at Georgetown University, explains.
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# Safecracking

BY DENNIS E. SHASHA

**Imagine that you are a thief** (but a big-hearted, Robin Hood type, of course). You must find the combination of a safe that has 10 switches, each of which can be put in three settings: low, middle or high. There are exactly $3^{10}$ (59,049) possible combinations of switch settings. Fortunately for you, $3^8$ (6,561) of the combinations will open the safe. The rule for opening the safe is simple: if two of the switches are in the right settings, all you have to do is pull the handle on the safe's door. The other eight switches are irrelevant. But you don't know which two switches are the crucial ones (they need not be adjacent).

Because there are so many opening combinations, choosing one randomly is a good strategy: for every nine tries, you are likely to hit one that will unlock the safe. But you are a very unlucky thief, so you want to devise a foolproof way to open the safe quickly. Can you guarantee unlocking it by trying fewer than 20 combinations of switch settings? And if so, which combinations should you try?

Here's a warm-up problem to give you a hint. Suppose there are only four switches, each with three settings, and opening the safe requires that two of the switches be in the right settings. To guarantee opening the safe, how many combinations must you try? Even if you knew which switches were the crucial ones, you'd still have to try nine different combinations of settings. (If A stands for the high setting, B for middle and C for low, the nine combinations are AA, AB, AC, BA, BB, BC, CA, CB and CC.) If you don't know the crucial pair, however, you can still guarantee opening the four-switch safe by trying the 11 combinations shown in the illustration below. As you can see, this relatively brief list contains all nine combinations for any pair of switches, whether they are adjacent or not. Now, can you find a similar list for the 10-switch safe?

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

**Answer to Last Month's Puzzle**

Choose a pile at random and take any flare from it. If the flare is good, take the remaining five from that pile. Otherwise, take five from the other pile. You can lose only if you choose the bad pile at first and get a good flare from it. The probability of doing both is $1/4$ ($1/2 \times 1/2$), so the probability of winning is $3/4$. With four duds in the bad pile, the probability of losing is $1/6$ ($1/2 \times 1/3$), so more duds means a higher probability of winning. For a fuller explanation, visit www.sciam.com

**Web Solution**

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

**Combinations for Opening a Four-Switch Safe**

| | Switch One | Switch Two | Switch Three | Switch Four |
|---|---|---|---|---|
| 1 | A | C | C | C |
| 2 | B | B | B | C |
| 3 | C | B | A | A |
| 4 | A | A | B | A |
| 5 | A | B | C | B |
| 6 | B | A | A | B |
| 7 | C | A | A | C |
| 8 | B | C | C | A |
| 9 | C | C | B | B |
| 10 | C | A | C | B |
| 11 | A | C | A | A |

HEIDI NOLAND

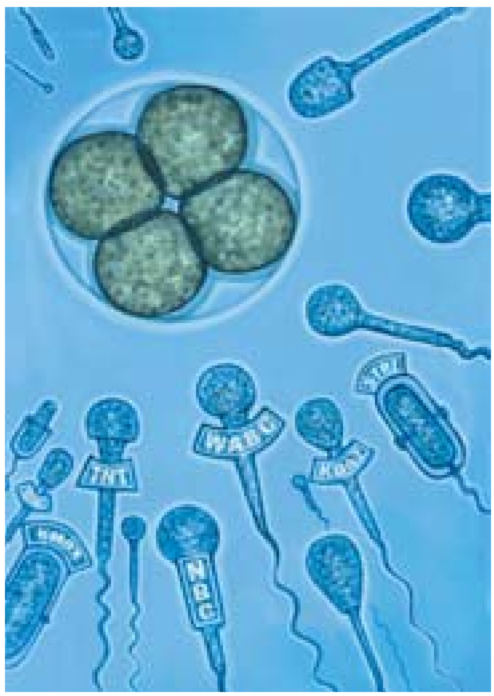
# The Rael Thing

IT'S NOT A MEDIA CIRCUS WITHOUT THE CLONE CAR BY STEVE MIRSKY

**By the time you read this,** one of four things has happened: (1) Someone has presented conclusive evidence that a newborn baby was, in fact, cloned from an adult. I would sooner bet that the next time you watch *The Wizard of Oz* the flying monkeys are replaced by flying pigs. (2) Someone is claiming that a newborn baby, who at least has been identified and photographed, is a clone. Someone may very well claim it, but I'm going double or nothing on the flying pigs. (3) Those touting their mystery clone babies as I am writing these words in mid-January will have stopped holding news conferences. (4) They're still holding news conferences, but reporters have stopped showing up for them, presumably to cover the flying pig story.

The Raelians' assertions of successful clone concoction were so widely covered in late December and early January that I need not review the details here. But a couple of points are worth mentioning. First, kudos to Donald G. McNeil, Jr., whose coverage of the Raelian misconception for the *New York Times* included the following: "Raelians are followers of Rael, a French-born former race-car driver who has said he met a four-foot space alien atop a volcano in southern France in 1973 and went aboard his ship, where he was entertained by voluptuous female robots and learned that the first humans were created 25,000 years ago by space travelers called Elohim, who cloned themselves." It's not clear whether the alien was green, but I am, with envy—I'll never write anything that funny.

Second, special thanks to Michael Guillen, a physicist turned freelance TV journalist, for his tireless work "on behalf of the world's press," as he put it. What Guillen was prepared to do, at what he said was the Raelians' invitation, was organize and oversee a panel of scientific experts that would determine the veracity of the clone's heredity. A physicist is especially useful in dealing with cloning questions: for example, using a sensitive enough barometer, a physicist could measure the atmospheric pressure at the top of a standing baby clone's head and at the soles of its feet and tell you the exact height of that baby clone. (If a clone's foot even *has* a sole.)




Unfortunately, or maybe fortunately, the Raelians quickly withdrew their offer to actually produce the baby, so to speak, citing the privacy concerns of the parents. I'm not sure how many parents a clone has, although I'd guess the number is an integer equal to or greater than zero. But I could be wrong.

Speaking of both being wrong and the aforementioned *Wizard of Oz,* many thanks to the numerous readers who e-mailed to tell me that, like the Scarecrow, I lack a brain. Why else, while nominating fictional characters for membership in real scientific organizations two issues ago, would I have written that the Scarecrow belonged in the American Heart Association for his efforts to procure a heart?

T. Richard Halberstadt of Wyoming, Ohio (make up your mind, T.), noted that his "four-year-old granddaughter, who dresses herself in red shoes and a blue-and-white-checked dress as often as her mother will let her, could tell you that it is the Tin Woodman, not the Scarecrow, who wanted a heart." Many fellow staffers have told me that I, too, have the mind of a four-year-old, who was glad to get rid of it.

J. Quinn Brisben (a real person, not a Groucho Marx character) of Chicago noted my error and then faintly praised, "Not everyone can be Martin Gardner or Douglas Hofstadter [two former *Scientific American* writers], and you are doing tolerably well." All I can say to that is, I know I have a heart, because it's breaking. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

# ASK THE EXPERTS

## What is the difference between artificial and natural flavors?

—J. Yerger, State College, Pa.

**Gary Reineccius, professor of food science and nutrition at the University of Minnesota, explains:**

Natural and artificial flavors are defined in the U.S. Code of Federal Regulations. A natural flavor is "the essential oil, oleoresin, essence or extractive, protein hydrolysate, distillate, or any product of roasting, heating or enzymolysis, which contains the flavoring constituents derived from a spice, fruit or fruit juice, vegetable or vegetable juice, edible yeast, herb, bark, bud, root, leaf or similar plant material, meat, seafood, poultry, eggs, dairy products, or fermentation products thereof, whose significant function in food is flavoring rather than nutritional." An artificial flavor is one that does not meet these criteria.

Practically speaking, however, the difference between these two types of flavorings is minimal. Both are made in a laboratory by a "flavorist," who blends the appropriate chemicals together in the right proportions, using "natural" chemicals to make natural flavorings and "synthetic" ones to make artificial flavorings. But the formulation used to create an artificial flavor must be exactly the same as that used for a natural one in order to produce the desired flavor. The distinction in terminology comes only from the source of the chemicals.

Is there truly *any* substantive difference, then, between natural and artificial flavorings? Yes—artificial flavorings are simpler in composition and potentially safer, because only safety-tested components are utilized, whereas natural flavorings can contain toxins inherent to their sources. Another difference is cost. The search for "natural" sources of chemicals often requires that a manufacturer go to great lengths. Natural coconut flavorings, for example, depend on a chemical found in the bark of a Malaysian tree. Extracting this chemical involves the removal of the bark, a costly process that also kills the tree. So although this natural chemical is identical to the version made in an organic chemist's laboratory, it is much more expensive. Consumers may pay a lot for natural flavorings, but they are neither necessarily better in quality nor safer than their less pricey artificial counterparts.

MATT COLLINS

## How long can the average person survive without water?

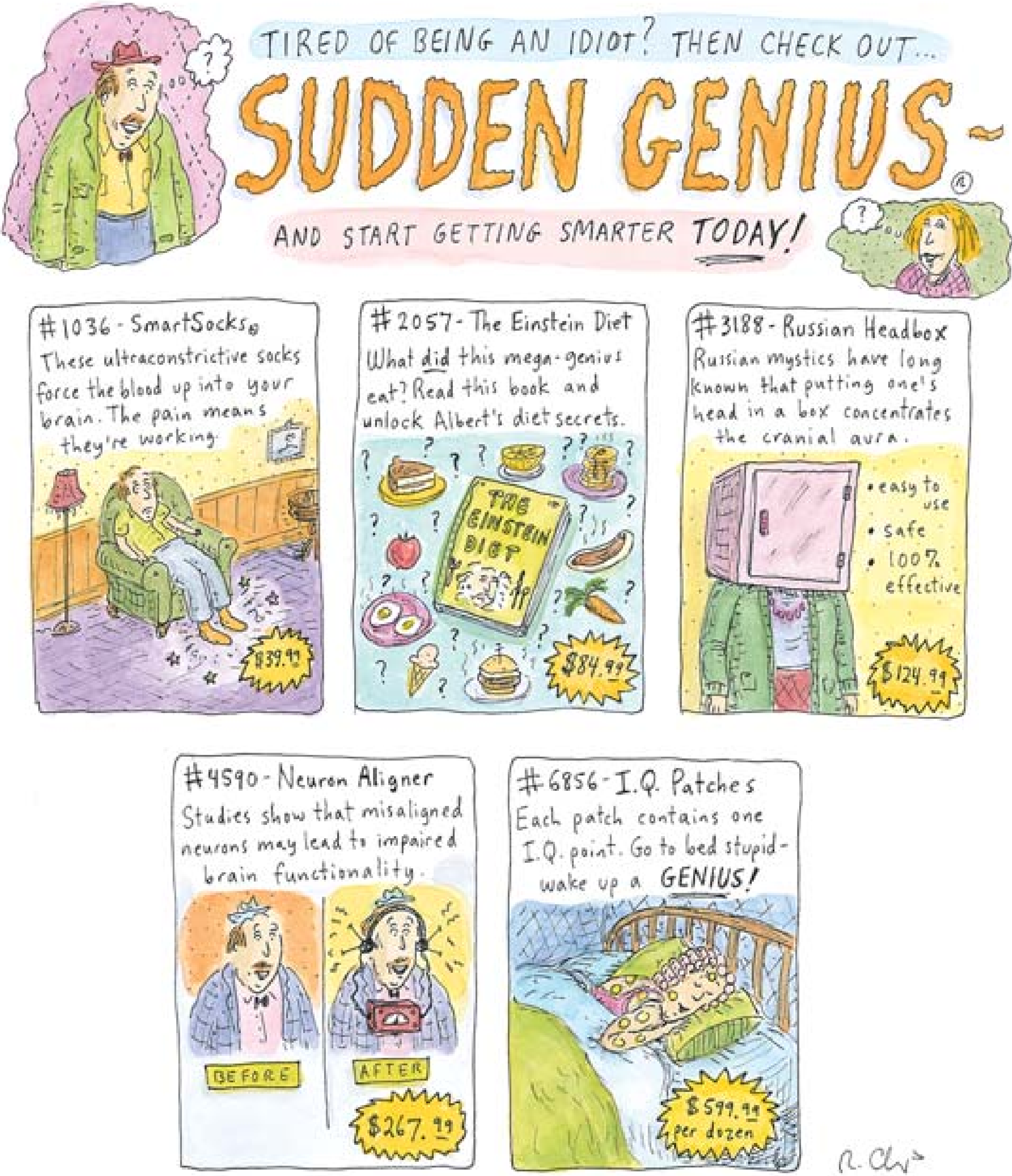
**Randall K. Packer, professor of biology at George Washington University, offers this answer:**

It is impossible to give a definitive answer to this seemingly simple question because many variable factors determine a person's survival time. Under the most extreme conditions—a child left in a closed hot car, say—death can come rather quickly. An adult in comfortable surroundings, in contrast, can survive for a week or more with no water intake.

To stay healthy, humans must maintain water balance. We get water from food and drink and lose it mainly as sweat and urine, with a small amount also present in feces. Another route of water loss usually goes unnoticed—we lose water each time we exhale. Sweating is the only physiological mechanism humans have to keep from overheating: evaporation of sweat cools blood in vessels in the skin, which helps to cool the entire body. If that lost water is not replaced, the total volume of body fluid can fall quickly and, most dangerously, blood volume can drop. If this happens, two potentially life-threatening problems arise: body temperature can soar even higher, while blood pressure decreases because of the low blood volume. Most people cannot survive long under such conditions. Because of their greater skin-surface-to-volume ratio, children are especially susceptible to rapid overheating and dehydration.

A person can stay hydrated by drinking various kinds of fluids, with one exception. Alcoholic beverages cause dehydration because ethanol increases urine volume such that more fluid is lost in urine than is gained from the beverage. SA

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