SPACE AGE ARCHAEOLOGY • MEMORY AND THE MIND'S EYE • FOOD, SEX AND INSECTS

SCIENTIFIC AMERICAN

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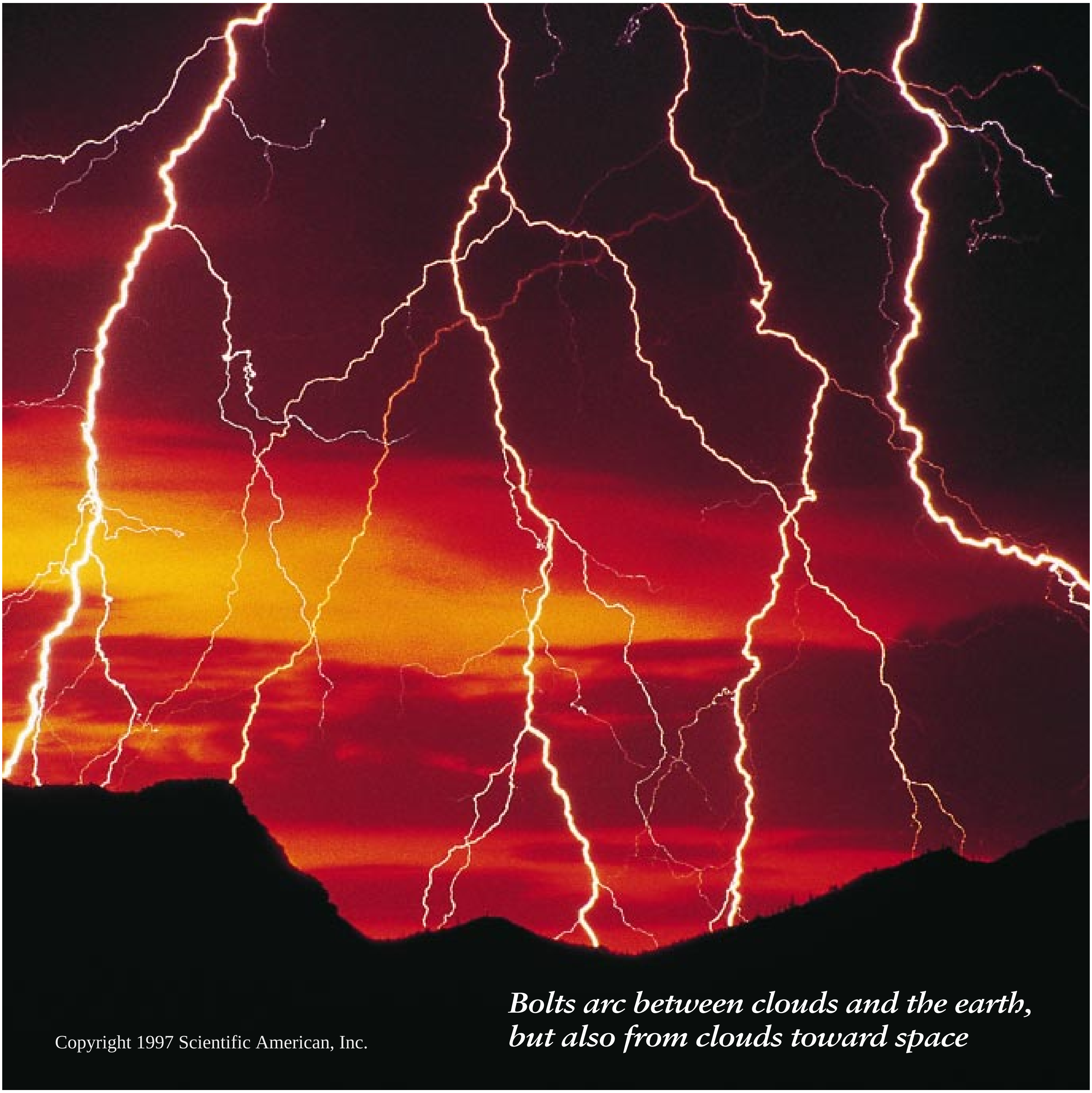
AGE AND ENERGY

HOW SUBTLE MUTATIONS IN CELLULAR DYNAMOS SLOWLY WEAKEN THE BRAIN AND MUSCLES



Bolts arc between clouds and the earth, but also from clouds toward space

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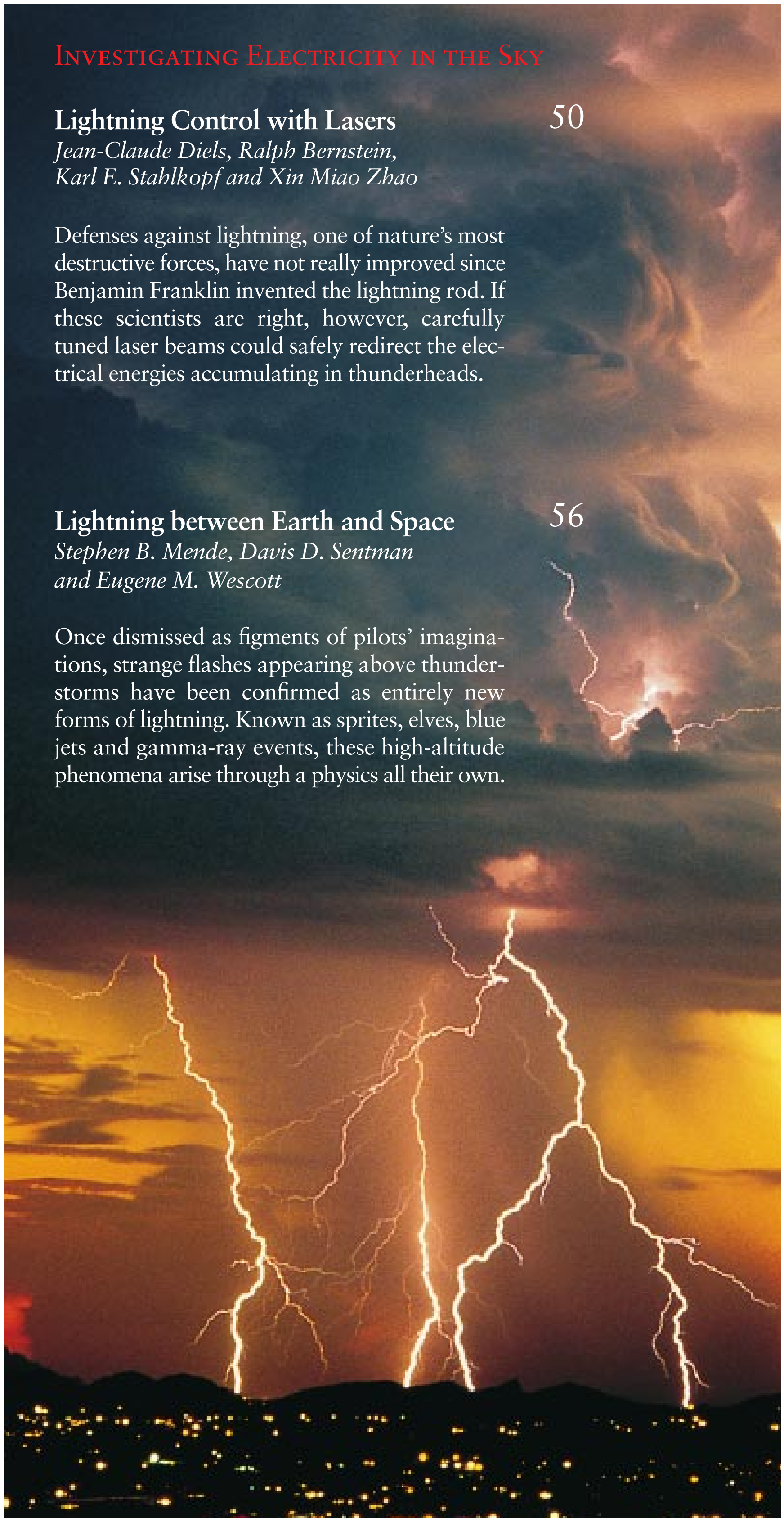
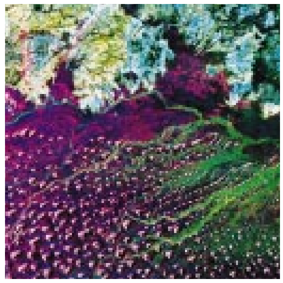
NEWS AND ANALYSIS



INVESTIGATING ELECTRICITY IN THE SKY



REVIEWS AND COMMENTARIES

About the Cover
One of the most awesome and energetic forces of nature, lightning continues to surprise researchers. In this 45-second exposure, photographed by Warren Faidley, jagged bolts slash the sky over mountains near Tucson, Ariz.

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FROM THE EDITORS

Current Events

Roy C. Sullivan of Virginia was not a lucky man, but the sorry circumstances of his life make for one of the most mythic entries in the *Guinness Book of Records*. He holds the distinction of having been struck by lightning seven times between 1942 and 1977. The first bolt cost him a big toenail; the second, his eyebrows. In subsequent strikes, he suffered burns and other injuries to his shoulder, legs, ankle, chest and stomach, and his hair was set afire (twice). He died in 1983, supposedly of a broken heart, Cupid finishing what Zeus could not.

Luckily, only a relative few have ever attracted lightning, but almost everyone has been attracted to it. While reading this month's pair of articles on lightning, beginning on page 50, I realized how soon and often lightning cut a jagged path through my own interests in science. For example, some of my earliest memories are of sitting on our family's front porch with my father and grandfather during thunderstorms, inhaling the odd tonic of ozone in the air. From them I learned to track the distance of storms by counting the seconds between lightning flashes and thunder—probably my introduction to the difference between the speeds of light and sound.

E. R. DEGGINGER *Bruce Coleman Inc.*

NEVER TWICE? Make that 23 times a year.

A sixth-grade expedition to the Museum of Science in Boston brought me face to face with what was, I think, at least for a time, the world's largest Van de Graaff generator. The museum used it to explain the physics of electricity and to puncture hopeful notions that rubber sneakers or automobile tires might offer enough insulation to protect against the 100 million volts of a lightning strike. (To do that, as I recall, the rubber would need to be about a mile thick.) These days I can measure to the block how close I get to most lightning: my office looks out at the Empire State Building, which is struck on average 23 times annually.

Lightning undoubtedly has plenty more to teach us. Many people swear to have seen ball lightning, weird globes of moving energy. Despite reports of ball lightning dating back to the ancient Greeks, science has not yet been able to document its existence convincingly. But maybe ball lightning's believers can draw encouragement from the example of astronomer Louis A. Frank of the University of Iowa. Ten years ago most experts dismissed his evidence that miniature cometlike bodies were constantly pelting the earth's atmosphere. As our story on page 19 reports, new data are starting to win him converts. Perhaps lightning will strike twice—*pace,* Mr. Sullivan.

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

MURPHY WAS A PERFECTIONIST

As the son of the man whose name is attached to "Murphy's Law," I want to thank you for accurately and respectfully identifying the origin of this "law" in your recent article ["The Science of Murphy's Law," by Robert A. J. Matthews, April]. My father was an avid reader of *Scientific American,* and I can assure you that were he still alive, he would have written to you himself, thanking you for a more serious discussion of Murphy's Law than the descriptions on the posters and calendars that treat it so lightly.

Yet as interesting as the article is, I suggest that the author may have missed the point of Murphy's Law. Matthews describes the law in terms of the probability of failure. I would suggest, however, that Murphy's Law actually refers to the *certainty* of failure. It is a call for determining the likely causes of failure in advance and acting to prevent a problem before it occurs. In the example of flipping toast, my father would not have stood by and watched the slice fall onto its buttered side. Instead he would have figured out a way to prevent the fall or at least ensure that the toast would fall butter-side up.

JOE CAPUTO *Gamma Liaison*

***CRASH TEST DUMMIES:** using Murphy's Law to prevent problems.*

Murphy and his fellow engineers spent years testing new designs of devices related to aircraft pilot safety or crash survival when there was no room for failure (for example, they worked on supersonic jets and the Apollo landing craft). They were not content to rely on probabilities for their successes. Because they knew that things left to chance would definitely fail, they went to painstaking efforts to ensure success.

EDWARD A. MURPHY III
Sausalito, Calif.

After receiving more than 362 intact issues of *Scientific American,* I received the April issue—with the article on Murphy's Law—that was not only assembled incorrectly by the printer but also damaged by the U.S. Post Office during delivery. My teenage daughter is taking this magazine into her science class to talk about Murphy's Law. The condition of this issue is an excellent example for her presentation.

BRAD WHITNEY
Anaheim, Calif.

SUSTAINABLE DEVELOPMENT

Like Richard E. Rice, Raymond E. Gullison and John W. Reid, authors of "Can Sustainable Management Save Tropical Forests?" [April], we are dedicated to conserving biodiversity in the tropical rain forest, and we are doing so both commercially and sustainably. We have been working for four years on 40,000 acres of Paraguayan forest that has been certified as well managed. In addition, we are shipping lesser known species to market, and we are making money. Our experience suggests that the authors' conclusions may not apply across the tropics. Their example—cutting only one species in a species-rich, high-volume forest—is both atypical and one of the least efficient ways to generate either short- or long-term profits. It has been our experience that sustainable forestry need not be any more expensive than massive, indiscriminate extraction or single-species elimination.

JEFFREY ATKIN
ALLEN COBB
KENNETH SEWALL
Sustainable Forest Systems
Incline Village, Nev.

GOOD VIBRATIONS

Pardon some observations from a simple patent litigator regarding the article by Leonard Susskind, "Black Holes and the Information Paradox" [April]. (Albert Einstein was a patent examiner, after all.) Consider that the quantity of information that can be transmitted is usually viewed as a function of carrier wave frequency—a 28.8 modem typically carries more information than a 14.4. If strings slow their vibration frequencies as they approach a black hole, their ability to carry information should also decrease. At a carrier frequency of zero, no information can be carried. How can strings carry or radiate information once they're at the horizon of a black hole?

ROBERT KUNSTADT
New York City

Susskind replies:

Kunstadt makes an interesting point. Someone stationed far from a black hole that is absorbing a flow of information carried by an electromagnetic wave sees the frequency of the wave diminish as it approaches the horizon. So, as Kunstadt indicates, the flow of bits must also diminish. But information is not lost at the horizon. There is no limit on how much information can be carried at low frequencies, only on the rate of flow of that information.

CELL AGING AND TELOMERES

I was disappointed to read "A New Take on Telomeres" [News and Analysis, "In Brief," May], which refers to studies purportedly demonstrating that the link between cell aging and telomere loss is wrong. Telomere length can be in a dynamic flux in immortal cells, but this finding does not negate the fact that aging is linked to telomere loss in mortal dividing cells. Our original observations have been confirmed and extended in numerous labs over the past seven years. Suggesting that new insight into additional regulators of telomere length in immortal cells disproves the telomere hypothesis of cell aging is a bit like concluding that since your bank account fluctuates up and down even when you have an income, it won't shrink when you spend without one.

CAL HARLEY
Geron Corporation

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50, 100 AND 150 YEARS AGO

AUGUST 1947

OIL WELLS AT SEA—"An oil well 10 miles out in the Gulf of Mexico—the first operation of this nature so far from land—is only a forerunner of others even greater distances off shore, states R. G. Watts of the Magnolia Petroleum Company. The platform is at an elevation of 20 feet above mean high water to give protection against waves of maximum expected height. Water at the site was 16 feet deep at mean low tide."

MICROFILMS AT WAR—"The miraculous revivals of several American fighting ships during the war were due to one of our most unusual weapons: microfilmed plans of every floating unit, stored in the Naval Archives Building in Washington, D.C., and, later, at Pearl Harbor. When a vessel was severely damaged, the facts were radioed to headquarters, and by the time the stricken ship limped into port, the new parts had already been pre-fabricated from plans flown to repair stations."

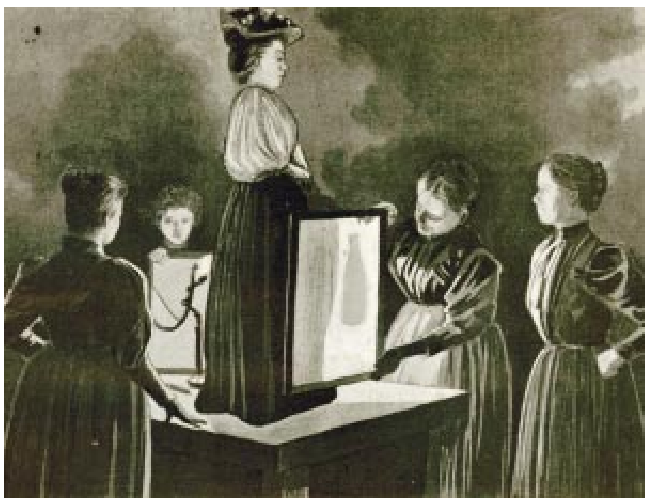
AUGUST 1897

KLONDIKE GOLD RUSH—"The announcement of the return of two steamers from the Alaskan gold fields along the Klondike River last month, with a small party of miners on board who carried about a million and a half dollars in gold between them, has gone through the world like an electric shock. The news is expected to set off a 'gold fever' comparable only to the wild excitement of the California discoveries in 1849. Already the 'rush' has begun, in spite of the warnings of the miners who have just come out of the country, and the detailed account by the press of the inhospitable and inaccessible nature of the placer districts."

WHAT'S FOR DINNER?—"An inhabitant of the Scilly Islands was struck by the fact that the rats there seemed to prosper greatly, although the place is very barren. He resolved to investigate the cause of this, and digging up some of the nests by the seashore, found that the rats had dragged crabs into their holes, and, in order to prevent their escape, had bitten off their legs. No doubt the prey had been seized at low tide and brought home."

BLOOD WORK—"Dr. Judson Deland, of Philadelphia, has invented an instrument for counting blood corpuscles. It works on the centrifugal force principle, and accomplishes the measurement by means of comparative bulks. A quantity of blood is placed in a finely graduated tube and the latter revolved at a speed of about 1,000 revolutions a minute. The corpuscles divide by force of gravity and form on the side of the tube in easily traceable divisions of red corpuscles, white corpuscles, and serum. The new method permits of larger quantities being used in experimenting, besides doing away with microscopic counting."

X RAYS FIGHTING CRIME—"The most recent application of X rays is the utilization of these inquisitive and all-seeing radiations by the custom house. In the railway stations of Paris, the X rays have been employed for a week past for examining packages of all kinds and sizes, as well as the travelers themselves. We reproduce a scene that occurred recently in the large merchandise hall of the Saint Lazare station. A woman whose appearance was such as to avert any suspicion was placed before the telltale apparatus, and there was immediately observed upon the fluorescent screen a bottle in front of her legs."



A smuggler detected by the X rays

AUGUST 1847

POWER OF MAGNETS—"The phenomena in magnetism have been attracting the attention of scientific men for a long time past, and it appears as if we are advancing to a knowledge of the most secret operations of nature. A very interesting discovery has recently been made by placing a glass trough on the poles of a powerful magnet and filling it with a fluid from which a precipitate is slowly forming. It is found that the precipitate arranges itself in the magnetic curves. Crystals forming under the same circumstances exhibit also the influence of magnetism on their molecular arrangements—all the crystals arranging themselves in the order of the magnetic curves."

FOOD PRESERVER—"A gentleman in Baltimore has invented a Meat Safe, which promises to be most important. It consists of a chamber, so cut off from the influence of heat as to be at a degree or so above the freezing point. The ice, which is the preservative power, is replenished but once a year. The temperature is so low that the rotting as well as the over-ripening of fruits is prevented. Persons engaged in the bacon business can protect their meats from the inevitable effects of warm weather. The theory that cold was a preserver has long been maintained, but this invention has for the first time practically tested its correctness."

NEWS AND ANALYSIS

IN FOCUS

SCIENCE'S SURVIVAL STRATEGY

Researchers are learning how to live in a new budgetary environment

NATIONAL CENTER FOR SUPERCOMPUTING APPLICATIONS, UNIVERSITY OF ILLINOIS

CRAY ORIGIN 2000 SUPERCOMPUTER is a resource for work supported by the federal government. Researchers are struggling with shrinking federal funding.

"If you want a friend in Washington, get a dog," advised Harry S Truman. Many scientists might now be pondering the advantages of canine company. After decades of growth, federal research spending has leveled off and is starting to decline, a casualty of budget-balancing efforts and the end of the cold war. The Clinton administration's request for spending on science and technology next year is 3.4 percent less than in 1994 after adjusting for inflation, according to the National Academy of Sciences. And because the ax has not fallen evenly on all subjects, some fields, such as high-energy physics, have taken much larger hits. Other areas, notably biomedicine, have continued to grow. Now the sea change has begun to affect the culture of science.

Empty laboratories are still unlikely in top-flight research institutions. But many universities now lack the flexible funds that they have traditionally used to help young scientists start their careers, says Cornelius J. Pings, president of the Association of American Universities.

Pings notes that industry-sponsored research at universities (including foreign industry) has increased in recent years, partly compensating for the federal shortfall. Last year a survey of 121 member companies of the Industrial Research Institute found that those firms planned to increase their research budgets by 5.6 percent in 1997. But the proprietary restrictions on corporate research can threaten academic freedom, Pings fears. "The other adaptation is to do less research—there's no escaping that," he states.

John H. ("Jack") Gibbons, the president's science adviser and head of the White House's Office of Science and Technology Policy (OSTP), maintains that overall the Clinton administration "has tried to protect" research with "essentially level purchasing power" in the face of the overarching need to balance the federal budget. Yet Gibbons acknowledges that over the past five years "we've gotten rid of most of the fat, and we're into the meat and bones."

The budget agreed on by Congress and the White House this past May means that deeper slicing might happen over the next five years, considering the growth in such politically sacred entitlement programs as Medicare. The budget resolution, by limiting nonmandatory "discretionary" spending, could force "cuts significantly greater than the 14 percent cut to federal R&D by 2002 projected from the president's latest budget," according to Kei Koizumi of the American Association for the Advancement of Science.

Cuts on that scale might never materialize, of course. Like previous budget resolutions, the latest one defers most of the monetary squeeze until its last few years, after 2000, and targets may change before then. Still, professional scientific organizations, opposing the threatened reductions, point out that the U.S.'s economic competitors in Asia are convinced of science's rewards and are increasing their research.

The U.S. budgetary gloom has prompted scientific organizations to urge supporters to speak out more for their profession. The American Institute of Physics, for instance, informs interested readers by e-mail how they can most effectively convey their views to congressional representatives. And Neal Lane, director of the federal National Science Foundation, which supports $1.8 billion in nonmedical basic research, has urged researchers to become "civic scientists" who promote their endeavors in public.

Other science leaders have gone even further. One is Bruce M. Alberts, president of the National Academy of Sciences. Alberts says scientists "have to think more broadly about what they respect" and bemoans "intellectual snobbery" that values only work that probes the deepest mysteries. Alberts maintains that "the future stability of the world" could depend on whether researchers can, for instance, provide the world's poor with rewarding ways to live that do not entail moving to overcrowded cities.

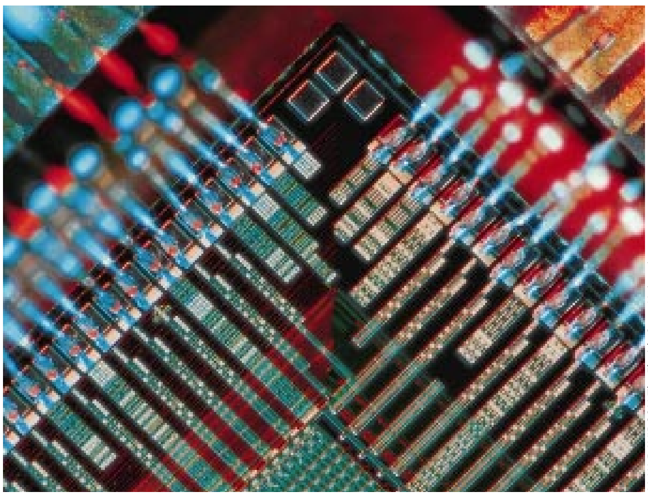
The budget squeeze is pushing science-funding agencies toward undue scientific conservatism, he believes. As a result, they neglect important cross-disciplinary studies that could yield important progress: Alberts sees neglected opportunities in human tissue engineering, to cite just one area that might be considered risky. He believes funding decisions should follow from high-level "thoughtful leadership" and then peer review of research proposals by scientists.

In response to political pressure to justify research expenditures, the National Science Foundation and the National Institutes of Health have recently revised the criteria they use for awarding grants. Both have clarified the value they attach to innovative work that is likely to have consequences beyond its immediate discipline. Although the changes may not mean agencies will immediately start supporting new areas of research, Alberts says the revised criteria "send young scientists the right signal."

Another prominent science leader who has designs on policy is Richard N. Zare, a chemist at Stanford University. Zare, the current head of the National Science Board, has served notice that he intends to be an activist. The board has traditionally concentrated on overseeing the National Science Foundation, but Zare notes that its mandate allows it to consider research more broadly.

"In constrained budgets, you face even more the need of making smart, long-range plans," Zare declares. "Everything you start is because you stop something else." Zare is now consulting with scientific leaders to see whether they might expand the use of priority-setting methods to steer money toward the most promising science. The idea has been floated in various reports over the years, but researchers have so far been unable to agree on a formula. "We keep talking about setting priorities, but we never do it in a satisfactory fashion," Zare says.

A principal obstacle to science planning, almost everyone agrees, is that budgets for different scientific agencies are distributed piecemeal among congressional committees. As a result, the administration has to contend with fragmented political battles. Gibbons maintains that the OSTP has had a substantial effect on the administration's science planning. Yet one influential new figure in research policy is not impressed: Representative F. James Sensenbrenner, Jr., of Wisconsin, who since January has been chairman of the House Science Committee.



M. W. DAVIDSON *The Florida State University*

***MIPS TECHNOLOGY R10000 CHIP** is used in scientific computing.*

Sensenbrenner, whose committee has jurisdiction over the National Science Foundation and the Department of Energy, is attempting to strengthen science and save money by extending peer review. The OSTP is "not doing its job," Sensenbrenner asserts. He blames the failure on Vice President Al Gore's interventions in support of specific areas of technology for priority development. Federal funds should not support near-term development, Sensenbrenner believes.

In the last Congress, bitter battles were fought over the administration's backing of the $225 million Advanced Technology Program, which Republicans dubbed corporate welfare and tried to abolish. Sensenbrenner seems to hew to a new consensus that federal support for technological research—as opposed to pure science—is justifiable, but only for long-term work and only if "we do not have government dollars replacing corporate dollars." The House has accordingly passed legislation that would reduce the Advanced Technology Program's proposed budget by almost 50 percent.

Sensenbrenner has also moved swiftly to extend competitive scientific review in some administration-backed energy technology programs. At the same time, he is demanding clear explanations from administrators: they must provide "plain English" accounts of how they evaluate research programs. "Agency heads who drag their feet will be sweating in front of my committee," Sensenbrenner warns. Already hurting from budget blows, science soon may be learning that money talks. *—Tim Beardsley in Washington, D.C.*

GEOPHYSICS

A BLUE NOTE

Seismologists find a mysteriously pure tone in the ocean

When Jacques Talandier of the French Atomic Energy Agency and Emile Okal of Northwestern University examined some loud rumblings recorded by the network of seismic stations in French Polynesia, they discovered, much to their surprise, a single frequency—in essence, a pure tone—blasting through the ocean. Was it an animal? A secret navy experiment? None of these speculations held up under scrutiny, and they were stumped. But Talandier and Okal can now rejoice with a new explanation. And perhaps they should have celebrated earlier, because opening a bottle of champagne might have helped them solve the mystery.

The "monochromatic" seismic signals that caught their attention were each composed of just one frequency—typically in the range between three and 12 cycles per second—making them purer than a note from a musical instrument, which invariably includes various overtones in addition to the fundamental frequency. (The combination of overtones present distinguishes a note played, for example, on an oboe from the same note played on a piano.) These oceangoing sound waves—called T waves—were particularly cacophonous in 1991 and the early months of 1992. Individual blasts lasted from a few seconds to several minutes. Earthquakes would have produced much more short-lived signals. Whales would have emitted higher-frequency sounds that showed seasonal changes. "This was quite different from anything we had seen anywhere else," Okal recalls.

Although similar seismic signals, called harmonic tremors, have come from the magma bodies lurking beneath some volcanoes, such resonances usually generate overtones. Perhaps, the two seismologists reasoned, it was merely a limitation of their instruments, which had been designed to filter out extraneous high-frequency noise. Talandier and Okal turned to recently declassified recordings made by the U.S. Navy, which operates arrays of underwater microphones designed to listen to higher frequencies—like those given off by submarines. But the navy's data from SOSUS (the military moniker for SOund SUrveillance System) showed that the oceangoing sounds curiously lacked high-frequency overtones.

The first clue to the solution came after the two seismologists determined the position of the source, which was within a poorly surveyed region of the South Pacific. Old charts indicated an underwater volcanic ridge in the area. And so the two researchers coaxed colleagues to visit that locale, an expedition completed last year. New probing revealed a flat-topped undersea volcano that rose to within about 130 meters of the surface. Although no volcanism was obvious at the time, the samples recovered contained fresh lava, indicating volcanic activity in the recent past.

Talandier and Okal knew that vast stretches of the seafloor are currently rife with such volcanism but that few volcanic events generate T waves. Those that do, such as the South Pacific seamount, are located at shallow depths, where the pressure is sufficiently low that bubbles can form in the water above the scorching lava. So the source of the curious T waves seemed linked in some way to undersea effervescence.

Searching for further insight, they consulted Bernard Chouet, a specialist on harmonic tremors at the U.S. Geological Survey, who urged them to consider the interesting things that can happen in a mixture of water and steam. For example, sound waves, which typically travel about 1,500 meters per second in the ocean, can go as slowly as one meter per second. "You can walk faster than that," Chouet quips. He imagined that the resonator in this case was probably a cloud of bubbles sandwiched between the top of the seamount and the surface of the ocean.

Chouet ran computer simulations to see whether such a cloud might behave as a resonant cavity—acting much the way an organ pipe does when it sounds a note. He found that sound waves would indeed shoot up and down through the cloud at some resonant frequency, reflecting back and forth between the ocean surface and the seamount. But little energy would bounce sideways, because the diffuse boundary of the cloud would not produce reflections. As a consequence, the fundamental frequency would remain steady, no matter what the lateral extent of the cloud. This bubbly body, like a musical instrument, would also generate overtones, but there would be a natural tendency for the gas bubbles to damp out the higher frequencies.

In their report in the *Bulletin of the Seismological Society of America* last year, Talandier and Okal presented this resonating bubble cloud under the heading "Volcanological Speculations." So they are perhaps not entirely convinced themselves. And although a resonating slab of frothy seawater seems a neat explanation, Chouet warns that "anything is possible." *—David Schneider*

BOB TALBOT

SEAS ABOIL WITH GAS AND VOLCANIC ROCK, such as these off Mexico's Socorro Island, could explain strange underwater sounds.

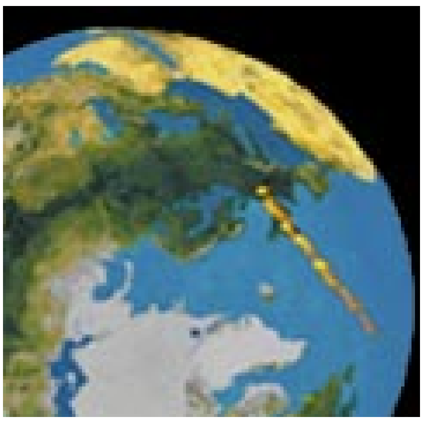
ASTRONOMY

RETURN OF THE SPACE SNOWBALLS

Did a blizzard of icy comets give the earth its oceans?

It was the kind of news Chicken Little would surely understand: on May 28 Louis A. Frank of the University of Iowa announced that miniature comets (each about the size of a house) are slamming into the earth's atmosphere at a staggering rate of some 40,000 a day. This pummeling is far beyond anything astronomers had envisioned based on the known components of the solar system. "If it is true, this is a very important result," comments Heinrich Holland of Harvard University.

But *is* it true? Frank made a similar announcement 11 years ago, drawing on views of the earth's atmosphere made with the Dynamics Explorer 1 satellite. Those pictures contained strange dark spots that Frank interpreted as "holes" in the glow of the upper atmosphere caused by the arrival of low-density iceballs—tiny cousins of ordinary comets. A number of researchers promptly raised stinging scientific objections to his small-comet hypothesis, however, and suggested that the holes were nothing more exotic than instrumental artifacts. Under a barrage of criticism, Frank's ideas faded from view.



NASA GODDARD SPACE FLIGHT CENTER AND THE UNIVERSITY OF IOWA

***ULTRAVIOLET STREAK**, superimposed on the visible earth, may be the wreckage of a small comet.*

Now Frank is back, armed with improved data from the recent POLAR satellite and a big publicity buildup as well. At the meeting of the American Geophysical Union where Frank delivered his results, "there were so many lights from the photographers that the audience couldn't see my slides," he says. Several former doubters are voicing a more open attitude. "I believe the POLAR evidence—the holes are real," says Thomas M. Donahue of the University of Michigan, a longtime skeptic.

Frank has released some fresh details about the physical nature of the small comets; he vividly describes them as icy objects so tenuous (about $^1/_{20}$ the density of water) that "you could walk up to one and put your arm right through it." Otherwise, his remarkable claims remain much the same as before. Small comets add about one inch (2.5 centimeters) of water every 10,000 years, he believes, enough to fill the oceans over the lifetime of the earth. And carbon compounds in these fluff balls, gently delivered to the earth, "may well have nurtured the development of life on our planet," Frank thinks.

Despite the increased respect for Frank's observations, many of the objections to his conclusions remain the same as well. "The new data show that there is some effect going on," Feldman agrees, "but there is a real credibility problem with Frank's explanation." In 1991 Alexander J. Dessler of Rice University published an exhaustive list of problems , "any one of which would be fatal to the idea of small comets," he says. The problems are still there.

Perhaps most damning is the evidence from the sensitive seismometers that Apollo astronauts placed on the moon. These instruments did not detect any signs of a hailstorm of small comets. Citing work by Thomas Ahrens of the California Institute of Technology, Frank explains that his comets are so diffuse that they would not create much of a seismic jolt. But Ahrens himself doubts that solution, noting that low-density objects "are actually a good way to make a seismic signal," because they couple effectively with the surface.

There is good evidence that interplanetary space contains little water or water-derived hydrogen atoms, so the small comets would need improbably effective surface coverings that prevent any water molecules from escaping. Yet even normal comets, which can leak enough material to make conspicuous tails, contain rocky or metallic grains; if the small comets had any significant amount of solid material, they would produce brilliant showers of shooting

IN BRIEF

The Claim in Spain
Paleobiologists from the National Museum of Natural Sciences in Madrid report that 800,000-year-old fossils from the Atapuerca Mountains belong to a new human species, *Homo antecessor*. The team, led by José Maria Bermudez de Castro, notes that the specimens bear some traits resembling those of *H. sapiens,* such as a relatively flat face. But other features of the braincase, lower jaw and teeth look like those of more primitive hominids. Thus, they guess that *H. antecessor* may be a common ancestor of both modern humans and Neanderthals. Other scientists contend that, given the range of anatomical variation among *Homo* specimens of the same age, it is impossible to credit the bones to a new evolutionary clan.

Leaky Electricity
Many household appliances—including cordless telephones, smoke detectors, burglar alarms and fax machines—draw power all the time, even when they are switched off. In fact, a new study from Lawrence Berkeley National Laboratory estimates that five billion watts, or the equivalent of five standard power plants, are lost to "leaking" appliances nationwide—about 50 watts per house a year. To limit leaking electricity, the study's authors advise using low-voltage power supplies with three-way on/ready/off switches. For devices that need continuous energizing, such as TVs and VCRs, they have designed a circuit that draws power only when a small rechargeable battery in the appliance requires it.

SPENCER JONES *FPG International*

Believe It's Not Butter
Saturated fats aren't the only no-no in a heart-healthy diet. A new study from Brandeis University, the University of Malaya and the Palm Oil Research Institute of Malaysia has found that substitute *trans* fatty acids—made from partially hydrogenated unsaturated vegetable oils—are even worse. Not only do *trans* fatty acids, which are often found in margarine, raise levels of "bad," or LDL, cholesterol in the blood, as do animal fats, they also lower levels of "good," or HDL, cholesterol.

More "In Brief" on page 20

In Brief, continued from page 19

Jurassic Gout

Sue may be the most complete *Tyrannosaurus rex* fossil ever found, but she is not the most perfect. Bruce Rothschild

ED GERKEN *Black Hills Institute of Geological Research, Inc.*

of the Arthritis Center of Northeast Ohio in Youngstown and his colleagues note that scars on the beast's bones suggest she suffered from gout. The crippling ailment occurs when the body produces too much uric acid, often the result of problem drinking, lead poisoning, kidney malfunction or, in Sue's case, eating a lot of red meat. Gout was most likely far less common among dinosaurs than among port-swilling nobility, the researchers say, but no less painful. Poor Sue is expected to fetch $1 million this fall when she is auctioned off at Sotheby's.

Crazy Glue, Stat

Surgical stitches could become a thing of the past. A recent clinical trial found that a tissue adhesive, called octylcyanoacrylate, provides a faster, less painful way for closing wounds than sutures. Wounds sealed with glue look as good as sewn ones and seem less susceptible to infection, too. What is more, the glue simply wears away as the skin heals. The study's lead author, James Quinn of the University of Michigan, points out that the painless glue is particularly useful for treating children, who are often scared of receiving stitches and sedated for simple repair jobs.

Flashy Mints

One of the fundamental mysteries of the fifth grade has at last been explained: scientists now know why wintergreen mints give off flashes of light when you crunch them. Linda Sweeting of Towson State University and colleagues tested the triboluminescence—the glow from certain crystals, such as the sugar in mints, when they are ground up—in 12 materials. She found that among pure crystals, only those lacking rotational symmetry—be it natural or because of impurities—lit up. The finding confirms an earlier theory: flashes appear when opposite charges on different faces of the fragmented crystal recombine and excite gas molecules. Such charges occur when voltage arises in a crystal under stress—a "piezoelectric" effect seen only in asymmetrical materials.

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stars in the earth's atmosphere. "To reasonable scientific certainty, Frank's ideas just can't be right," Dessler declares.

Still, the POLAR images have convinced many scientists that something odd is going on. "The challenge now is not to point out the problems with Frank's model but to develop an interpretation that respects the other constraints," Donahue says. Frank stands firm, unfazed by his many doubters. "It is human nature," he reflects. "There are still some people who don't believe in continental drift." *—Corey S. Powell*

ENVIRONMENT

FRANKLY, MY DEAR, I DON'T WANT A DAM

How dams affect biodiversity

Perhaps more than any other ecological no-no out there, dams enrage environmental activists. Legend has it that John Muir, founder of the Sierra Club, died of a broken heart after the O'Shaughnessy Dam in Yosemite National Park was built despite his group's protests. These activists argue that you can't redirect millions of gallons of water—even for such worthy causes as flood control or renewable-energy projects—without having at least some deleterious effect on the local environment. But documenting long-term changes to ecosystems along rivers is complex, so such conclusions have been difficult to test.

A recent study of Swedish rivers published in *Science*, however, has succeeded in quantifying the extent to which biodiversity can be choked off by dams. Researchers at Umeå University counted different species of trees, shrubs and herbs at some 90 sites along rivers that had been dammed. Some of the Swedish dams are nearly 70 years old, which enabled the team to examine how ecosystems change over decades. In addition, the group surveyed species along pristine rivers in Sweden—hard to find in an era when the majority of rivers around the world are controlled by dams.

Christer Nilsson, who led the Umeå team, recalls that "when I began my career, engineers told me that everything would recover" after dams were constructed. "[We have] now shown that different things happen." Nilsson and his colleagues Roland Jansson and Ursula Zinko demonstrated that in some areas, certain types of trees and shrubs did recover, especially along small, so-called run-of-river impoundments. But in total, the number of plant species fell by 15 percent, and the size of the habitat along the riverbank also decreased. Near larger storage reservoirs, the researchers found that the number of species within a given area dropped by about 50 percent.

More surprising to Nilsson were the long-term trends in these ecosystems. After a dam was built, the diversity of plant species rebounded only during the first 20 or 30 years before tapering off. Nilsson attributes the subsequent scarcity of new species to either a gradual depletion of seeds over the decades or a slow deterioration of the habitat.

Studies such as this one should figure prominently in the ongoing debate about whether and how to maintain aging networks of dams throughout the world. One option being considered in the U.S.

THANE *Earth Scenes*

COLUMBIA RIVER, IN THE PACIFIC NORTHWEST, is heavily regulated by dams, like most other rivers around the world.

In Brief, continued from page 20

www.Rx or Not

The World Health Assembly, which governs the World Health Organization in Geneva, has recently set up a committee to study how medicines are offered on-line and delivered by mail. Although it is legal in many countries to sell prescription drugs on-line, provided the customer produces a doctor's writ, public health officials worry that some companies do not always require an Rx. The WHO points out that many of the drugs currently available have serious side effects and should not be taken without continual medical supervision.

Mon Appétit

Gourmand syndrome is not an eating problem Richard Simmons can fix. This newly identified disorder renders patients obsessed with eating, thinking,

PETER SAMUELS *Tony Stone Images*

talking and writing about fine foods. In a study of 723 patients with known or suspected brain lesions, Swiss neurologist Theodor Landis and psychologist Marianne Regard found that 36 suffered gourmandlike symptoms, and 34 had a single lesion in the right anterior region of the brain. Although not all patients with right anterior lesions develop a fancy for haute cuisine, the correlation is strong—demonstrating that compulsive behaviors can have a physical cause.

FOLLOW-UP

Unbuckling the Kuiper Belt

Past Pluto and the rest of the Kuiper belt, which girds the rural reaches of our solar system, but before the misty, comet-filled Oort cloud, Jane Luu and her colleagues have sighted a new object, named $1996TL_{66}$. Besides Pluto and its moon, Charon, $1996TL_{66}$ is the brightest bit of mass ever found beyond Neptune—and perhaps the weirdest, too. It has an eccentric orbit, suggesting that the Kuiper belt may be bigger both in area and in mass than scientists thought. Although $1996TL_{66}$'s origins are unknown, Gerard Kuiper himself speculated in 1951 that the gravity of the outer planets might pluck protocomets from the Oort cloud and send them reeling around the fringes of the solar system. (See May 1996, page 46.)

—Kristin Leutwyler

is the periodic opening of certain dams. Last year's uncorking of the Glen Canyon Dam and the resulting flood in the Grand Canyon, intended to revitalize riverbanks and wildlife, were ecologically "trivial," according to Jack Stanford of the University of Montana's Flathead Lake Biological Station. "But from a sociological standpoint, it was huge," he says. That brief flood could be the first drop in a very large bucket to restore the ecology of dammed rivers, in which the primary concern is endangered animals, particularly fish.

In an effort to protect salmon populations, the Clinton administration has been pushing for the removal of two dams along the Elwah River in Washington State; at press time, the proposed 1998 budget contained $32.9 million for the project. The U.S. Army Corps of Engineers is studying the possibility of breaching four dams along the Snake River and lowering the reservoir behind the John Day Dam on the Columbia River as part of a plan to protect salmon runs. Even the Glen Canyon Dam has been targeted by a number of environmental groups, including the Sierra Club, that are arguing for its removal.

Opponents of such plans protest that dams are vital to the livelihood of the West. Lewiston, Idaho, for example, is an inland port along the Snake River. Without the current system of dams, jobs in the area shipping goods to market would dry up.

Dismantling dams would take years of construction work. And the payoff could take decades or more, even with extensive environmental rehabilitation. Dutch Meier of the U.S. Army Corps of Engineers points out that the removal of the dams on the Snake River could very likely reveal "scoured, denuded hillsides with entirely changed ecosystems." Meier adds: "Just because you pull the plug on the tub and make the water go away doesn't mean you won't leave a bathtub ring." *—Sasha Nemecek*

FIELD NOTES

PLAY TIME AND SPACE

New York Hall of Science builds Newtonian fun park

"Hey, maybe we can go to a Mets game," intones my 10-year-old son, Benjamin, when he learns that our destination is right by Shea Stadium. A few minutes later the yellow cab carrying Benjamin and his fellow fifth grader, Geoffrey Hamilton, pulls up in front of a one-time exhibit hall from the 1964 World's Fair, a structure that resembles an architect's abstraction of the lower part of a rocket. The two have won a reprieve from class on this brightly lit mid-May day to provide a connoisseur's perspective on a new play area adjoining what is now called the New York Hall of Science. I need a fifth grader's eye to give this place the proper once-over.

The science museum, located in Flushing Meadows–Corona Park in Queens, is about to open what it breathlessly calls the "largest science playground in the Western Hemisphere." (Michael Walker, who handles public relations for the museum, assures me that it is not the only science playground in the Americas.) The idea for the playground actually comes from India, where municipalities sometimes build such parks before they move ahead with construction of an entire museum.

The structures in the new $3.1-million playground are not unlike many of the exhibits inside the museum building, except that their dimensions are many times larger. Slides and teeter-totters attempt to merge the activity

ROBERT PROCHNOW

***SCIENCE LESSONS** are absorbed by **Benjamin Stix** (left) and **Geoffrey Hamilton** (right).*

of play with the discipline of physics.

Benjamin and Geoffrey stop first at the three-dimensional spiderweb, similar to a jungle gym and big enough to accommodate a classroom of kids. Flexible steel cable sheathed in nylon wrapping is tied into interconnected hexagons, the entire structure taking the form of an octahedron. The netlike structure demonstrates the concept of tensile forces—the same ones that hold up the deck of a suspension bridge. Weight applied by the random sneaker induces ripples that realign the hexagonal elements. "It moves with your body," Geoffrey remarks. Asked later what science he learned from his climb, he takes a stab at translating the experience of sitting on top of the 20-foot-plus structure into the requisite physics speak: "For every reaction there is a reaction."

Next we mount a platform where a red parabolic dish faces another positioned 80 feet away. A metal ring near the dish marks the focal point, the spot where an ear or mouth can be placed to communicate with someone at the other dish. "Hey, can you hear me?" Benjamin asks softly. "Yeah," Geoffrey replies. "Whoa, this is awesome," Benjamin says. The lesson: a parabolic shape focuses and reflects sound. "It's like a walkie-talkie but with no electronics," Benjamin explains.

We move along through the exhibits in the 30,000-foot-square playground, some of which are suspended from an overhead pipe. Geoffrey stops to hit a gong in different places, testing the concept of resonance. Alan J. Friedman, the museum's director, demonstrates how softly tapping the gong repeatedly at certain spots causes the volume to rise steadily to a level louder than if it receives just one good whack. Both kids stage a race down adjacent slides, learning that the fastest path between two points is not necessarily a straight line. The straight slide is a slower ride than the curved one, which resembles a catenary arch, a trajectory that moves steeply for the first few feet before easing off at the bottom. Friedman, who won the American Association for the Advancement of Science's 1996 award for public understanding of science and technology, goes on to show the boys at a different exhibit the distinction between a standing and a traveling wave.

The playground, which opened this

ANTI GRAVITY

Space Invaders

Discretion, rumor has it, is the better part of valor. When it comes to driving, however, discretion often goes out the window, usually the driver's. Normally mild-mannered, deferential individuals metamorphose into zealous defenders of territorial rights when behind the wheel. Two centuries ago one sure way to get a rise out of a guy was to backhand your glove across his face. One can achieve the same result today by cutting off another driver on the highway. A recent study shows, however, that even in stationary cars drivers cannot resist the urge to mark their territory.

MICHAEL CRAWFORD

The research took place at the epicenter of late 20th-century social interaction—the shopping mall. As any Saturday shopper can attest, nowhere are cars more stationary than at a mall parking lot. The inevitable game of musical chairs that occurs over parking spaces leads to what exosociologists might call close encounters of the third kind. "Primary territories are those that are central to our lives—our home or office," explains Pennsylvania State University researcher R. Barry Ruback, whose study appeared in the *Journal of Applied Social Psychology*. "Secondary territories are those that we occupy on a regular basis; Norm's bar stool at *Cheers* would be one. It's sort of generally acknowledged that when you're there, it's your place. The third are public territories, the things that we own temporarily." Such as mall parking spaces.

Ruback decided to examine the speed with which the possessors of parking spaces accomplished spot removals, thereby relinquishing their temporary ownership. The question is intriguing because once the bargain hunting is done, a mall parking space is perhaps the area least worth defending on the face of the earth. Defense is actually counterproductive, because the intention once a driver has returned to the car is to leave the scene of the carnage and bring home the kill. Nature, however, has been described as "red in tooth and claw," and vestiges of ancient behaviors survive the millions of years between maul and mall. The average driver spent 32 seconds leaving his or her spot when no one else was jockeying for it, but an additional seven seconds maintaining possession when another car appeared eager to enter.

Part of that difference may result from performance anxiety, a common problem in tasks involving the insertion or removal of objects into and out of tight spaces. Ruback believes, however, that an additional response accounts for at least some of the extra time. A second part of the study bears him out. He and his students fixed the game by confronting those about to pull out with a shill vehicle that either waited patiently or—and here's where things really get ugly—honked. The result: blow your horn, pal, and you can sit there for another 12 seconds. "Somebody infringes on your freedom," Ruback says, "and the first thing you do is react against it." Or, as high-strung taxi driver Travis Bickle might put it after returning to his cab after a hard afternoon accessorizing at Weapons 'R' Us, "You honkin' at *me?*"

For better, or more likely for worse, we all have at least a bit of Bickle in us and are quite willing to squander time and energy in senseless posturing when strangers attempt to horn in on our spaces. What we think of as civilization, then, may be less a wholesale move away from primitive reactions than a substitution for them—a trade of head busting for 12 seconds of chop busting. And if that is true, the old notion of counting to 10 to diffuse an emotionally charged situation is probably a good idea, although counting to 12 is most likely even better.

—Steve Mirsky

past June, will also have placards and roaming college and high school students relating the experience of climbing the giant net or other exhibits to underlying physical principles. Even if children don't read or ask, Friedman believes they will still learn. "Ten-year-olds may not know physics terms, but they can get a feel for how a structure responds to them, so they have in their head the basic science concepts."

As we leave, both Geoffrey and Benjamin give the playground high marks, particularly compared with their three-times-a-week science class. Their elementary science curriculum, in fact, was designed to incorporate hands-on learning experiences. But it definitely did not light flames in young minds. "The first two or three months [of this school year], the only thing we worked on was measuring and classifying string beans," Benjamin says. Maybe a Mets game, accompanied by an explanation of how a curveball is subject to various physical principles, isn't such a bad idea after all. —*Gary Stix*

BY THE NUMBERS

Plants at Risk in the U.S.

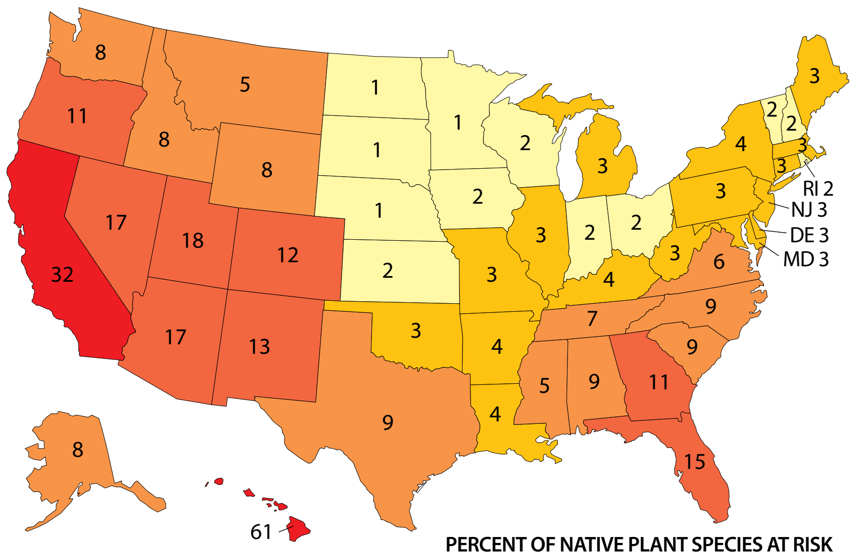
Loss of plant species, even those that are rare, may lead to ecological imbalance. Furthermore, rare plants may prove of economic or medicinal value, as in the case of the meadowfoam wildflower, which contains high-grade industrial oil. It is therefore of some concern that almost a third of all plant species in the U.S. appear to be at risk, a substantially larger proportion than in the case of mammals and birds. The record of plant species extinction is incomplete but suggests that the current rate is considerably higher than historical norms. (Over the past 200 years, at least 13 plant species have gone extinct, and an additional 125 have not been seen for years and may also be lost forever.)

This assessment comes from the Nature Conservancy of Arlington, Va., and its partners in the Natural Heritage Network, organizations that have measured the risk of extinction to individual species by considering rarity, population trends and known threats. The map is based on their data for about 16,000 species of higher plants native to the U.S. Higher plants—also called vascular plants—generally have stems, leaves and roots. They include conifers, ferns and flowering plants and span such diverse species as Douglas fir, sugar maple, sagebrush, saguaro cactus, California poppy and Kentucky bluegrass. (Nonvascular plants, which include such groups as mosses and liverworts, account for a small fraction of all plant species.)

Habitat loss or degradation is the single biggest threat to native plant species, but other, less obvious factors come into play. Introduced plants and animals, for example, have been invading natural habitats, posing serious threats to native flora. (Introduced plant species, which number about 5,000, are not included in the map or chart.)

Factors peculiar to particular states or regions also have a decisive role. In Hawaii, for example, most of the nearly 1,200 native species are endemic—found nowhere else on the earth. Extreme endemism, combined with a large number of nonindigenous plants and major habitat alteration by both Polynesians and Europeans, has made Hawaii's flora the most threatened of any state. Plant species in the upper Great Plains and much of the Midwest are the least threatened, partly because of the fairly uniform climate, topography and geology, conditions that favor species with widespread ranges. Additionally, during the period of Pleistocene glaciation, rare species tended to become extinct, whereas widespread species were more likely to survive south of the glacier and repopulate the land as the ice receded.

California harbors more native plant species than any other state and has the second highest proportion of species at risk. The state's large size and diverse habitats provide abundant opportunities to adapt and evolve, giving rise to numerous narrowly restricted species, which are vulnerable to California's spectacular urban and agricultural growth. Certain other areas, such as Oregon, the southern Rocky Mountain states, Florida and Georgia, also have high proportions of rare species because of the great diversity of their habitats. Areas of patchwork mountain and desert, which provide ample opportunities for geographical isolation, are especially rich in locally evolved plant species. Extreme examples of such habitats are the mountaintop "sky islands" in the deserts of New Mexico and Arizona, many of which support local and rare plant species. —*Rodger Doyle (rdoyle2@aol.com)*



SOURCE: The Nature Conservancy in cooperation with the Natural Heritage Network and the Biota of North America Program. The numbers on the map indicate the percent of native, higher plant species at risk.

RODGER DOYLE

PROFILE: JEREMY RIFKIN

Dark Prophet of Biogenetics

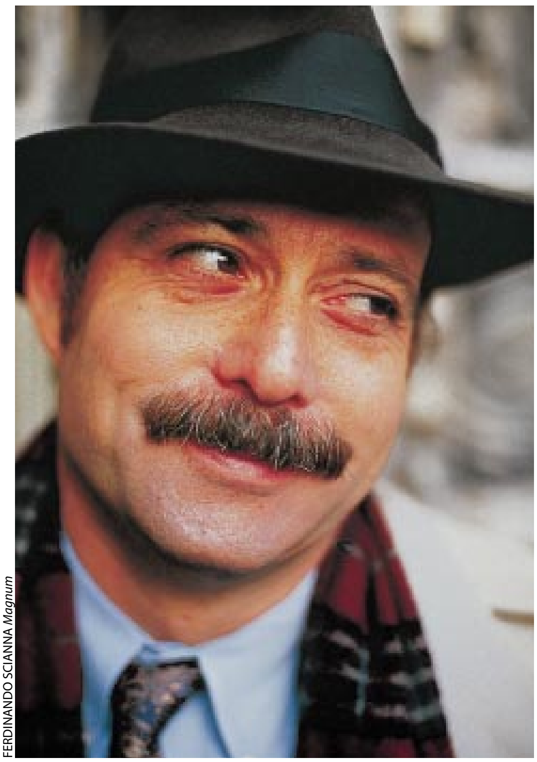
When the announcement came in February of the cloning of a sheep named Dolly, Jeremy Rifkin remembered an earlier milestone. It was 20 years earlier, almost to the month, that Rifkin and a group of protesters invaded a meeting on genetic engineering at the National Academy of Sciences and chanted, "We Will Not Be Cloned!" That event marked Rifkin's entry into the public arena as one of the nation's most hectoring critics of biotechnology.

During the ensuing years, Rifkin has been a strident voice on issues ranging from genetically engineered crops to the patenting of genes to biological weapons—and has also served as a social critic on various economic questions, including the effect of information technologies on the workplace. His 1960s-activist style of pressing his views on the world has been executed with every tool at hand: lawsuits, boycotts, guerrilla-theater-like demonstrations, 13 books, and quote after quote purveyed to the media.

One day in late May I visited him at the Foundation on Economic Trends, his small nonprofit group in downtown Washington, D.C. Rifkin is intrigued by the prospect of training his oratory on SCIENTIFIC AMERICAN, an institution that is by and large viewed as a representative of the scientific establishment. It has been only a month or so since his organization and others put together a global protest to oppose genetically engineered foods, cloning and genetic patenting.

Cloning, he informs me, represents a lot more than just improved animal breeding. Coupled with the prospect of "genetic customization"—the manipulation of germ-line, or sex, cells to produce desired traits—cloning portends the dawn of an era of eugenics and "bioindustrial design," Rifkin declares.

A few days after our meeting, the National Bioethics Advisory Commission, established in 1995 by President Bill Clinton, recommended that legislation be enacted to ban human cloning. But Rifkin, in a subsequent conversation, thinks the proposal does not go far enough and that the temptation to design human beings and make copies of these engineered works will persist. The ability of genetics to reengineer each generation, he argues, could undermine the sense of self, the notion that one's identity is, in part, an endowment of the natural world. "We're creating multiple personas. We're creating a thespian sense of personality where we see ourselves as a work of art, and we see everything in our environment as a prop, as a set, as a stage, as a backdrop for filling ourselves in. We don't see ourselves as ever completed. We are *in*-formation."



FERDINANDO SCIANNA *Magnum*

ACTIVIST JEREMY RIFKIN has long decried the risks of bioengineering.

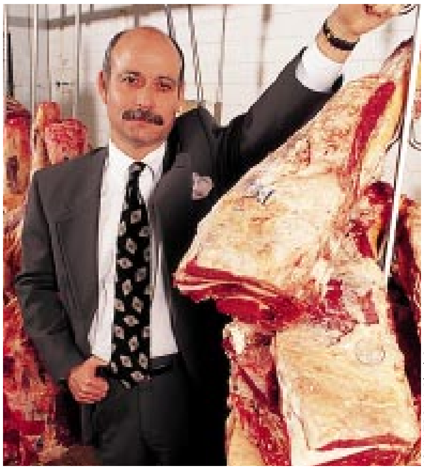
Such posturing, not to mention the lawsuits, have made the mere mention of the name "Rifkin" enough to agitate government regulators, microbiologists and industry executives. The loathing runs deep. The head of the National Milk Producers Federation called Rifkin a "food terrorist" for his work against recombinant bovine growth hormone (rBGH), which induces cows to produce more milk. Microbiologist and Nobel laureate David Baltimore once referred to Rifkin as a "biological fundamentalist." And a *Time* magazine headline dubbed him "The Most Hated Man in Science." "One can't say enough negative things about a guy like this," rails Henry I. Miller, the former head of the Food and Drug Administration's Office of Biotechnology, now a senior research fellow at the conservative Hoover Institution at Stanford University and a prominent Rifkin basher.

Of course, Rifkin believes that society needs its Rifkins, voices that can add critical perspective to the headlong rush to commercialize knowledge about the workings of DNA—what he calls the "genetic commons." Rifkin reiterates his long-standing argument that public debate was missing for previous technology revolutions until the worst happened, pointing to catastrophes at Three Mile Island and Bhopal.

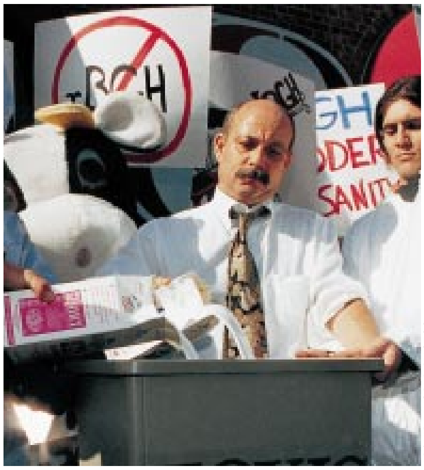
An upbringing on the South Side of Chicago did not necessarily prepare him for the life of an activist. His father was a manufacturer of plastic bags. His mother set up a charity to tape books for the blind after first doing so to help his sister, who is legally blind, through school. He became involved in the antiwar and civil-rights movements while studying at the University of Pennsylvania's Wharton School of Finance. Becoming a professional activist, he acknowledges, owes a certain amount to time and place. "I often wonder if I had been eight years older whether I would be in the family business," he says.

Over the years, he has not succeeded in the U.S. in his quest to stop genetic patenting or to halt the release of genetically engineered organisms into the environment—nor have postulated worst-case scenarios come to pass. But the war, he says, is by no means over.

Within five to 10 years, bioengineered plants will inadvertently lead to weeds that resist herbicides or to insects that can withstand a natural insecticide used by organic farmers, he maintains. "That will create tremendous liability problems, and it will raise the specter of genetic pollution to front and center." (Rifkin and other environmentalists have had more success in pressing their causes in Europe.)



JOHN TROHA *Black Star*



AP/WIDE WORLD PHOTOS

JEFFREY MARKOWITZ *Sygma*

***CAREER IN ACTIVISM* has taken Rifkin from campaigns on beef to bovine growth hormone to animal and human cloning.**

During his tenure as a gadfly, Rifkin and his Foundation on Economic Trends have, in fact, won a few battles. A 1984 suit against the Department of Defense helped to stop construction of a facility in Dugway, Utah, that could have been used for testing the most dangerous of airborne biological toxins. Numerous legal actions by the foundation during the 1980s did not permanently halt any releases, but they did prompt the federal government to increase scrutiny of environmental risks. "He caused people to think more about what they were doing and why they were doing it," says Elizabeth Milewski, special assistant for biotechnology at the Environmental Protection Agency's Office of Prevention, Pesticides and Toxic Substances.

That assessment is not universally shared. Some of Rifkin's opponents charge that he polarized or misled the debate. Dale E. Bauman, a professor of nutritional biochemistry at Cornell University and a leading researcher on rBGH, characterized as "nonsensical" Rifkin's claim that the hormone poses a threat to the food supply. "The problem with Rifkin personally and his organization specifically is that a very large portion of the material that they put out represents misinformation," Bauman charges. "It usually contains some pieces of accurate scientific information, which are then put in a context that misrepresents it."

Among Rifkin's greatest successes has been drawing attention to his concerns by bringing together nonscientists into grassroots coalitions to oppose biotechnology-related issues. One of Rifkin's most noteworthy organizing efforts came in 1995, when he helped to persuade 180 leaders, from more than 80 different religious groups, to sign a statement calling for a ban on the patenting of genetically engineered animals and human organs, cells and genes. The announcement became the lead story in the *New York Times,* and it struck fear into biotechnology and pharmaceutical industry executives, who defend the need for patents to commercialize new products.

Predictably, in the aftermath, controversy erupted. Ted Peters, a professor of theology at the Pacific Lutheran Theological Seminary, wrote in his recent book, *Playing God: Genetic Determinism and Human Freedom*: "How did it happen that so many otherwise thoughtful theologians and leaders of different religious traditions [got] hoodwinked?"

The invitation letter from Rifkin's collaborator, the United Methodist Church, obscured many of the subtleties surrounding the patenting debate, Peters says. It mentioned a 1991 patent granted to a California company, SyStemix, for human bone marrow stem cells (progenitors of blood cells). The letter stated that many in the science community were outraged that a patent had been granted for "an unaltered part of the human body." But the company, Peters writes, had not patented stem cells in their natural state, as the letter implied, but only modified versions of the cells and a process for harvesting them, thereby qualifying the cells as a novel invention. The cells may eventually help cancer and AIDS patients.

In an interview, Peters goes on to conclude that Rifkin's ideas display a tacitly naturalistic or vitalistic bent. They imply that nature is sacred and should be left alone, uncontaminated by technology, a position not accepted by Judaism or Christianity. Rifkin expressed reverence for nature and the need for society to consider forgoing bioengineering in *Algeny.* That 1983 book outraged some by questioning the objective validity of Darwinian evolution, even citing a prominent creationist to back its arguments.

Concern over Rifkin's involvement, Peters acknowledges, had the positive effect of drawing scientists and industry officials into dialogues with the religious community (sans Rifkin) to better explain their respective positions. C. Ben Mitchell of the Southern Baptist Christian Life Commission, which signed the statement, notes, "I'm not sure that the discussions would have occurred without Rifkin's first having pushed the issue."

For his part, Rifkin denies that he manipulated anyone. He points out that none of the religious leaders who signed the document have since changed their position. He balks at vitalist or Luddite labels, emphasizing that he has never opposed biotechnology for making pharmaceuticals, for genetic screening or for applying genetic knowledge to areas such as preventive medicine. Over the years, his litany of ideas—he also devotes much time to heralding the perils and promise of the information age—continues to win support from a few philanthropies. According to Rifkin, the Foundation on Economic Trends, with a staff of seven, brings in between $250,000 to $800,000 annually, averaging $450,000 a year.

As time passes, Rifkin's pace may be slowing. When news of Dolly arrived, he decided not to go into the office to take calls from the media, something he would have done a decade earlier. Still, the 52-year-old Rifkin, if he so chooses, may continue his militant ways for another 20 years. That means that what has been called the "biological century" may begin with a shrill oracle prophesying its perils. *—Gary Stix*

SOFTWARE ENGINEERING

COMMAND AND CONTROL

Inside a hollowed-out mountain, software fiascoes—and a signal success

The focal point of North America's defense network looks like nothing so much as a Laundromat. Here in the computer room of the NORAD Command Center, 1,750 feet below the surface of Cheyenne Mountain in Colorado, sensor readings from heat-sensing spacecraft, tracking stations, weather satellites and coastal radar arrays converge in order to alert American and Canadian commanders of any bomber, missile or satellite attack. Sorting through that barrage of data falls to an odd lot of computers, some running software written a generation ago. My guide, Russell F. Mullins, proudly points out three shiny new VAX machines, which last year took over the processing of air defense intelligence from 74 antiquated predecessors. But I am more fascinated by the bank of magnetic tape units and the fleet of 20-year-old disk drives—they look more like coin-operated washing machines—that are still used to track ballistic missiles.

They should not be here. In 1981 the Pentagon started the Cheyenne Mountain Upgrade (CMU) program to replace the center's five main computer systems over six years, at a cost of $968 million. But as with many attempts to build grandiose software, the project soon derailed. In 1994 the General Accounting Office reported that the CMU was running 11 years behind schedule and about $1 billion over budget. Despite the extra time and money sunk into development, most of the new systems were still too slow or unreliable to use, so the air force had to keep the old systems running alongside as a backup.

This duplication created a problem, Mullins explains as he steers me through a maze of unmarked steel corridors to the bunker's systems center, which he heads. In this cramped room, technicians monitor the base's computers and its connections to the sensors, commanders and world leaders aboveground. Each new system added more warning panels and more glitches to fix. "We used to call this the Double Jeopardy Room," Russell laughs, "because we had to constantly scan more than 20 monitors for a wide variety of alerts" to network failures—alerts as subtle as "yes" changing to "no." His team fell behind amid the growing complexity. "If a missile warning component fails, we have to switch to backup systems in only two minutes," he says, suddenly very serious. "The best we could do was about four."

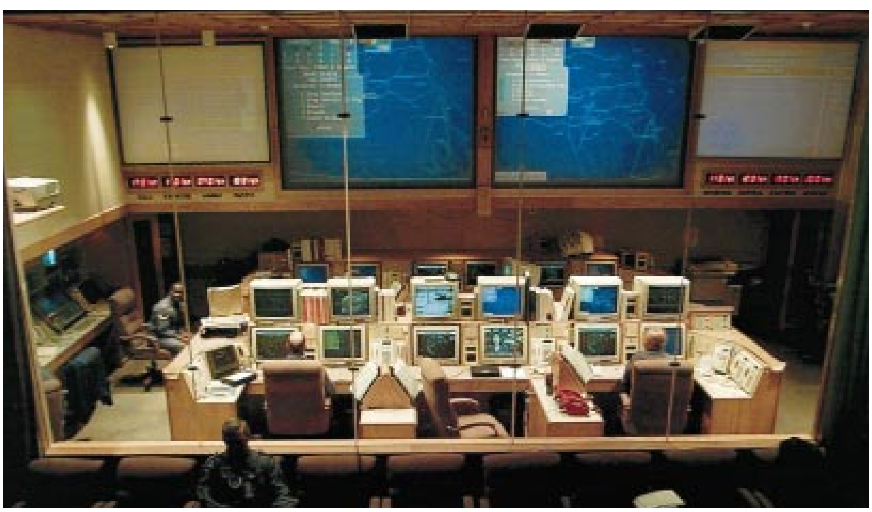
To solve the problems caused by too much software, CMU managers decided in April 1995 to build yet another software program, an automated tracking and monitoring system (ATAMS). With it, Mullins's crew could control the entire network using just two monitors and a simple, consistent interface that made failures hard to miss.

But the project seemed doomed from day one. Contractors estimated it would take two years to build; the air force allowed one. Bureaucratic snafus delayed delivery of Sun Microsystems workstations, forcing programmers to write the software for IBM hardware, then convert it later. Users demanded 10 times more functions than originally planned. Tests turned up unexpected bugs in the systems that ATAMS keeps tabs on. And Mullins's group found several errors just before the system was finished.

Yet in April 1996 ATAMS was complete, on time and within its $2-million budget. Unlike the rest of the CMU, it immediately worked as intended. "Now we regularly make the switchover to backups in 45 seconds," Mullins beams as he simulates losing communications with a missile launch detector. "It cut down on operator errors. And we can now operate this whole system with just two people, rather than four." To date, users have uncovered only two bugs in the software; both were fixed easily.

The success of ATAMS was surprising but no fluke, claims Buford D. Tackett of Kaman Sciences, who led the development team. He combined several techniques that were shown years ago to produce better software faster yet are still rarely used. Mullins sketched out what he wanted to see on the ATAMS screens, and Kaman built the displays first, rather than last. Tackett split the system into small segments and put the riskiest parts at the head of the line, rather than letting them slip to the end. The team incorporated off-the-shelf software and large sections from other systems. Programmers peer-reviewed one another's designs and code, catching more than 200 major design errors while they were still easy to fix. Tackett forced his engineers to perfect each segment before moving on, and rather than avoiding contact with the users, "they begged us periodically to come see what they had done," Mullins recalls.

Perhaps the most important difference between ATAMS and conventional systems is that it will be updated ev-



ERIC DRAPER AP Photo

NORAD COMMAND CENTER ***fell a decade behind in its upgrade effort. But amid the failures, one successful system proved that delays and cost overruns are not inevitable.***

ery year, rather than replaced once a decade. And it was designed to be just the first in a product line of related systems. Like a line of car models, its relatives will look and perform differently but share an underlying design and many of the same innards. "As we replace more elements of Cheyenne Mountain systems, we will use this product-line approach, applying the lessons of ATAMS," promises Colonel John M. Case, head of the Space and Warning Systems Directorate. Other contractors have begun experimenting with the process as well. "So eventually we should reach the point where we can evolve software continuously," he says, "at a much lower cost."

If so, perhaps future billion-dollar fiascoes will be fewer. But as I leave this cold war relic and pass three-foot-thick blast doors that take 45 seconds to open, I suspect obsolete mind-sets may prove hardest to upgrade. —*W. Wayt Gibbs inside Cheyenne Mountain, Colo.*

MANUFACTURING

MAKING LIGHT WORK

Blasting metal powder with lasers to make precision parts

Fabricating precisely shaped metal components has always been a challenge for industry. Making tools and dies is especially difficult because they are built of very hard alloys, and machining is liable to introduce microscopic cracks and weak points. Now researchers at Sandia National Laboratories have developed a novel technique for fabricating highly accurate, complex parts directly out of powdered metal. The approach might not be limited to metals: the Sandia team believes its method could in time yield parts that seamlessly blend metals and ceramics in variable proportions.

The technique is known as laser-engineered net shaping, or LENS. A continuous thin stream of finely powdered metal in argon gas is directed onto a working surface, where it is illuminated by an industrial-strength laser. The laser melts a few milligrams of the powder, so the molten material fuses onto the surface. The surface can be swiftly moved around in a horizontal plane by computer-driven actuators.

Parts are built up by driving the working surface so as to overlay consecutive layers of metal in the desired pattern. In a few hours, for example, LENS can build a hollow bar of tool steel 20 centimeters long with a complex cross-section, a task that would be a much larger project using conventional approaches. Superalloys and even high-melting-point materials such as tungsten can be shaped with the technique. Some samples the Sandia group built in two hours would be "exceedingly difficult" to make with any other method, the workers maintain.

Sandia is investigating LENS because of its potential to make components for weapons systems, but the approach has started to attract the interest of civilian industrial giants. Kodak has used LENS to fabricate dies at possibly lower cost than standard procedures, and 3M and other companies are also investigating its potential for making tools and dies. A key advantage, according to Sandia team leader Clinton L. Atwood, is that metal parts fabricated with LENS are "fully dense"—they contain essentially no detectable pores or cracks.

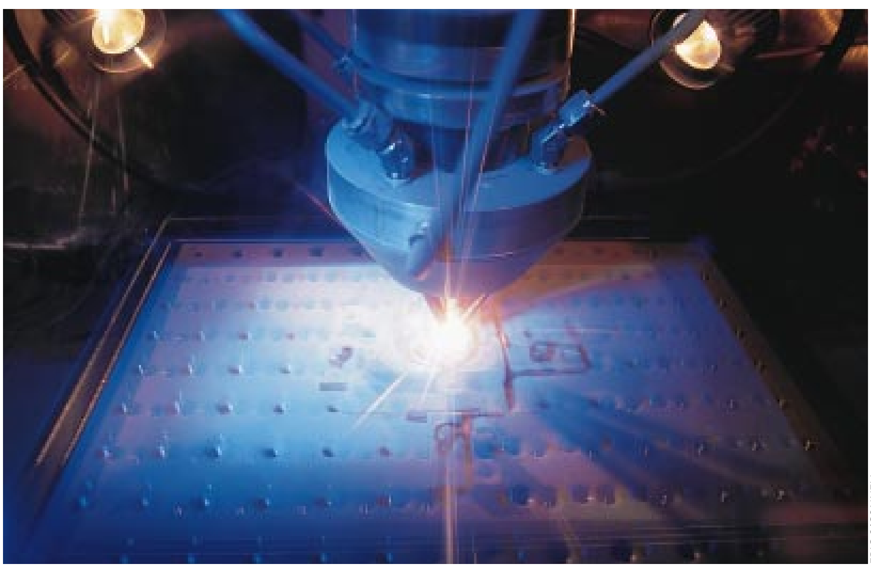
Moreover, because only a tiny amount of material is molten at any instant, the melt cools in a fraction of a second. Eric M. Schlienger of Sandia notes that as a result, less soluble components of a molten alloy do not have time to separate out, which can occur in casting. The net effect is that LENS-made parts are stronger and harder than would be expected from standard material samples, and they do not shrink or warp, because they have little internal stress. The surfaces of LENS-made parts are about as smooth as those of cast parts, but that should be improvable, Atwood states.

One experimental rig that employs a 300-watt laser lays down about a third of a cubic inch of material an hour. But the process is "very scalable," according to Atwood—larger systems can accurately deposit metal at a higher rate. The key to success, the team says, is ensuring very smooth delivery of the powder to the working area. Although most components of a LENS system are available commercially, the Sandia group had to build its own high-performance powder systems.

Ceramics can also be built up in a layering process similar to that used in LENS, notes Sandia's Duane B. Dimos. Delivered in a supersonic jet, the particles melt on impact with the working surface without the need for a laser. Sandia researchers plan to combine ceramic deposition and LENS within the next three years. Parts made of variable metal-ceramic blends might then be possible.

Various research groups and companies around the world are using powders in different ways to make complex parts. Some, for example, press polymer-coated metal powders into shape, then later heat the part to fuse the particles together. But Atwood's team may be unique in using pure metals to make finished parts directly. "In five to 10 years this will be very common in manufacturing," Atwood declares.

—*Tim Beardsley in Albuquerque, N.M.*



ERIC O'CONNELL

EXPERIMENTAL LENS SYSTEM
melts finely powdered metals with a laser to produce high-performance precision components that would be hard to make with conventional techniques.

RECYCLING

FARMING WITH LINT

Lint from blue jeans as plant boosters and bricks

Imagine the dinner conversation at David Dotson's house when he told his parents he was going to put his brand-new graduate degree to good use—collecting lint. Yes, those lowly bits of clothing fiber found between one's toes and clinging to the screens of dryers. Dotson, who had just received his master's degree from New Mexico State University in Las Cruces, had signed on with Livingston Associates, an environmental consulting group based in Alamogordo, N.M. And his first job would be to help El Paso, Tex., figure out what to do about its overabundance of lint.

El Paso is the garment-finishing capital of the world, where six major plants wash blue jeans for Levi-Strauss, Gap, Polo, DKNY, Kmart and others. One large finisher, International Garment Processors (IGP), estimates that it stonewashes, sandblasts and otherwise weathers some 300,000 pairs every week. That leads to a lot of lint: IGP can throw away up to 70 cubic yards, about three full garbage trucks of the stuff every week. It was eating up profits at the rate of $900 a week for disposal.

DAVID DOTSON

BLANKET OF LINT helps grass to grow on a largely sterile plot.

Al Romero, IGP's director of environmental health and safety, suspected there was a solution to their lint problem. "I knew it was cotton fiber, just organic matter, so there had to be something we could do with it besides put it in a landfill," he says. He approached agricultural engineer Dana Porter, then at N.M.S.U., who enlisted Dotson, one of her graduate students. "I knew at the very least it could be composted," Porter recalls. "But I wanted to see if we could do something simpler with the fiber."

That something simpler was mixing it with farmland. Porter and Dotson started with cotton and wheat seeds in five-gallon buckets. One bucket had just local soil; three others had varying amounts of IGP's lint mixed in. The results were dramatic. Germination rates improved in all the lint-filled buckets, some increasing by 60 percent. The lint

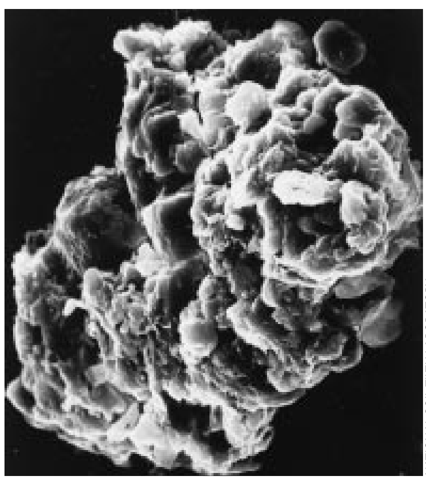
AGRONOMY

Getting the Dirt on Dirt

It may look like just a speck of dirt to the naked eye, but under an electron microscope this crumb of prairie soil is really a carefully constructed "apartment building," home to the small critters that recycle decaying organic matter into usable nutrients. About a millimeter across, this soil crumb—or macroaggregate—is riddled with water- and air-filled pores that shelter such organisms as bacteria, fungi and nematodes. As these organisms dine on dead roots, fertilizer and even one another, they release the nitrogen compounds that feed growing plants.

U.S. Department of Agriculture soil scientist Cynthia Cambardella is passionate about macroaggregates. She and her colleagues at the National Soil Tilth Laboratory in Ames, Iowa, study soil structure and its effect on nutrient cycling in the hope of developing more efficient and environmentally friendly farming techniques. Soils with abundant macroaggregates do a better job of supporting plant life and lose fewer nutrients to leaching; therefore, much of Cambardella's work focuses on the formation and degradation of these rich crumbs in agricultural lands.

Cambardella has her graduate student Jeff Gale of Iowa State University use radioactive carbon 14, for example, to observe the aggregation process in soil as the debris from harvested oat plants decomposes. Gale sows his oats in large pots kept in a walk-in growth chamber. As the plants grow to a height of a meter, he periodically doses them with radioactivity by combining carbon 14–tagged sodium bicarbonate with a dilute acid inside the growth chamber. When the acid hits the radioactive baking soda, the mixture foams, liberating "hot" carbon dioxide that is fixed by the growing plants and incorporated into their tissues.



NATIONAL SOIL TILTH LABORATORY

SOIL MACROAGGREGATE may be vital to the health of the earth.

After the plants are harvested, Gale and Cambardella can trace the radioactive organic materials from the remaining roots and straw as they decompose and become incorporated into the soil structure. They are finding that the presence of relatively fresh plant matter in the soil helps to stabilize its structure—the number of macroaggregates peaks about 180 days after the harvest, and then the aggregates start to break down, potentially compromising soil quality.

Studying aggregate formation, Gale says, will help farmers learn to maintain good soil structure in the field. Cambardella believes that understanding soil structure is vital to developing agricultural practices that do not cause topsoil erosion or the contamination of aquifers and surface waters with fertilizer runoff. "We need to learn more about what's really going on in the soil," Cambardella says. "We can't black-box it anymore." *—Rebecca Zacks*

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boosted the water-holding capacity of the soil 300 percent, not an insignificant finding for parched El Paso.

Suddenly, there seemed to be endless potential for IGP's "problem." The unprocessed lint could be applied directly to alfalfa fields that IGP also maintains, allowing it to plant another profitable 70 acres with 25 percent less water.

Dotson had also noted that in their preliminary tests the lint increased soil permeability, a quality that might aid land reclamation efforts. He went to White Oaks, N.M., to test his theory on soil that had remained largely sterile for the past 100 years because an especially harsh cyanide-leaching process had been used to mine the area. Dotson found that by using a mixture of fertilizer and lint (which also acts as a slow-release fertilizer), he could increase the grass yields by 1,000 percent over untreated soil. Dotson is now looking at using lint sludge to make a superior kind of compost for gardeners.

Porter and Dotson aren't the only ones collecting lint in El Paso. Naomi Assaidan of Texas A&M University's agricultural outreach center in El Paso has been working with American Garment Finishers (AGF) to turn their sludge into bricks and cement. Each garment processor relies on a proprietary finishing process; AGF in particular incorporates alum in its wash water. As a result, its lint sludge differs from IGP's. "It comes out looking like feathery blue chalk," Assaidan says. She fired up chunks of the claylike sludge in a kiln and discovered that they did indeed turn into the first lint bricks. "They're blue, but that's okay. Albuquerque is pink from all the clay it uses in construction. I don't see any reason why El Paso can't be blue," Assaidan says.

In the meantime, IGP's Romero finds that he doesn't send his lint to the landfill anymore. Last year he shipped seven to 10 tons of sludge to N.M.S.U. for its projects. Shipping costs have kept IGP from seeing a profit in lint, but Romero anticipates that within the next year, he'll be applying it to the IGP farms onsite, which will be more cost-effective. "Within a year, the sludge will be a direct source of income," Romero says, "and we'll be in the green—or, I should say, in the blue." *—Brenda DeKoker*

ONCOLOGY

A COLD FOR CANCER

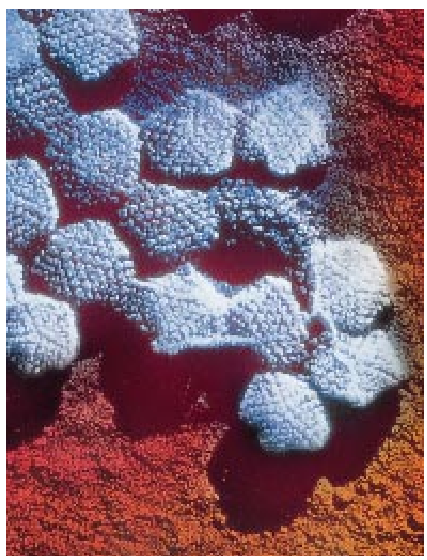
Infection with a mutant virus makes some sick patients better

This summer, if all goes as planned, several dozen patients dying of head or neck cancer will each be injected with 50 billion living virus particles. Their doctors hope the infection will take hold and even spread. Radiation treatments and chemotherapy no longer help these people; there is good reason to suspect that the infection might.

This past May researchers reported that head and neck tumors shrank by half or more in six of 19 patients given a lower dose of the virus. Tumors stopped growing in five others. The results are only preliminary, but they support a bold new strategy of attacking cancer with a living drug: in this case, a mutant adenovirus.

In the wild, adenoviruses are common and cause no more harm than mild colds. The organism spreads by invading a cell, commandeering its genetic machinery and forcing the host to crank out viral clones until the cell membrane explodes. To succeed in its coup, adenoviruses must in most cells overcome a formidable defense, a protein called p53.

Like a genetic sentry, p53 monitors a cell's DNA for mutations caused by injury or viral attack. If it spots any, p53 halts the cell's reproductive cycle—pre-



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***ADENOVIRUSES** have been genetically altered to kill tumor cells but to spare healthy neighbors.*

venting a virus from replicating, a mutation from propagating—and then signals for genetic repairs. Sometimes p53 goes a step further, activating a self-destruct mechanism to sacrifice the cell for the good of the body. Radiation treatment and chemotherapy injure tumor cells (as well as a lot of healthy ones) in the hope that p53 will then dispose of them or at least stop their growth.

When those treatments fail, it is often because p53 inside the tumor cells has been genetically disarmed or blocked by other proteins. Adenovirus contains genes that do the same, and that point of commonality led scientists at Onyx Pharmaceuticals in Richmond, Calif., to a clever idea.

They opened up the genome of an adenovirus and knocked out one of its anti-p53 genes. This new mutant strain, called O15, can still infect and kill defenseless cells that lack p53, so it dispatches many kinds of cancer cells handily. But it is nearly powerless against cells with normal p53—that is, most of the healthy parts of the body.

Whether O15 acts as a "smart bomb" against cancer, as some have called it, will depend on how patients' immune systems respond to the virus. In the first trial, subjects reported only flulike side effects. Many produced antibodies to O15, but Allan Balmain, head of laboratory research at Onyx, does not know whether the immune system will mop up the viral particles before they can kill the cancer or whether the body might actually go after infected cancer cells with new vigor.

Human safety trials, now under way for pancreatic, ovarian and colon cancer, do show that O15 is not perfect. After injection into the tumor, the virus does replicate, but it does not spread throughout the malignancy as hoped. David Kirn, Onyx's director of clinical research, thinks that is because his colleagues knocked out useful virulence genes that reside near the anti-p53 code on adenovirus DNA.

So Onyx is busily preparing new strains with a smaller disabled region. They appear to attack cancer more aggressively in animal studies, Kirn reports. Balmain is testing a version that makes infected cells vulnerable to the antiviral drug ganciclovir. "We can also add genes into the virus to make it kill cells better," he says. Not the usual goal in medical research, but oncology is a field accustomed to drastic measures.

—W. Wayt Gibbs in San Francisco

Parental Discretion Advised

What do *Baywatch* star Pamela Anderson Lee and dead poet Robert Frost have in common? Their works both run afoul of would-be Internet censors. Lee's very name is beyond the pale for software such as CYBERsitter, designed to keep children and teenagers away from undesirable stretches of the infobahn. Frost's "Stopping by Woods on a Snowy Evening" uses the word "queer," a word proscribed right along with "fairy," "gay" and "nigger" as signals of forbidden access.

The U.S. Supreme Court is expected to put an end for the time being to government attempts to legislate the content of Web sites, newsgroups and e-mail. Although a number of state legislatures have passed laws regulating on-line material, they are not currently being enforced, thus leaving the bowdlerization business to the private sector. About half a dozen software packages compete for the job of making sure that only a sanitized Internet reaches the computer screens of those who use them, and sales claims total well into the millions.

Although CYBERsitter, SurfWatch, Net Nanny, Cyber Patrol, Net Shepherd and other programs first sprang up in response to fears about children downloading pornography or being entrapped by child molesters, the range of topics that can be blocked is much larger. Depending on the program in question, users can restrict Web pages that feature drugs, alcohol, cigarettes, extreme bad taste, radical politics of the left and right, explosives, safe sex or the existence of homosexuality. Parents (or, in some jurisdictions, teachers and librarians) can choose which particular shibboleths they want to defend against. SafeSurf, for example, has developed a rating system that includes 10 different kinds of dangerous information (and nine levels of concern within each category). Some programs can be configured to permit access to only a small list of sites known for safe content and links.

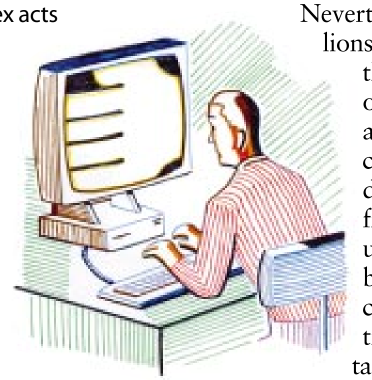
Even more thorough are those blocking-software packages that vet Web-page text, e-mail and anything else a computer receives on the basis of key words and phrases. As America Online found out last year, blocking access on the basis of keywords—even with the best of intentions—can lead to embarrassment. The on-line service had to rescind its proscription of breast-cancer support groups and stop barring mention of medieval liturgies (*cum Spiritu Sancto*). Similarly, Solid Oak Software, makers of CYBERsitter, probably never intended to censor students' reading of Frost or keep them from finding out about the company DTP Express, a small Web-site design firm owned by one P. J. Lee. The same goes for sodom.mt.cs.cmu.edu, home of a thoroughly unremarkable bilingual Web site by an Italian graduate student at Carnegie Mellon University.

But when CYBERsitter's president engaged in a public flaming bout with critics last winter—using language that cannot be reproduced here—the software's criteria became rather more narrowly encompassing. Try accessing a Web site that incorporates the phrase "Don't buy CYBERsitter." Better yet, try "Bennett Haselton." That happens to be the name of a student who published a list of some of the words and sites the program blocks. In fact, the company threatened legal action against anyone who disclosed what sites were blocked—even though the program logs such information in a text file for parents to monitor their children's activity.

Don't Look

SafeSurf's categories of adult themes for restricting access (adapted from http://www.safesurf.com/ssplan.htm):

1. Profanity
2. Heterosexual themes without illustrations
3. Homosexual themes without illustrations
4. Nudity and consenting sex acts
5. Violent themes—writing, devices, militia
6. Sexual and violent themes, with profanity
7. Accusations/attacks against racial or religious groups
8. Glorification of illegal drug use
9. Other adult themes
   A. Gambling
   B to Z. For future expansion of categories


DAVID SUTER

Such shenanigans are not necessarily typical of blocking-software companies, of course. Microsystems Software, makers of Cyber Patrol, offers a Web page where visitors can search to find out which URLs are blocked and which ones aren't. The company has also enlisted the help of both GLAAD (the Gay & Lesbian Alliance against Defamation) and the National Rifle Association to make sure that its ratings are as accurate as possible. Several blocking-software companies tout their commitment to free speech, and the existence of commercial blocking software was a key point in legal arguments this past spring against federal regulation of Internet content.

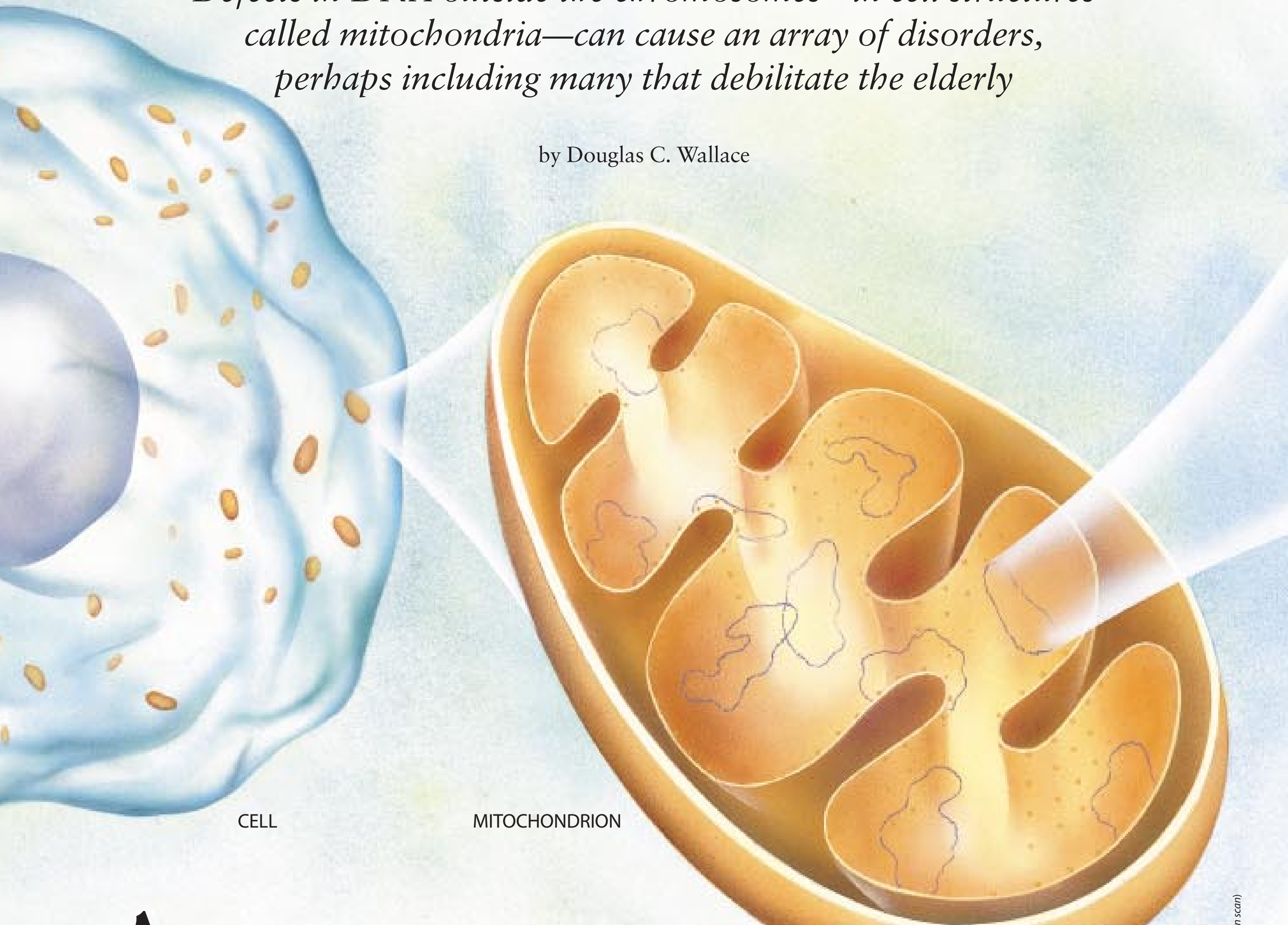
Nevertheless, given the millions of links that constitute the Web and the dozens of megabytes of e-mail and Usenet articles that cross the Internet daily, distinguishing the good from the bad and the ugly may be an impossible task. Net watchers concerned with promotion of alcohol have tagged the Dewar's scotch Web site, for example, but not the one for Absolut vodka. And those looking out for cigarette promotion have unaccountably missed www.rjrnabisco.com, even though tobacco products appear many times in its pages. (Observers rating sites for their promotion of drug use, meanwhile, snagged at least one Web site containing largely academic studies of drug policy.) Hence, it appears that blocking software neither allows people using it to reach all the information they should, given its criteria, nor does it keep them from all the information they shouldn't see.

Are such shortcomings the price of not watching children's every keystroke? Some parents (and school administrators) clearly think so. Other adults may not be so happy with the idea of introducing the Internet to young people as a universal library with a police informer behind every bookcase and under every desk. And for the time being, adults at least are free to make these decisions for themselves. *—Paul Wallich*

Mitochondrial DNA in Aging and Disease

Defects in DNA outside the chromosomes—in cell structures called mitochondria—can cause an array of disorders, perhaps including many that debilitate the elderly

by Douglas C. Wallace



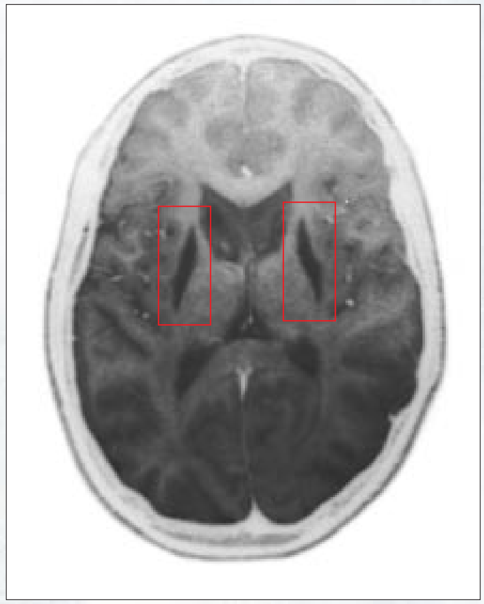
At age five a seemingly healthy boy inexplicably began to lose his hearing, which disappeared entirely before he turned 18. In the interim, he was diagnosed as hyperactive and suffered occasional seizures. By the time he was 23, his vision had declined; he had cataracts, glaucoma and progressive deterioration of the retina. Within five years he had experienced severe seizures, and his kidneys had failed. He died at 28 from his kidney disorder and a systemic infection.

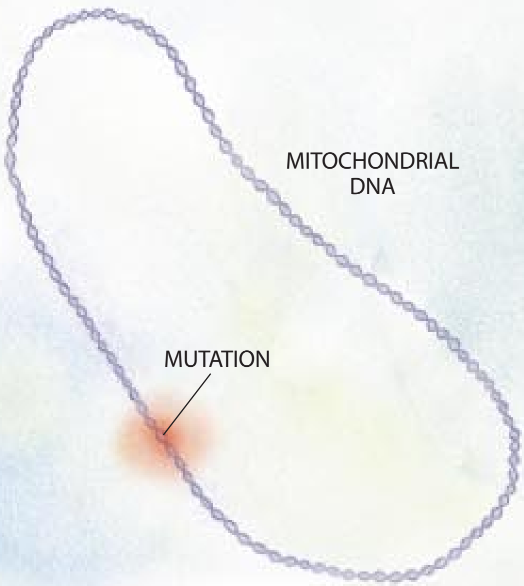
At the root of his problems was a minute imperfection in his genes—but not in the familiar ones residing in the long, linear strings of chromosomal DNA that populate every cell nucleus. Instead he was killed by an abnormality in tiny circles of lesser known DNA located in his mitochondria, the power plants of cells. Each such circle contains the genetic blueprints for 37 of the molecules mitochondria need to generate energy.

Scientists have known since 1963 that mitochondria in animals harbor their own genes, but errors in those genes were not linked to human ailments until 1988. In that year, my laboratory at Emory University traced the origin of a form of young-adult blindness (Leber's hereditary optic neuropathy) in several families to a small inherited mutation in a mitochondrial gene. At about the same time, Ian J. Holt, Anita E. Harding and John A. Morgan-Hughes of the Institute of Neurology in London connected deletion of relatively large segments of the mitochondrial DNA molecule to progressive muscle disorders.

ROB WOOD *Wood Ronsaville Harlin, Inc. (illustration)*; DOUGLAS C. WALLACE *(brain scan)*

EVERY CELL IN THE BODY contains hundreds of mitochondria, the power plants of cells. A single mitochondrion contains several loops of DNA, each of which includes 37 genes involved in energy generation. Mutations in mitochondrial genes are inherited solely from mothers. They have been linked to sometimes devastating, often degenerative disorders, especially of the brain and muscles. The brain scan (*right*) shows a pattern common in many people with mitochondrial DNA diseases—degeneration of the basal ganglia (*boxed*), areas that are important to coordinated motion.





Investigators at Emory and elsewhere have now learned that flaws in mitochondrial DNA cause or contribute to a wide range of disorders, some of which are obscure but potentially catastrophic. Of perhaps more general interest, mutation of this DNA has a hand in at least some, and perhaps many, cases of diabetes and heart failure. Further, a growing body of evidence suggests that injury to genes in mitochondria may play a role in the aging process and in chronic, degenerative illnesses that become common late in life—such as Alzheimer's disease and various motor disturbances.

Mitochondrial DNA has been attracting attention lately on other grounds, too. By comparing the sequences of base pairs (the variable "rungs," or coding units, on the familiar DNA "ladder") in the mitochondrial DNA of different populations across the globe, scientists have gained exciting clues to the evolution and global migrations of anatomically modern humans [*see box on pages 46 and 47*]. And forensic investigators have found smaller-scale comparisons useful for identifying the remains of soldiers missing in action (and for others long dead) and for determining whether accused criminals are responsible for misdeeds attributed to them [*see box on page 44*].

Although most biologists paid little attention to mitochondrial DNA until quite recently, mutation of the genetic material in mitochondria might have been predicted to have consequences for human disease. Mitochondria provide about 90 percent of the energy that cells—and thus tissues, organs and the body as a whole—need to function.

They generate energy through a complicated process that involves the relay of electrons along a series of protein complexes (collectively known as the respiratory chain). This relay indirectly enables another complex (ATP synthase) to synthesize ATP (adenosine triphosphate), the energy-carrying molecule of cells.

Early on, logic suggested that anything able to compromise ATP production severely in mitochondria could harm or even kill cells and so cause tissues to malfunction and symptoms to develop. Indeed, in 1962 Rolf Luft and his coworkers at the Karolinska Institute and the University of Stockholm reported that an impairment in mitochondrial energy production caused a debilitating disorder. Eventually it became clear that the tissues and organs most readily affected by cellular energy declines are the central nervous system, followed, in descending order of sensitivity, by heart and skeletal muscle, the kidneys and hormone-producing tissues.

Scientists initially sought the explanation for mitochondrial disorders in mutations of nuclear genes, some of which give rise to mitochondrial components. But by the early 1980s, researchers understood that mitochondrial DNA codes for a number of important molecules. It specifies the structure of 13 proteins (chains of amino acids) that become subunits of ATP synthase and the respiratory chain complexes, and it specifies 24 RNA molecules that help to manufacture those subunits in mitochondria. These findings implied that mitochondrial DNA mutations able to disrupt mitochondrial proteins or RNAs could potentially disturb the energy-producing capacity of mitochondria and produce disease—a suspicion that was borne out by the 1988 reports.

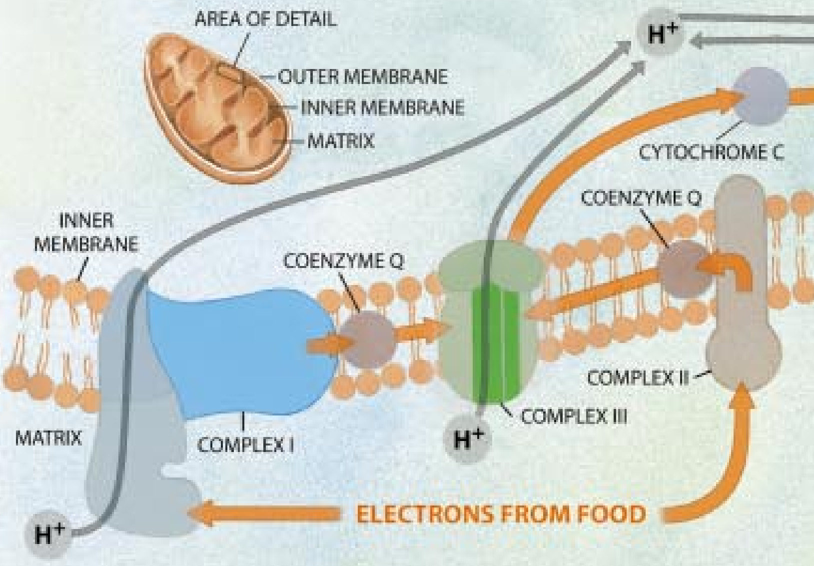
Odd Rules of Inheritance

Since 1988, investigators have uncovered several remarkable features of the syndromes that spring from defects in mitochondrial DNA. For instance, these conditions are often inherited, though not in the same way as disorders issuing from mutations in nuclear genes. And the resulting symptoms are more unpredictable than those caused by nuclear genetic mutations.

The well-known processes governing inheritance of nuclear genetic diseases begin, of course, with fertilization of an egg by a sperm. The single-cell embryo emerging from this union ends up with a solitary nucleus containing matching sets of gene-laden chromosomes—one set of approximately 100,000 genes (spread along about three billion base pairs) from the mother and an equivalent set from the father. This cell and its descendants replicate repeatedly to form the fully developed child. Before the cells divide, they duplicate their chromosomes, so that they can bequeath a complete complement of maternal and

Why Mitochondrial DNA Is Needed

Mitochondria produce energy by relaying electrons from food (*orange arrows in left diagram*) down the respiratory chain—a series of protein complexes (I–IV) in the mitochondrial inner membrane. At complex IV, the electrons interact with oxygen and protons (H^+) to form water. Mitochondria use the energy released from the oxidation of hydrogen to pump protons (*gray arrows*) across the inner membrane. The resulting charge and chemical differential enables another complex, ATP synthase, to synthesize the energy-carrying molecule ATP (adenosine triphosphate). Thirteen proteins in the complexes are specified by genes in mitochondrial DNA; regions incorporating those proteins are colored brightly. The DNA, shown schematically at the right, also gives rise to 24 RNA molecules used to synthesize those proteins. Each building block (base pair) of mitochondrial DNA is numbered counterclockwise from the position labeled O_H. Some sites of disease-causing mutations are indicated; see the table on the opposite page for full names of acronyms. —*D.C.W.*



paternal chromosomes to each daughter cell. In this way, every cell of the body comes to carry identical genes—and identical mutations.

In contrast, the genes spread along the 16,569 base pairs in each circle of mitochondrial DNA are inherited solely from the mother, through the mitochondria in her egg; sperm make no lasting contribution. Further, each egg and all other cells of the body carry not one but hundreds of mitochondria, and every mitochondrion can contain several mitochondrial DNA molecules. Although a cell will approximately double its number of mitochondria and mitochondrial DNA molecules before dividing and will provide roughly equal amounts to its daughter cells, the original cell does not regulate which specific mitochondria go to each daughter.

Consequently, if a fertilized egg carries a mutation in some fraction of its mitochondrial DNA (a condition known as heteroplasmy), one daughter cell may inherit a larger proportion of mitochondria bearing mutant DNAs, and the other cell may inherit a larger percentage of mitochondria bearing normal DNAs. The laws of probability dictate that as the cells continue to reproduce, the mitochondrial DNA populations in the emerging daughter cells will move toward uniformity (homoplasmy), tending to consist of predominantly normal or predominantly mutant molecules.

A child born from a heteroplasmic egg can therefore have some tissues enriched for normal mitochondrial DNAs and others enriched for mutant DNAs. Moreover, the eggs of a woman with heteroplasmic cells can differ in their percentages of mutant mitochondrial DNA; her children can therefore differ markedly in the extent and distribution of mutant molecules in their tissues and in the severity, and even in the kind, of symptoms they display. Individuals who become ill from a homoplasmic mutation, however, will all display similar symptoms.

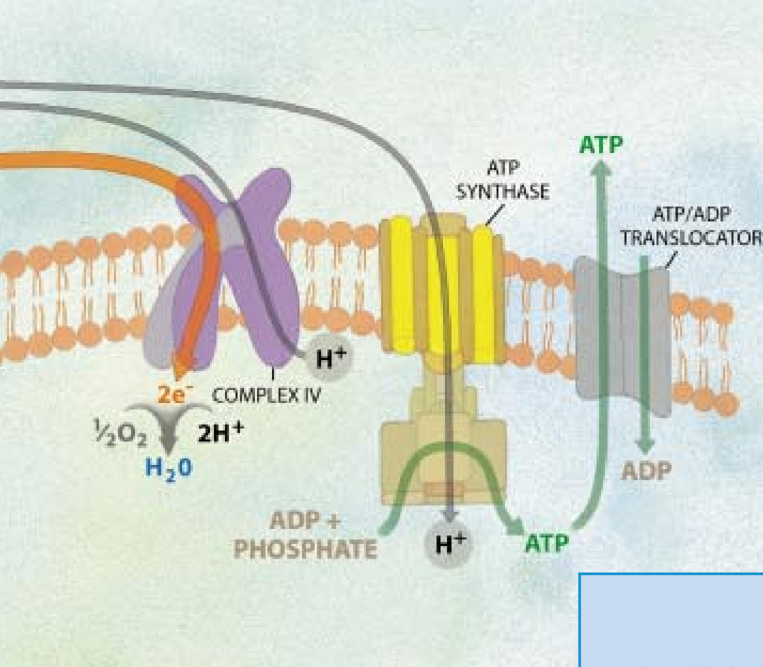
Striking Features of the Diseases

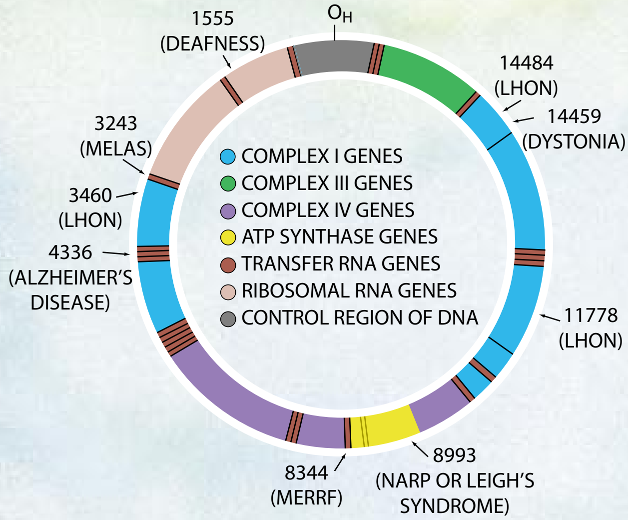
Disease-causing mitochondrial DNA defects are frequently inherited, but they do occasionally arise spontaneously in an egg or early in embryonic development. The latter mutations, like inherited ones, can become widely distributed in the body as the fetus develops, in which case they may produce rather profound effects. Mitochondrial DNA mutations can also form in tissues throughout life, with different mutations potentially occurring in different cells and even in different mitochondrial DNA molecules in a single cell; these changes are called somatic mutations.

The accumulation of somatic mutations might help explain two features frequently observed in inherited mitochondrial DNA diseases. People born with mitochondrial DNA mutations often become ill only after a delay of years or sometimes decades, and their conditions usually worsen over time. My colleagues and I have proposed that many inherited mitochondrial DNA mutations affect mitochondrial function only subtly, allowing tissues throughout the body to produce the energy they need, at least for a time. But the added buildup of random, somatic mutations in the course of a lifetime further depresses energy production, until eventually a given tissue's energy level falls too low to allow normal operations to continue. Then the tissue begins to perform improperly, and symptoms emerge. As somatic mutations accumulate further, energy output continues to decline, and symptoms progress.

Actually, inborn and somatic mutations appear to contribute to disease in ways that go beyond reducing energy production directly. As the respiratory chain participates in energy production, toxic by-products known as oxygen free radicals are given off. These oxygen derivatives, which carry an unpaired electron and so are highly reactive, can attack all components of cells, including respiratory chain proteins and mitochondrial DNA. Anything that impedes the flow of electrons through the respiratory chain can increase their transfer to oxygen molecules and promote the generation of free radicals. A single mutation, then, can presumably initiate a recurring cycle of inhibited electron transport, leading to increased free-radical production and more mitochondrial DNA mutations.

As a rule, a severe mitochondrial DNA mutation—one that suppresses energy production so much that it causes life-threatening disease early on—will turn out to be heteroplasmic; that is, the mutant gene will be found to coexist in the





ROB WOOD *Wood Ronsaville Harlin, Inc. (left)*; JENNIFER C. CHRISTIANSEN *(right)*

patient's tissues with the normal version of the gene. The reason for this pattern is that severe homoplasmic mutations (which reside in every copy of a given gene in every tissue) would reduce energy production so profoundly that they would become lethal before birth; they are therefore never seen in patients. In contrast, when a severe mutation is heteroplasmic, the normal copies of the affected gene may provide enough energy to allow a person to survive into childhood or later. Milder diseases can stem from either a heteroplasmic or a homoplasmic mutation that leads to only a weak decline in energy production.

Small Mutations, Powerful Effects

In the text that follows, I will first describe examples of disorders stemming from inherited (or embryonic) mutations in mitochondrial DNA. Few of these ills are household names, but their study has provided important insights into how mitochondrial DNA mutations cause disease. I will then summarize current thinking on the tantalizing possibility that inherited and somatic mitochondrial DNA mutations have a significant role in the aging process and in common late-life diseases.

Various inherited mutations substitute a solitary base pair for another in a protein-coding gene, thereby causing an incorrect amino acid to replace a correct one in the encoded protein. One such "missense" mutation offers a striking illustration of the principle that a heteroplasmic mitochondrial DNA muta-

Mitochondrial DNA Diseases

This table lists only some of the disorders that can be caused by mutations in mitochondrial DNA. Certain of these conditions can also be caused by nuclear mutations or other processes that hinder mitochondrial function.

DISORDER	FEATURES
Alzheimer's disease	Progressive loss of cognitive capacity
CPEO (chronic progressive external ophthalmoplegia)	Paralysis of eye muscles and mitochondrial myopathy [see below]
Diabetes mellitus	High blood glucose levels, leading to various complications
Dystonia	Abnormal movements involving muscular rigidity; frequently accompanied by degeneration of the basal ganglia of the brain
KSS (Kearns-Sayre syndrome)	CPEO combined with such disorders as retinal deterioration, heart disease, hearing loss, diabetes and kidney failure
Leigh's syndrome	Progressive loss of motor and verbal skills and degeneration of the basal ganglia; a potentially lethal childhood disease
LHON (Leber's hereditary optic neuropathy)	Permanent or temporary blindness stemming from damage to the optic nerve
MELAS (mitochondrial encephalomyopathy, lactic acidosis and strokelike episodes)	Dysfunction of brain tissue (often causing seizures, transient regional paralysis and dementia) combined with mitochondrial myopathy [see below] and a toxic buildup of acid in the blood
MERRF (myoclonic epilepsy and ragged red fibers)	Seizures combined with mitochondrial myopathy [see below]; may involve hearing loss and dementia
Mitochondrial myopathy	Deterioration of muscle, manifested by weakness and intolerance for exercise; muscle often displays ragged red fibers, which are filled with abnormal mitochondria that turn red when exposed to a particular stain
NARP (neurogenic muscle weakness, ataxia and retinitis pigmentosa)	Loss of muscle strength and coordination, accompanied by regional brain degeneration and deterioration of the retina
Pearson's syndrome	Childhood bone marrow dysfunction (leading to loss of blood cells) and pancreatic failure; those who survive often progress to KSS

tion can often express itself in disparate ways in different people. This mutation—the substitution of a base at position 8993—leads to an amino acid substitution in a subunit of ATP synthase (the complex that makes ATP).

For a family in which four generations were available for study, the same mutation caused several individuals to suffer mild retinal degeneration in the periphery of their visual field (retinitis pigmentosa), another person to undergo severe retinal and central nervous system degeneration, and two ill-fated boys to acquire a potentially lethal childhood disease known as Leigh's syndrome. This devastating illness is marked by relatively rapid degeneration of the basal ganglia, a brain region important to coordination of movement. Evidently the differences in symptomatology within this family stemmed to a great extent from differences in the percentages of mutant mitochondrial DNA molecules in the patients' tissues. Those with higher percentages had lower ATP production and more extensive disease.

Certain inherited base substitutions need to reach homoplasmy before they cause problems; these mutations yield more predictable effects. The genetic defects now known to underlie most cases of Leber's hereditary optic neuropathy, otherwise known as LHON, fall into this category. LHON first becomes apparent, usually in young adulthood, when the central region of the optic nerve stops functioning, leading to loss of vision in the center of the visual field. Three mitochondrial DNA mutations, all of which affect electron transport early in the respiratory chain, account collectively for about 90 percent of cases worldwide. Patients with either of two mutations generally suffer permanent vision loss; those with the third mutation occasionally recover some vision.

A number of pathological base substitution mutations in mitochondrial DNA disrupt RNA molecules that are part of the machinery mitochondria use to construct proteins; these mutations can thus interfere with the synthesis of many different mitochondrial proteins simultaneously and may depress ATP production substantially. For this reason, patients born with such so-called protein synthesis mutations can end up with serious multisystem diseases, often including both central nervous system and muscle abnormalities.

The case I mentioned at the beginning of this article—of the youth who died at age 28 from kidney failure and infection—reflects the potential lethality of protein synthesis mutations. He was felled by a point mutation in which one base in a gene for a transfer RNA molecule was deleted. This RNA molecule normally brings the amino acid leucine to proteins being synthesized in mitochondria. The mutation probably arose in the mother's germ-line cells, because nonreproductive cells (blood cells) of the mother were tested and found to contain only normal mitochondrial DNA.

Ten other mutations in the same gene have been shown to cause a range of serious disorders. For instance, three of the mutations result in mitochondrial myopathy, a form of progressive muscle weakness characterized by the presence of ragged red fibers—degenerating muscle fibers filled with abnormally shaped, defective mitochondria that turn red when exposed to a specific stain. Two of the genetic defects cause abnormal enlargement and progressive deterioration of the heart muscle (hypertrophic cardiomyopathy). Five mutations affect multiple systems, causing a set of symptoms collectively referred to as MELAS (mitochondrial encephalomyopathy, lactic acidosis and strokelike episodes). One MELAS-inducing mutation also causes approximately 1.5 percent of all diabetes mellitus and can cause diabetes even when the mutation is present in low levels.

Although many inherited protein synthesis mutations in mitochondrial DNA can be fatal at a young age, some are more moderate, making themselves felt quite late in life. One example, a mutation in a gene coding for a transfer RNA molecule that transports the amino acid glutamine, is found in about 5 percent of Europeans with late-onset Alzheimer's disease.

Mitochondrial DNA mutations that affect many genes at once—by deleting or duplicating large chunks of genetic

Mitochondrial DNA as a Forensics Tool

On September 3, 1996, in Chattanooga, Tenn., a 27-year-old man was found guilty of murdering a four-year-old girl. He was convicted largely on the strength of an analysis that matched mitochondrial DNA from his saliva to that from hair recovered on his victim. His case was the first in which mitochondrial DNA evidence was allowed into the courtroom.

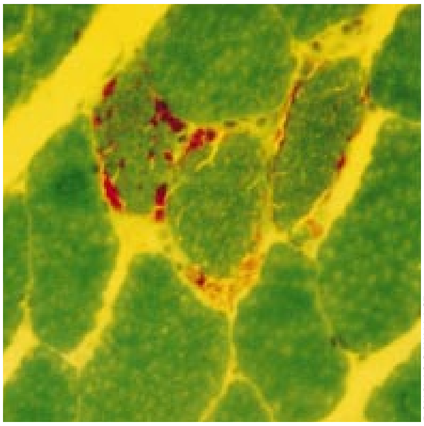
Mitochondrial DNA tests are also being used increasingly to link names to human remains. For example, the U.S. is sponsoring a program aimed at identifying skeletal fragments of soldiers who died in conflicts dating back to the Korean War in the early 1950s. And less mournful exercises have established that bones unearthed in Russia in 1991 belong to Czar Nicholas II and that the fellow buried as Jesse James in April 1882 was in fact the fabled bandit. (The various other men who had claimed to be James were thus frauds.)

Scientists perform the tests by comparing the sequences of base pairs in mitochondrial DNA molecules, especially in the control region, which contains no genes. Sequences in this region usually vary from one person to another at several positions. If the DNA from, say, a hair found on a murder or rape victim and DNA from an accused attacker show no differences, chances are good that the hair came from the accused. Similarly, if mitochondrial DNA from bones of a soldier lost in war closely match those of the siblings in a family, investigators can conclude that the remains are those of a member of the tested family.

Nuclear DNA comparisons are still preferred when enough of it can be obtained, because clear similarities and differences are easier to establish. Many times, however, the available tissue (such as a strand of hair, solid bone or teeth) lacks usable nuclear DNA but has abundant mitochondrial DNA. *—D.C.W.*

CORBIS-BETTMANN

Jesse James, 1864



DOUGLAS C. WALLACE

RAGGED RED FIBERS are a frequent hallmark of mitochondrial muscle diseases. They are readily identifiable by red staining of the abnormally large and misshapen mitochondria that accumulate in deteriorating muscle fibers.

material—have also been identified. Like base substitutions, these "rearrangement" mutations can cause diseases of varying seriousness.

Wholesale DNA Changes

Among the most studied disorders involving rearrangement mutations are two marked by paralysis of eye muscles and mitochondrial myopathy: chronic progressive external ophthalmoplegia (which generally strikes after age 20) and Kearns-Sayre syndrome (which may become manifest at even younger ages and can include retinal degeneration, heart disturbances, short stature and various other symptoms). Rearrangement mutations also underlie many cases of Pearson's syndrome, a condition in which children fail to make blood cells, become dependent on transfusions from an early age and have impaired pancreatic function. If the children survive, they ultimately suffer the eye paralysis and other problems associated with the Kearns-Sayre syndrome. Sadly, patients afflicted with any of these disorders become ever sicker over time and, in many instances, die of respiratory failure or other systemic dysfunctions.

The cells of a patient with one of these disorders can contain a mixture of mitochondrial DNA molecules, including some DNAs with deletions and some with duplications. But it is the deletions that probably explain why the diseases can be serious from the start. The lost DNA inevitably includes genes for transfer RNA molecules, which means, as will be recalled, that many different proteins needed for energy production are made improperly, if at all. The characteristic worsening of the diseases over time is thought to occur in part because certain tissues—namely, muscles and others composed of nondividing cells—selectively replicate the incomplete ("deleted") mitochondrial DNAs.

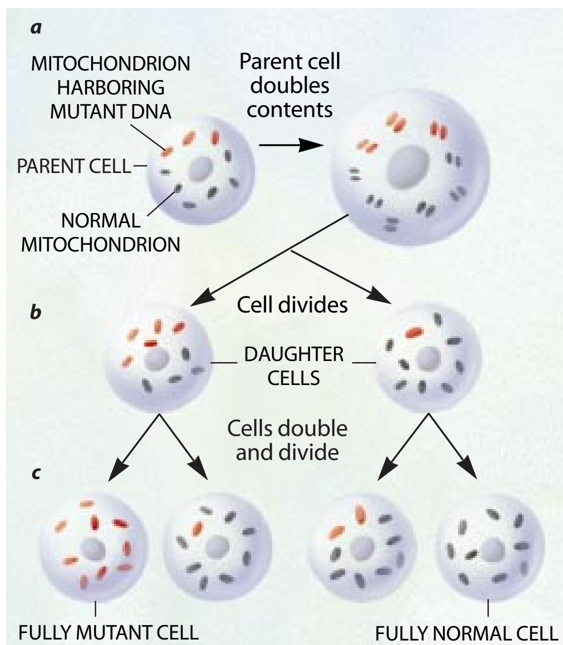
No one knows why deleted mitochondrial DNAs are selectively amplified in nondividing tissues, but two speculations have been put forward. The first is that molecules bearing deletions, being smaller than normal DNA circles, take less time to replicate and so become enriched. The second explanation relates to the internal organization of muscle fibers. Each fiber consists of many merged muscle cells and so contains multiple nuclei. Various findings imply that when a nucleus detects an energetic deficit in its vicinity (such as one caused by mutant mitochondrial genes), the nucleus attempts to compensate for the power shortage by triggering the replication of any mitochondria nearby. Unfortunately, this response promotes replication of the very mitochondria that are causing the local energy deficit, further aggravating the problem.

The origin of the deletions that cause mitochondrial diseases has puzzled scientists for some time. Even though these disorders can be passed from generation to generation, deleted mitochondrial DNAs themselves are rarely inherited, probably because a cell or embryo harboring mainly deleted mitochondrial DNAs would die. The solution seems to rest with mitochondrial DNA molecules containing gene duplications. These molecules contain all the genes needed for energy production, and so they may not cause problems directly. Because the molecules have internal duplications, however, they can undergo processes—possibly internal pairing and recombination—that ultimately result in disruptive deletions.

Sometimes inherited mitochondrial DNA defects yield premature versions of disorders that afflict many people in their later years, such as diabetes, deafness, heart disease, muscle weakness, movement problems and dementia. Moreover, certain mitochondrial DNA mutations have been proved to cause some fraction of cases of Alzheimer's disease, dystonia (a progressive movement disorder) and other neurodegenerative diseases. These patterns—combined with the fact that a number of late-life degenerative diseases have been associated with declines in the activity of protein complexes involved in energy production (just as many mitochondrial DNA diseases are)—suggest that progressive reductions in mitochondrial energy (ATP) production in nerve, muscle or other tissues could be an important contributor to aging and to various age-related degenerative diseases.

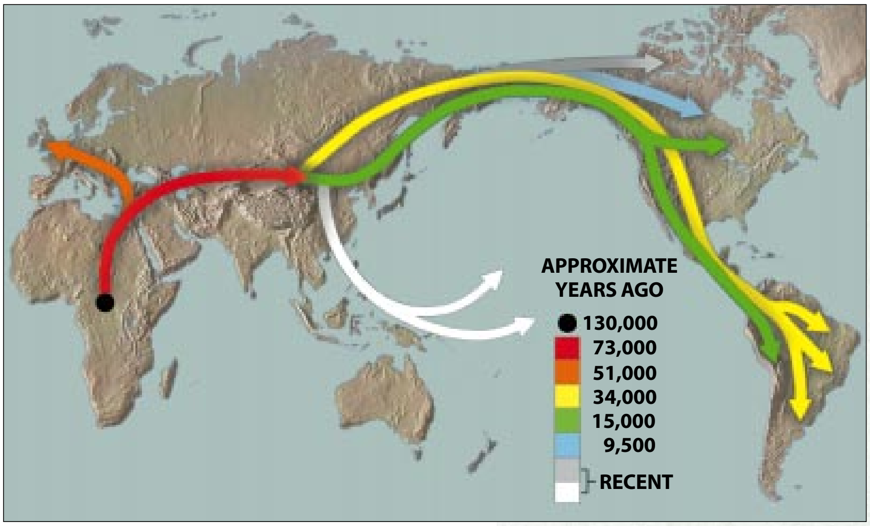
Aging and Age-Related Diseases

Several factors could cause mitochondrial energy production to decline with age even in people who start off with healthy mitochondrial and nuclear genes. Long-term exposure to certain environmental toxins is one. Many of the most potent toxins work their mis-



JENNIFER C. CHRISTIANSEN

CELL containing some mitochondria with mutant DNA and some with fully normal DNA (*a*) will often give rise to "daughter" cells that differ from the "parent" and from one another in the number of mitochondria having flawed DNA (*b*). As daughter cells reproduce, their mitochondrial DNA populations drift toward 100 percent mutant or normal (*c*). This drift toward uniformity occurs in cells during the development of an embryo. It also occurs in the eggs of successive generations of females, causing some children to end up with more mutant DNA, and worse symptoms, than their mother had.



JENNIFER C. CHRISTIANSEN

What Mitochondrial DNA Says about Human Migrations

Comparative analyses of mitochondrial DNA molecules obtained from people around the world have enabled geneticists to trace the major migrations of anatomically modern humans. These analyses, carried out by many laboratories, have also put rough dates on the ages of various continental populations, although different groups favor different dates, depending on their methods of calculation.

A scenario based on data from my laboratory suggests that *Homo sapiens* emerged in Africa approximately 130,000 years ago. The initial migration out of Africa took people to Asia (*red arrow on map*) by about 73,000 years ago. Roughly 51,000 years ago another cohort left the Middle East and colonized Europe (*orange arrow*).

Several migratory waves from Asia introduced early modern humans to the New World. About 34,000 years ago some wanderers traveled through Siberia and Alaska and then down through North America and Central America to South America (*yellow arrows*). These were the ancestors of such modern Paleo-Indians as the Pima of Arizona, the Maya of Mexico and the Yanomami of Venezuela. About 15,000 years ago a second wave of immigrants from Asia bypassed the interior of Siberia, possibly hugging the coast before reaching Alaska and dispersing through the Americas (*green arrows*). They mixed with the existing population to create today's Amerind-speaking Paleo-Indians.

About 9,500 years ago an exodus from Siberia brought the founders of the Na-déné, a linguistic group that encompasses northwestern Canadian and Alaskan Athabascan tribes

chief by inhibiting mitochondria. Another factor could be the lifelong accumulation of somatic mitochondrial DNA mutations.

The mitochondrial theory of aging holds that as we live and produce ATP, our mitochondria generate oxygen free radicals that inexorably attack our mitochondria and mutate our mitochondrial DNA. This random accumulation of somatic mitochondrial DNA mutations in people who began life with healthy mitochondrial genes would ultimately reduce energy output below needed levels in one or more tissues if the individuals lived long enough. In so doing, the somatic mutations and mitochondrial inhibition could contribute to common signs of normal aging, such as loss of memory, hearing, vision and stamina.

In people whose energy output was already compromised (whether by inherited mitochondrial or nuclear mutations or by toxins or other factors), the resulting somatic mitochondrial DNA injury would push energy output below desirable levels more quickly. These individuals would then display symptoms earlier and would progress to full-blown disease more rapidly than would people who initially had no deficits in their energy production capacity.

Is there any evidence that energy production declines and somatic mitochondrial DNA mutation increases as humans grow older? There is. Work by many groups has shown that the activity of at least one respiratory chain complex, and possibly another, falls with age in the brain, skeletal muscle, heart and liver. Further, various rearrangement mutations in mitochondrial DNA have been found to increase with age in many tissues—especially in the brain (most notably in regions controlling memory and motion). Rearrangement mutations have also been shown to accumulate with age in the mitochondrial DNA of skeletal muscle, heart muscle, skin and other tissues. Certain base-substitution mutations that have been implicated in inherited mitochondrial DNA diseases may accumulate as well.

All these reports agree that few mutations reach detectable levels before age 30 or 40, but they increase exponentially after that. Studies of aging muscle attribute some of this increase to selective amplification of mitochondrial DNAs from which pieces have been deleted.

Supportive Findings

Analyses of tissues from people afflicted late in life with chronic degenerative neurological and muscle diseases also lend support to the hypothesis that some of these conditions may involve the buildup of somatic mutations. For instance, patients with Huntington's disease lose motor control and become demented late in life as a result of having a specific inherited mutation in their nuclear DNA. But they also display higher levels of mitochondrial DNA deletions in their brains than do healthy individuals of equal age—a sign that the somatic mitochondrial mutation rate is elevated. The nuclear mutation and the somatic mitochondrial mutations may well combine to depress energy production in brain cells and to produce symptoms in adulthood.

As I noted earlier, a certain amount of Alzheimer's disease has also been attributed to inborn mitochondrial DNA mutations. But the failure of these mutations to produce immediate symptoms implies that they may not be sufficient in themselves to cause disease. Acquired mitochondrial mutations that add to the effects of the inherited mutations might again be a missing link. Indeed, brain tissue from Alzheimer's patients appears to have unusually high levels of somatic changes in its mitochondrial DNA.

A particularly intriguing possibility is that a significant fraction of type II (maturity-onset) diabetes mellitus, which afflicts millions of Americans older than 40 years, may be rooted in inherited mitochondria DNA defects still to be discovered. People with this kind of diabetes secrete insulin into the bloodstream, but not enough to meet their body's needs. Diabetes is known to run in families, and the mother is often the affected parent (as would be expected with mitochondrial DNA inheritance). Further, research has already established that known mitochondrial DNA rear-

(such as the Dogrib) and the southwestern U.S. Apache and Navajo (*blue arrow*). The migrations that brought Eskimos and Aleuts to North America (*gray arrow*) and island peoples to the Pacific (*white arrows*) were more recent but have not been accurately dated on the basis of mitochondrial DNA data.

The global migrations can be reconstructed through mitochondrial DNA analyses because as women migrated from continent to continent, their mitochondrial DNAs gradually accumulated one nonpathogenic mutation after another. Consequently, the sequences of base pairs in mitochondrial DNAs on one continent came to differ in distinctive ways from the sequences on other continents. By grouping related sequences on a continent into "haplogroups" and then comparing the haplogroups from the various continents, investigators can determine the relatedness of the females from different places. Scientists can also determine which lands were colonized first, because greater sequence variation in the mitochondrial DNAs on a continent is a sign of greater longevity. African populations are oldest because they harbor the greatest mitochondrial DNA variation. Asians, Europeans and the Native American populations display progressively less variation.

The actual time at which each continent came to be colonized can only be estimated, however, because the dates depend on the rate at which the mitochondrial DNA molecule accumulates mutations. This rate is relatively constant but is not known precisely. Mutations seem to occur about once in every 2,000 to 3,000 years. The dates presented here assume the mutation rate is roughly in the middle of that range.

Aside from revealing global migration patterns, analysis of mitochondrial DNA suggests that early *H. sapiens* replaced all the more primitive human species (such as Neanderthals) they encountered in their new homes. This conclusion, though, is disputed by a number of anthropologists. Those investigators hold that human predecessors of *H. sapiens* emerged in Africa more than a million years ago. They then fanned out through the Old World and evolved regionally into the major races of *H. sapiens* [see "Debate: Where Did Modern Humans Originate?"; SCIENTIFIC AMERICAN, April 1992]. *—D.C.W.*

rangement and base-substitution mutations can at times cause type II diabetes. It stands to reason that other mutations may have the same effect. One plausible diabetes-producing mechanism could be that, by reducing ATP synthesis, mitochondrial DNA mutations deprive insulin-producing cells of the energy they need to secrete insulin appropriately.

Another interesting proposal is that heart failure in patients with atherosclerosis is accelerated by the development of somatic mitochondrial DNA mutations. As arteries that are partially occluded by an atherosclerotic plaque constrict, they can close off temporarily, blocking blood flow to the heart and starving the heart muscle of oxygen—a state known as ischemia. Without oxygen, the respiratory chain stops working, only to emit a burst of oxygen free radicals when blood flow and oxygen return (reperfusion). Such bursts would be expected to damage mitochondrial DNA in the heart muscle and to limit ATP for contraction. In keeping with this scenario, patients whose hearts have become dilated from chronic ischemia and reperfusion show a high degree of mitochondrial DNA damage.

Studies of rodents bolster the suspicion that an accelerated buildup of mitochondrial DNA mutations can hasten aging. Animals raised on restricted diets remain healthy and survive longer than do their free-feeding counterparts [see "Caloric Restriction and Aging," by Richard Weindruch; SCIENTIFIC AMERICAN, January 1996]. The long-lived, diet-restricted animals, who produce fewer oxygen free radicals, accumulate less mitochondrial DNA damage than do their well-fed littermates.

What Is to Be Done?

If free-radical damage does indeed drive the accumulation of somatic mitochondrial DNA mutations and thus influences the speed of aging, then treatments that block mitochondrial production of such radicals and thereby protect mitochondrial DNA could potentially slow aging and delay the onset of age-related diseases. Such approaches could perhaps consist of lifelong treatment with antioxidants (for example, coenzyme Q or vitamins C or E). Animal studies are encouraging in this regard.

Another strategy for slowing aging would be to limit the amplification of mutated mitochondrial DNAs in muscle and other tissue. To that end, scientists are attempting to clarify the molecular interactions by which nuclei detect local energy deficits and stimulate the reproduction of aberrant mitochondria in their neighborhood.

Ten years ago few biologists would have imagined that mutations in mitochondrial DNA would be implicated in dozens of mysterious disorders as well as in aging and a variety of chronic degenerative diseases. Today study of this DNA is offering new clues to the development of many ailments and, even better, is suggesting approaches to treating them and preventing their progression. If speculations on the role of mitochondrial DNA mutations in aging and disease prove correct, further studies of mitochondrial biology should have great potential for lessening a good deal of human suffering. SA

The Author

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Further Reading

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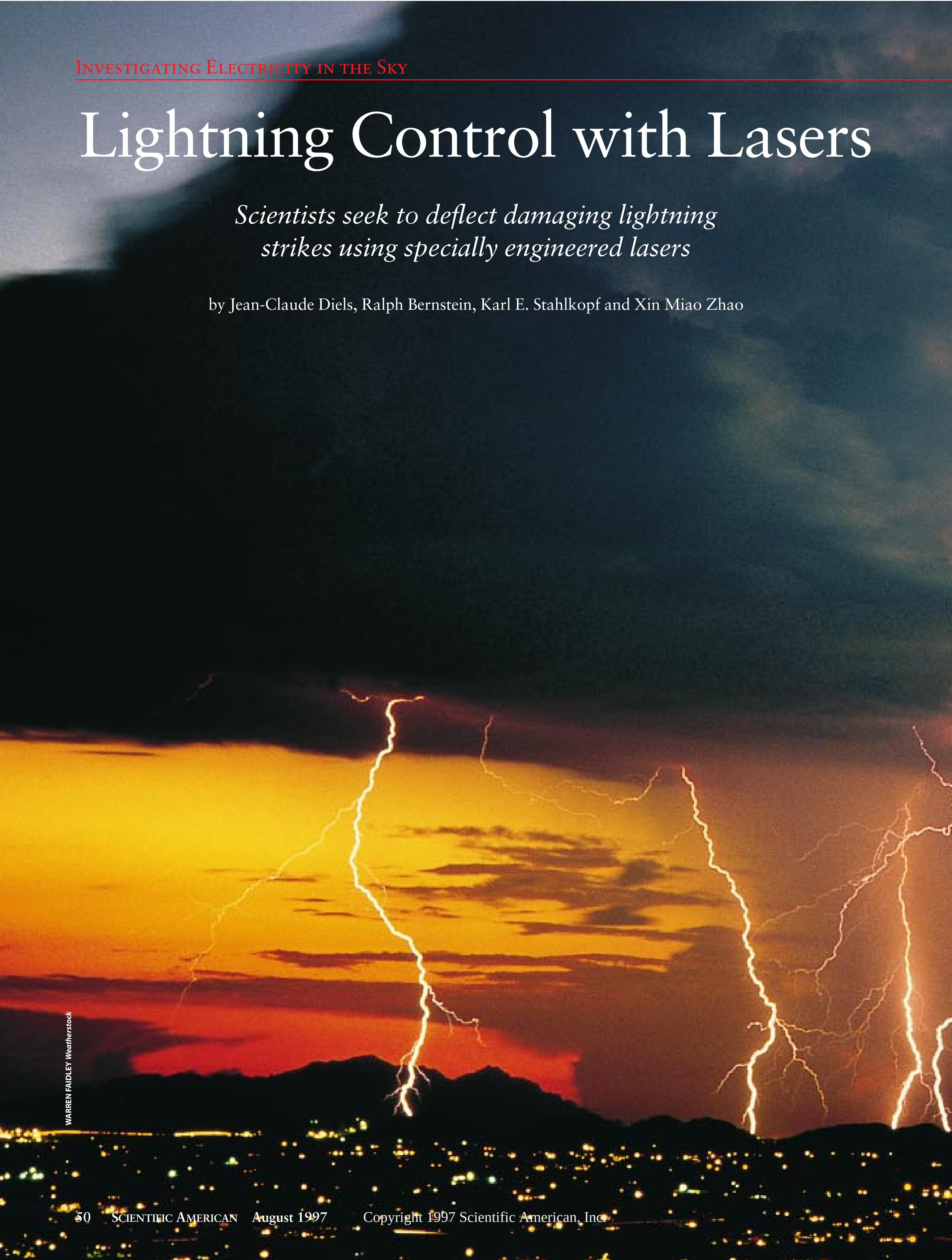
Lightning Control with Lasers

Scientists seek to deflect damaging lightning strikes using specially engineered lasers

by Jean-Claude Diels, Ralph Bernstein, Karl E. Stahlkopf and Xin Miao Zhao



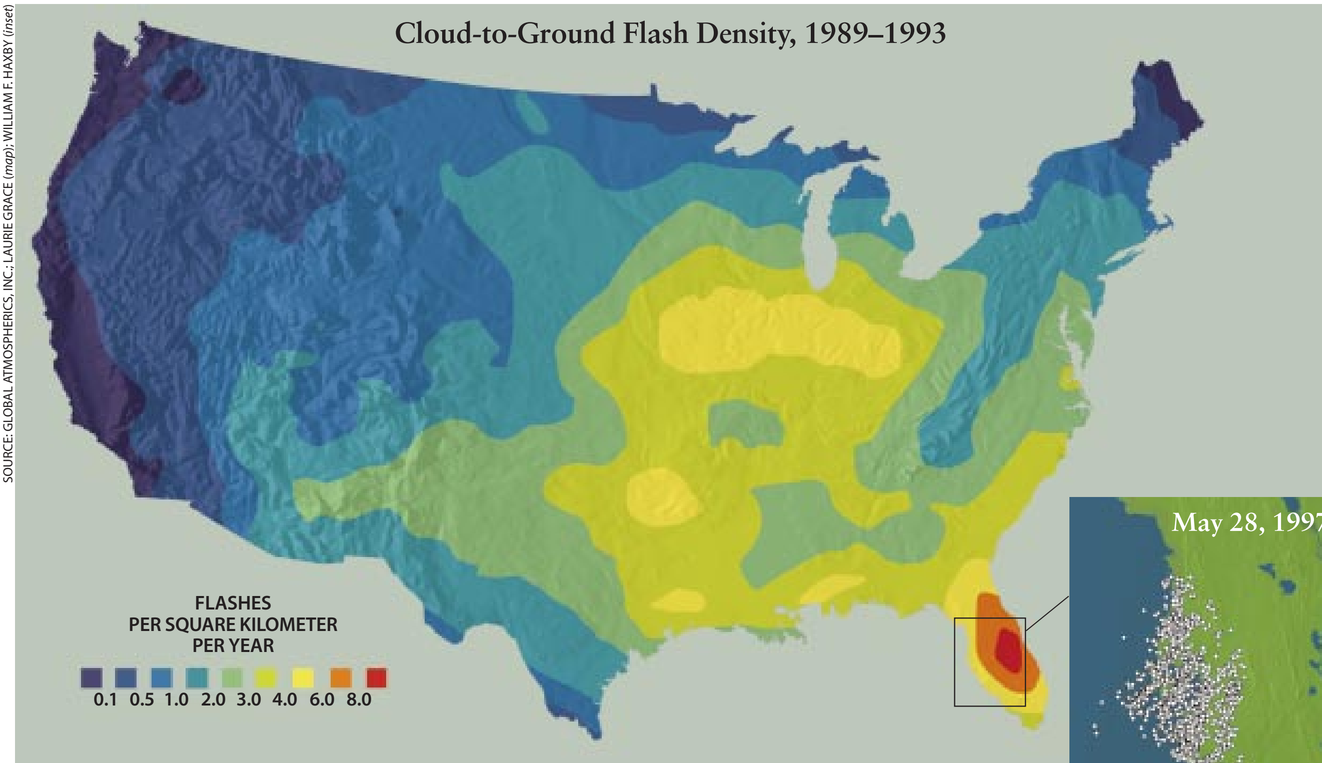
WARREN FAIDLEY *Weatherstock*

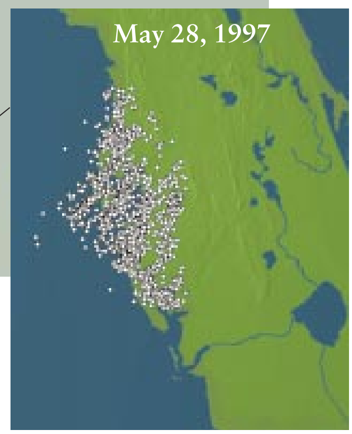
Despite centuries of scientific scrutiny—including Benjamin Franklin's famous experiment with a kite—lightning has remained a strangely mysterious phenomenon. Although scientists from Franklin's time onward have understood that electrical charges can slowly accumulate in clouds and then create brilliant flashes when the stored energy suddenly discharges, they puzzled for years over the exact physical mechanisms governing this process. How quickly do lightning strokes travel? What determines the path the energy takes? What happens to the bolt of electric current after it penetrates the ground? Such questions eventually yielded to scientific investigation. And this research has not only expanded the fundamental understanding of lightning, it has raised the prospect of exerting control over where lightning strikes—something traditionally considered a matter of divine whim.

Although lightning is inherently erratic, its aggregate effect is enormous. Every year in the U.S. (where about 20 million individual flashes hit the ground), lightning kills several hundred people and causes extensive property damage, including forest fires. Lightning is also responsible for about half the power failures in areas prone to thunderstorms, costing electric utility companies in this country perhaps as much as $1 billion

LIGHTNING BOLTS can leap between clouds and the ground when the air, which is normally an electrical insulator, breaks down and becomes conductive. This time exposure shows multiple flashes over Tucson, Ariz.

SOURCE: GLOBAL ATMOSPHERICS, INC.; LAURIE GRACE (*map*); WILLIAM F. HAXBY (*inset*)





NATIONAL LIGHTNING DETECTION NETWORK, which is now run by Global Atmospherics in Tucson, Ariz., monitors lightning activity across the U.S., where the density of lightning flashes varies enormously. By tracking the timing and direction of electromagnetic pulses given off by lightning, this network of sensors can pinpoint the location of individual flashes and estimate their magnitudes. The inset shows the many flashes that struck western Florida during a spring thunderstorm.

annually in damaged equipment and lost revenue. Lightning can also disrupt the navigational devices on commercial airliners (or even on rockets bound for space), and it has caused one serious malfunction at a nuclear power plant.

So it is no wonder that people have sought ways to prevent lightning from doing harm. Unlike the ancients who tried to protect themselves by offering sacrifices to the gods, scientists and engineers have come up with solutions that have proved moderately successful. People can often avoid the worst effects of lightning by mounting well-grounded lightning rods on buildings, as first suggested by Franklin soon after he reeled in his experimental kite in 1752. Although he initially believed that such pointed rods worked because “the electrical fire would...be drawn out of the cloud silently, before it could come near enough to strike,” Franklin later realized that these devices either channel the discharge or work to direct lightning away. This same principle—to divert rather than to prevent a strike—provides the basis for currently used methods of protection (such as lightning arrestors or grounded shielding) as well as our own efforts toward controlling lightning with lasers.

Locating the Problem

Beginning in the late 1970s, researchers at the State University of New York at Albany established a small network of direction-finding antennas that served to track cloud-to-ground lightning strikes over a limited area of their state. Throughout the 1980s, that network of specialized detectors slowly expanded to include other states, and by 1991 (the year commercial operations started), this group of specialized antennas could sense the occurrence of lightning anywhere in the country.

That vast array, now known as the National Lightning Detection Network, consists of about 100 stations that monitor lightning by sensing the exact timing and direction of the bursts of electromagnetic energy given off by these discharges. The stations relay their many measurements through communications satellites to a control center in Tucson, Ariz., where a computer processes this information and continually disseminates reports about lightning activity. Hundreds of subscribers benefit from this service, including various electric utility companies, airlines and even the U.S. Strategic Air Command. The managers of some electric utilities, for example, have been able to save more than half a million dollars annually by using this information to dispatch repair crews swiftly to sites where lightning might soon strike or where it has already damaged the lines. But the people who oversee particularly sensitive installations—including nuclear power plants and electric power substations—await even more sophisticated methods to make lightning less of a threat.

Efforts to satisfy that need include research being conducted at a unique field laboratory near Starke, Fla. In 1993 two of us (Bernstein and Stahlkopf), along with other members of the Electric Power Research Institute in Palo Alto, Calif., arranged for Power Technologies in Schenectady, N.Y., to build a special facility at the Camp Blanding Florida National Guard station to test the susceptibility of various underground and overhead structures to damage from lightning. Rather than waiting for a chance strike, researchers working at this field site (which is now operated by the University of Florida) can trigger lightning using small rockets that trail a thin, grounded wire.

Unlike such triggered discharges, a natural lightning bolt begins with a barely visible precursor, called the leader phase, which propagates downward from the cloud toward the ground in stepwise fashion, knocking electrons loose from molecules of atmospheric gas along the way and creating a channel of ionized air that then serves as a conductive conduit. Immediately after the leader phase connects with the ground, the bright and energetic "return phase" erupts. As happens during the leader phase, the return stroke, which carries currents that range from a few thousand amperes up to about 300,000 amperes (household wiring typically carries no more than a few tens of amperes), is driven by the tremendous voltage potential—hundreds of millions of volts—between the ground and the thunderclouds overhead. This dazzling bolt travels at speeds that can approach half the speed of light, and the huge electric current it carries with it can easily destroy an object caught in its path.

Averting Catastrophe

Just as rockets trailing grounded wires represent a modern version of Franklin's kite experiment, we believe that in the near future laser beams may serve as high-tech lightning rods, offering a way to divert lightning from especially critical sites where it might do great harm. Decades ago some forward-thinking people envisioned using lasers to trigger lightning by creating an electrically conductive channel of ionized air. But their attempts—including some that employed the most intense lasers available—were unsuccessful. Those lasers ionized the air so thoroughly as to make it essentially opaque to the beam, which then could not penetrate any farther.

TOM WOHLMUT *Electric Power Research Institute*

FULGURITES result when lightning penetrates the ground and fuses the sandy soil in its path. This example shows how lightning has reached an underground utility cable (which, prior to this strike, was thought to have been safely buried one meter underground).

Two teams of Japanese scientists have recently endeavored to overcome this difficulty by using powerful infrared lasers. Rather than trying to create a continuous channel of ionized particles, these scientists have worked out a way to focus one or more laser beams at successively displaced points so as to create a dotted line of separate plasma bubbles along the intended path of the lightning bolt. They have achieved a controlled discharge more than seven meters long in laboratory tests. Still, they were able to achieve that feat only with extreme electrical fields, when the air was already close to the point of breaking down spontaneously.

Two of us (Diels and Zhao) have explored another approach that uses ultraviolet light from a relatively low energy laser. At first glance, this technique does not seem at all promising. Such beams do not ionize the air molecules in their paths particularly effectively, and the few negatively charged electrons that are shaken loose by the ultraviolet light quickly combine with neutral oxygen molecules nearby, forming negative oxygen ions (which reduce the conductivity of the channel). Nevertheless, this method can produce uniform ionization along an extended straight path. That ionized line then acts much as a lightning rod, concentrating the electrical field so intensely at its tip that the air ahead breaks down and adds more length to the conductive path.

We have also found that directing a

TOM WOHLMUT *Electric Power Research Institute (left)*; COURTESY OF RALPH BERNSTEIN *(center and right)*

ROCKETS trigger lightning in various field experiments. The small, specially constructed missile (*left*) carries at its base a spool of thin, grounded wire that unwinds in flight (*center*). The first stroke triggered in this way follows this copper filament and creates a conductive channel of ionized air; later strokes of the same flash event (which can occur repeatedly within a fraction of a second) travel along increasingly tortuous routes as the wind deforms the conductive path (*right*).

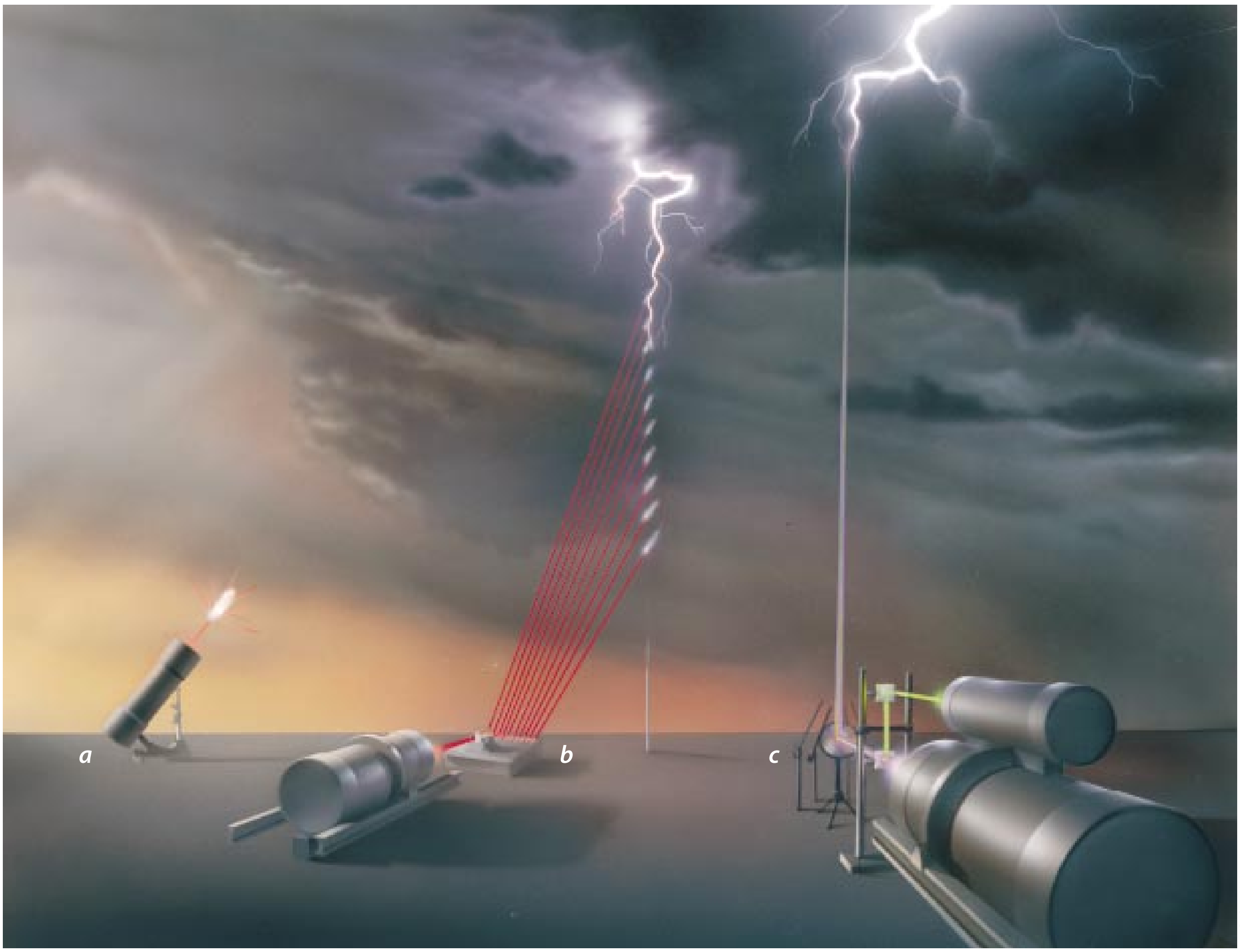
second visible-light laser along the path of the ultraviolet beam counteracts the tendency for free electrons to attach to neutral oxygen molecules, forming negative oxygen ions. This tactic works because photons of the visible-light beam carry sufficient energy to knock electrons free from the negative ions.

Although the ultraviolet laser we have tested operates at low power levels overall, it ionizes air surprisingly well. The key is to use extremely short laser pulses. The brief duration of these bursts (less than a trillionth of a second) makes it possible for the laser light to have high peak intensity, although the average power consumed by the apparatus is quite modest. What is more, we can take advantage of the physics of laser propagation in air and impart a particular shape to the pulses emitted by the laser. The pulses will then tend to compress as they propagate through the atmosphere. The higher energies jammed into these compact packages of light compensate for energy lost along the way from scattering or absorption.

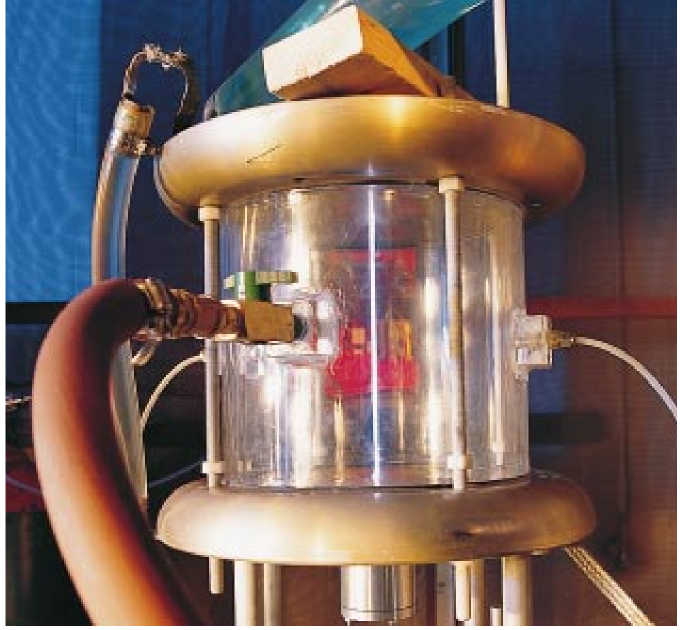
Although we have not yet tried to trigger lightning in this way, the agreement of our theoretical calculations, numerical simulations and small-scale laboratory experiments makes us confident that we are well on the way. We have, for example, succeeded in using short pulses of ultraviolet laser light to create a conductive channel between two highly charged electrodes spaced 25 centimeters apart. The lasers are able to trigger an electrical discharge when the voltage difference between the electrodes is less than half of what is normally required for the air to break down. That is, we can force laboratory-scale lightning to form along a prescribed channel well in advance of the point that a discharge would spontaneously occur.

Moving Outdoors

With the help of Patrick Rambo, our colleague at the University of New Mexico, we have recently built an ultraviolet laser that is 100 times more powerful than any we have previously tested. We plan to fire this laser 10 times each second during a thunderstorm. Although we are anxious to see just how effective such a laser can be, we have not yet arranged the proper preliminary



LASER DIVERSION of lightning might take various forms. Engineers initially imagined that powerful infrared lasers could produce a conductive path in the sky, but these beams completely ionize the air in front of them, which then becomes opaque and scatters the light (*a*). Researchers in Japan are experimenting with multiple beams that are focused using a series of mirrors to form a line of ionized pockets that should help channel a lightning bolt (*b*). The authors' method relies on paired ultraviolet and visible-light laser beams (aimed upward with a single mirror), which should be able to form a straight path of ionization for lightning to follow (*c*). Grounded rods would interrupt the resulting lightning strike, protecting the mirror and the laser apparatus. Alternatively, the beam could be arranged to graze a tall grounded mast as it shoots skyward.



COURTESY OF STAN GRZYBOWSKI *Mississippi State University High Voltage Laboratory (left image)*; ERIC O'CONNELL *(right images)*

ELECTRICAL DISCHARGE (*above, right*) occurs immediately after paired laser beams ionize the air over the short distance between the two electrodes. Extending these experimental discharges has been difficult, because the authors' laser apparatus (*right*) is too bulky to move to special high-voltage test facilities, which are located at Mississippi State University (*above*). But a new, mobile laser should soon allow them to trigger longer artificial bolts.

tests, which require a special high-voltage facility, such as the one operated by Mississippi State University.

Unfortunately, our laser is too delicate and cumbersome to move across the country. But we hope soon to complete a mobile ultraviolet laser, which (when coupled to a suitable visible-light laser) should be able to trigger laboratory discharges many meters long. Perhaps the same laser pair will finally provide the means to set off lightning from clouds—an accomplishment that has so far eluded our various competitors working with other types of lasers.

If any of these approaches to sparking lightning with laser beams ultimately succeeds, application of the technique could be commonplace. Lasers might one day scan the skies over nuclear power plants, airports and space launch centers. And electric utilities of the 21st century, with their growing network of equipment at risk, may finally acquire the means to act on the threat of a gathering storm, instead of being destined to react only after the damage is done. SA

The Authors

JEAN-CLAUDE DIELS, RALPH BERNSTEIN, KARL E. STAHLKOPF and XIN MIAO ZHAO became involved in lightning diversion for somewhat different reasons. Diels, a professor in the department of physics and astronomy at the University of New Mexico, and Zhao, a researcher at Los Alamos National Laboratory, began working together in 1990 with "ultrafast" pulsed lasers and quickly saw the possibility of using such devices to control lightning. After two years of further research, they received a patent for their invention. Bernstein, a project manager at the Electric Power Research Institute, and Stahlkopf, a vice president working with him, both trained as electrical engineers; they earned, respectively, a master's degree from Syracuse University and a doctorate from the University of California, Berkeley. Their wish to speed the development of technologies to lessen the damage from lightning motivated them to provide funding for lightning detection, rocket-triggered lightning experiments and, most recently, lightning control with lasers.

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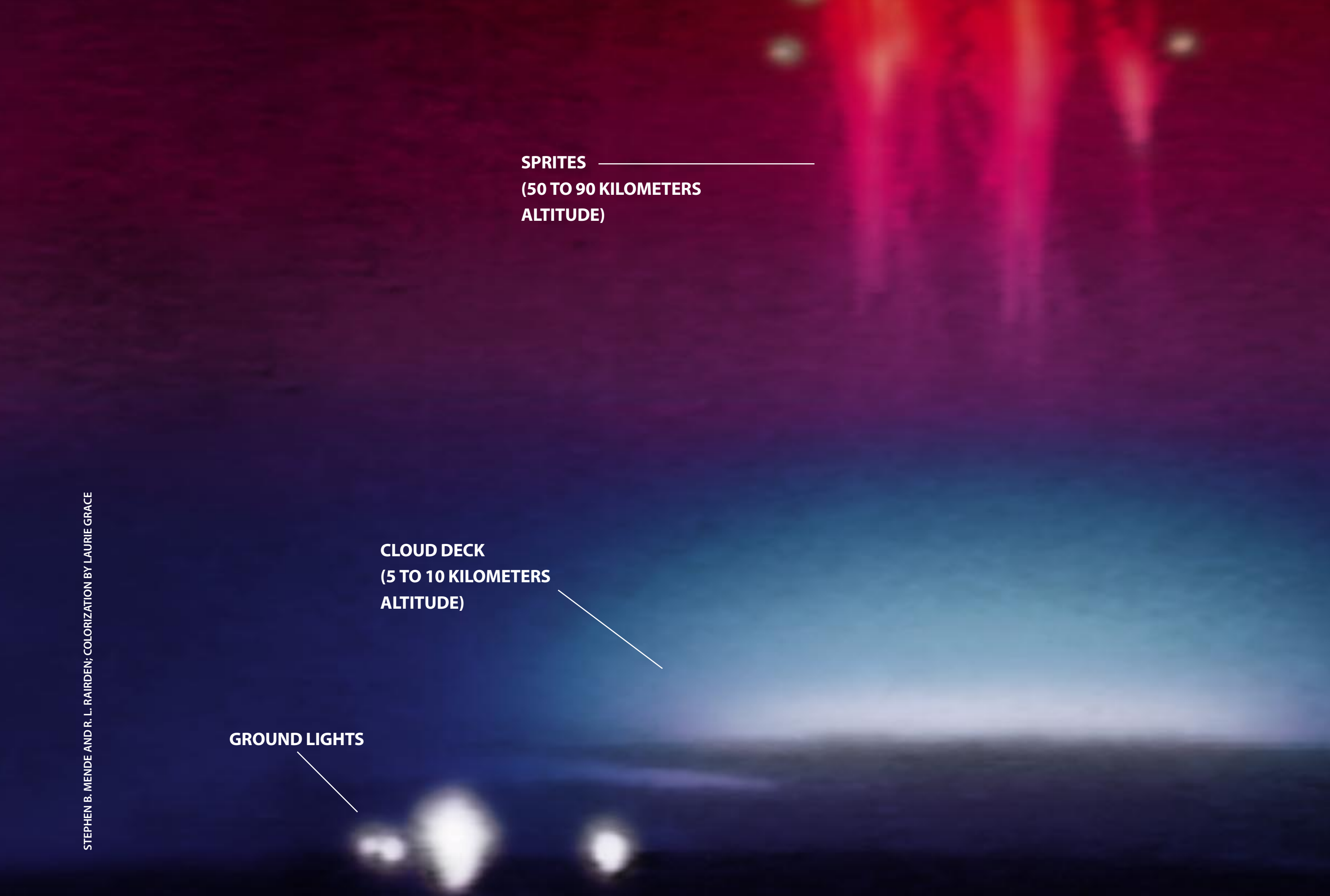
Lightning between Earth and Space

Scientists discover a curious variety of electrical activity going on above thunderstorms

by Stephen B. Mende, Davis D. Sentman and Eugene M. Wescott



STEPHEN B. MENDE AND R. L. RAIRDEN; COLORIZATION BY LAURIE GRACE

SPRITES are high-altitude luminous flashes that take place above thunderstorms in a part of the atmosphere called the mesosphere. Although sprites are usually rare, some storms can spawn them frequently. Typically the upper parts of clouds are charged positively and the lower parts negatively. Most often, it is the negative base of the cloud that flashes to the ground. But at times the upper, positive part can discharge directly to the earth, producing a lightning flash of exceptional intensity. About one out of 20 such positive cloud-to-ground lightning bolts are sufficiently energetic that they spawn sprites. These examples, recorded from the ground with a monochromatic video camera, have been colorized to match a color image obtained from an aircraft.

Since ancient times, lightning has both awed and fascinated people with its splendor and might. The early Greeks, for instance, associated the lightning bolt with Zeus, their most powerful god. And even after a modern understanding of the electrical nature of lightning developed, certain mysteries persisted. Many observers described luminous displays flickering through the upper reaches of the night sky. Some of these curiosities could be explained as auroras or weirdly illuminated clouds, but others were more baffling. In particular, pilots flying through the darkness occasionally observed strange flashes above thunderstorms. But the scientific community largely regarded these reports as apocryphal—until 1990, when John R. Winckler and his colleagues at the University of Minnesota first captured one of these enigmatic phantoms using a video camera. Their images revealed lightning of a completely new configuration.

Winckler's achievement ushered in a flurry of activity to document such high-altitude electrical phenomena. And hundreds of similar observations—from the space shuttle, from aircraft and from the ground—have since followed. The result has been a growing appreciation that lightninglike effects are not at all restricted to the lower atmospheric layers sandwiched between storm clouds and the ground. Indeed, scientists now realize that electrical discharges take place regularly in the rarefied air up to 90 kilometers above thunderclouds.

It is remarkable that these events, many of which are visible to the naked eye, went undiscovered for so long. In retrospect, the existence of some form of lightning high in the atmosphere should not have come as a surprise to scientists. They have long known that well above the turbulent parts of the atmosphere, ultraviolet rays from the sun strike gas molecules and knock electrons loose from them. This process forms the ionosphere, an electrically conductive layer that encircles the earth. Large differences in voltage can exist between storm clouds and the ionosphere, just as they do between clouds and the ground. Impelled by such enormous voltages, lightning can invade either zone when the air—which is typically an electrical insulator—breaks down and provides a conductive path for electric currents to follow.

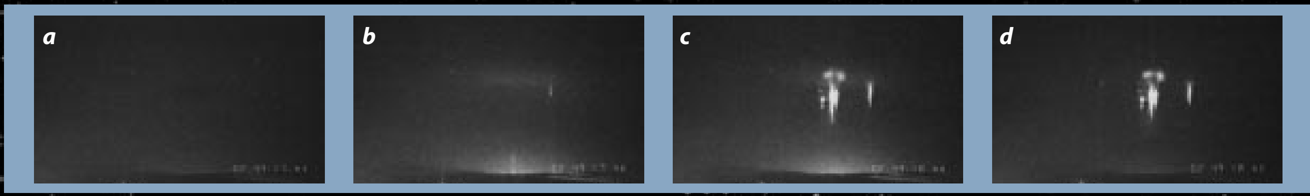
Because the atmosphere becomes less dense with increasing altitude, the lightning that happens at greater heights involves fewer air molecules and produces colors not seen in typical discharges. Usually they appear red and are only faintly visible. Thus, researchers must employ sensitive video cameras to record these events against the backdrop of the darkened night sky. The feebleness of the light given off and the transient nature of such emissions combine to present severe technical challenges to the researchers involved in studying these ghostly atmospheric events. Nevertheless, in just a few years investigators have made considerable progress in understanding them.

Two of us (Sentman and Wescott) have mounted airborne research campaigns using specially outfitted jets. All three of us (and many others) have also studied high-altitude electrical activity from the ground: for example, we gather every year at the invitation of Walter A. Lyons, a scientist at ASTeR in Fort Collins, Colo., and set up our equipment in his backyard laboratory—a site that offers an unobstructed view of the night sky over the thunderstorms of the Great Plains. (The images on pages 56 and 58 are views from this informal observatory.) Umran S. Inan and his colleagues at Stanford University have also recorded low-frequency radio waves from Lyons's home, measurements that have helped them to formulate theoretical models.

The newly discovered electrical events of the upper atmosphere fall into four categories. Two types of high-level lightning, termed sprites and elves, appear (despite their fanciful names) to be manifestations of well-understood atmospheric physics. The causes for the other two varieties, called blue jets and gamma-ray events, remain more speculative. But our research group and many others around the world are still amassing our observations in hopes of deciphering the physical mechanisms driving these strange occurrences as well. Until that time, we must admit something like the ancient sense of awe and wonder when we contemplate these curious bursts of energy that dance through the ethereal world between earth and space.

LIGHTNING (*left*) usually carries negative charge from the base of a cloud down to the earth. Sometimes powerful strokes (*center*) cause the positive charge that had built up near the top of the cloud to disappear abruptly. The large electrical field (*gradation in color*) created between the cloud top and the ionosphere pulls electrons upward, where they collide with gas molecules. If the electrical field is sufficiently strong and the air sufficiently thin, the electrons will accelerate unimpeded and reach the velocity needed to transfer their kinetic energy to the electronic structure of the molecules with which they collide, raising such molecules to an "excited state." The excited molecules give away their newly acquired energy by the emission of light, causing sprites (*right*). They typically span from 50 to 90 kilometers altitude.

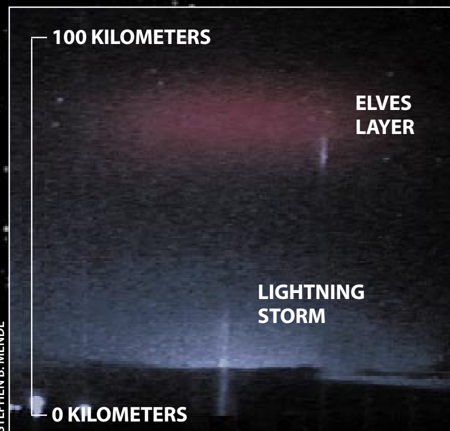
BRYAN CHRISTIE



STEPHEN B. MENDE

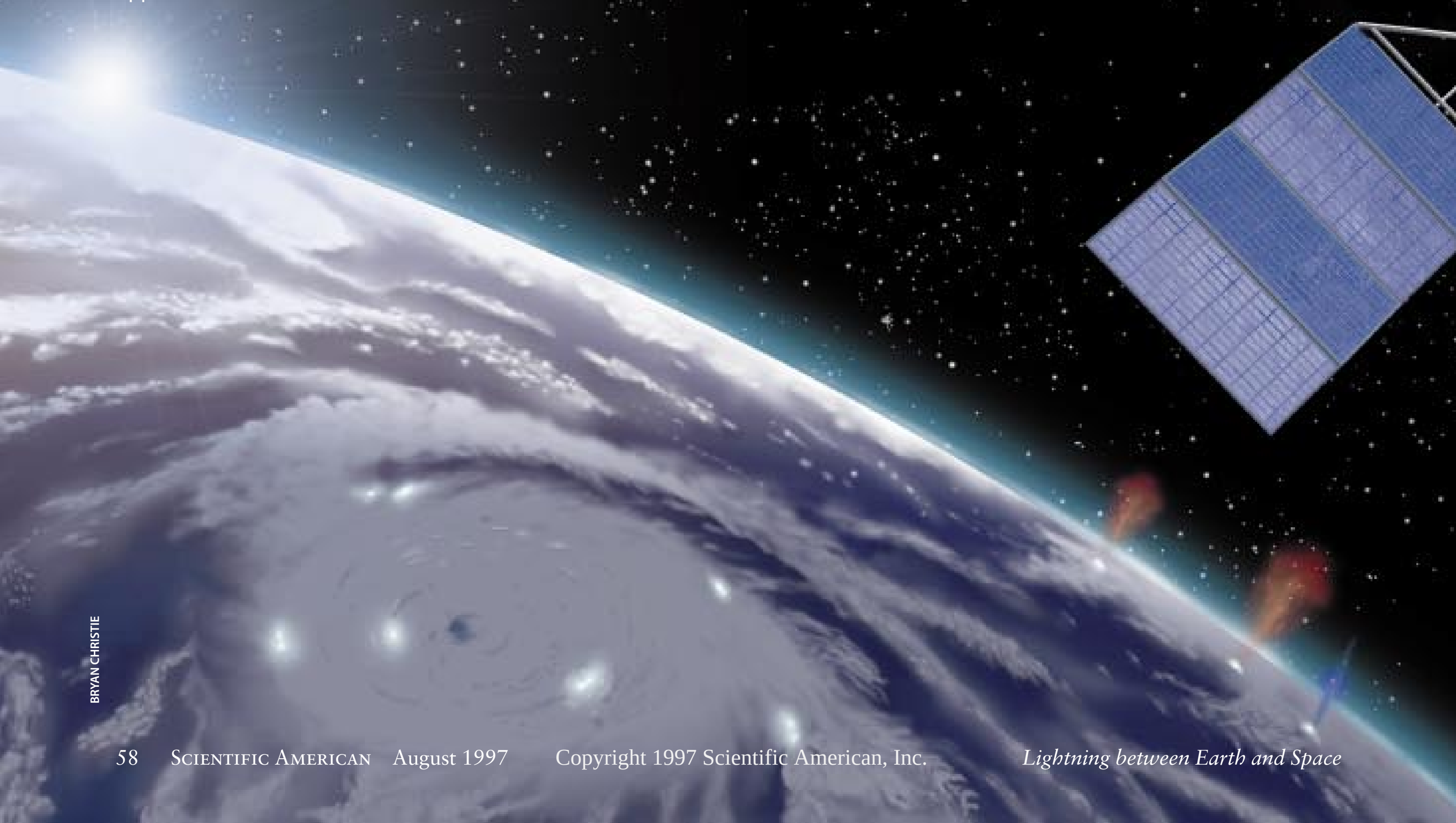
ELVES, like sprites, are high-altitude manifestations of the electrical fields created by exceptionally intense conventional lightning. They show themselves as glowing, pancake-shaped layers (*below, right, colorized to match the most probable true appearance*). Elves can occur with sprites but form first and do not last as long. The sequence of video images (*above*) shows the relative timing: just before the conventional lightning strike occurs, the sky is uniformly dark (*a*). The ensuing flash illuminates the cloud deck and immediately spawns the flattened glow of elves high in the mesosphere (*b*). Momentarily, sprites erupt throughout this part of the atmosphere, adding their radiance to the faint light from the luminous layer (*c*). Finally, only the sprites persist (*d*).

BRYAN CHRISTIE



STEPHEN B. MENDE

ELECTROMAGNETIC PULSES given off by strong lightning discharges create elves. Such a pulse, which is in essence an intense burst of radio static, propagates at the speed of light in all directions away from a lightning bolt. When the upward-going part of the pulse (*spherical shells*) reaches a critical height in the atmosphere (about 75 to 100 kilometers), the electrical field it carries accelerates electrons with great efficiency. These electrons strike air molecules, knocking them into an excited state that allows the release of light. This mechanism generates expanding rings of light along the intersection of the spherical pulse with the critical layer. This intersection widens so quickly (in fact, faster than the speed of light) that these expanding rings appear as flattened disks.



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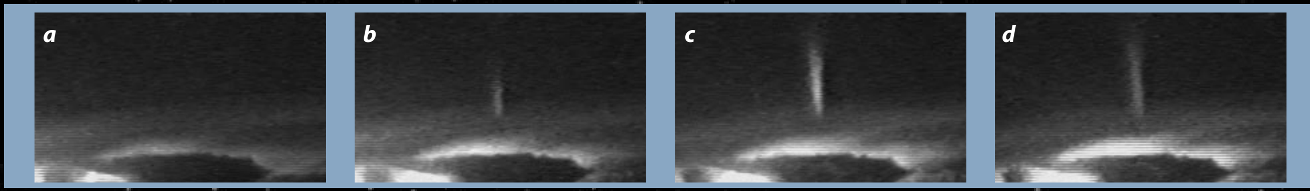

BLUE JETS, which are restricted to the part of the atmosphere below about 40 kilometers altitude, are comparatively difficult to observe. A color image (*right*) shows that the jets give off a deep-blue light, which does not penetrate the atmosphere readily—quite unlike the reddish hues that dominate sprites and elves. So observation requires going above the dense lower atmosphere. Sentman and Wescott recorded such eerie cones of blue light for the first time while flying over an intense storm in Arkansas in 1994. This sequence of video images from a sensitive monochromatic camera (*a–d*) reveals how these lights jet upward from the top of thunderclouds at speeds of about 120 kilometers per second. Researchers are still trying to reconcile competing theories to explain exactly how blue jets come about.

DANIEL L. OSBORNE *University of Alaska–Fairbanks*

GAMMA-RAY AND X-RAY events above thunderstorms are the most puzzling of all high-altitude electrical phenomena. Their existence was uncovered only recently by one of the instruments on the Compton Gamma Ray Observatory satellite (*left*), which showed gamma rays emanating from the direction of the earth. Gamma rays are usually taken as signatures of high-energy nuclear or cosmic sources and thus were not expected to be produced within the earth's atmosphere. In sprites, for example, electrons rarely reach energies above about 20 electron volts (the energy a single electron would gain when accelerated by a potential difference of 20 volts), whereas gamma rays require about one million electron volts. The discrepancy is the same as the difference between the energy of a chemical explosive and an atomic bomb. As is the case with blue jets, gamma-ray events are just now beginning to yield to scientific scrutiny. Future observations from satellites should help in this quest.

The Authors

STEPHEN B. MENDE, DAVIS D. SENTMAN and EUGENE M. WESCOTT have spent much of their time during recent years investigating curious electrical activity of the upper atmosphere. Mende received a Ph.D. in physics from Imperial College at the University of London in 1965. From 1967 to 1996 he worked for Lockheed Palo Alto Research Laboratory. Mende is currently a fellow at the space sciences laboratory of the University of California, Berkeley. Sentman studied space physics under James Van Allen at the University of Iowa, where he earned his doctorate in 1976. After 14 years at the University of California, Los Angeles, Sentman joined the physics department at the University of Alaska–Fairbanks, where he now serves on the faculty. Wescott received a Ph.D. in geophysics from the University of Alaska–Fairbanks in 1964. He worked for three years at the National Aeronautics and Space Administration Goddard Space Flight Center in Maryland before returning to the University of Alaska–Fairbanks as a professor of geophysics.

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Space Age Archaeology

Remote-sensing techniques are transforming archaeology. Excavations may become less essential as researchers explore hidden sites and examine buried artifacts without unearthing them

by Farouk El-Baz

The Empty Quarter of Arabia, or Ar Rub'al-Khali, is truly deserted. Covering some 777,000 square kilometers, this wasteland is infamous as a harsh environment, devoid of life. Lore has it, however, that the region hosted much kinder conditions in the recent past. Travelers are told of the lost city of Ubar, a legendary oasis along the frankincense trade route that the Koran describes as the "City of Pillars." T. E. Lawrence (perhaps better known as Lawrence of Arabia) himself hoped to find this "Atlantis of the Sands" but was unable to—and the search continues today.

The quest for Ubar recently made progress when images from a space shuttle and from Landsat satellites revealed an array of thin lines converging to a point nestled among the 200-meter-high dunes of this mysterious desert. Researchers looking at the pictures theorized that the hub of the ghostly spokes might be a cemetery or a city—and the hunt for Ubar was on again. Expeditions were mounted in 1990 and 1991, and excavations along a road are now unearthing the long-concealed structures of a walled city.

On the other side of the world, advanced technology has led scientists to the remains of a very different ancient era. This time the clue came from ground-penetrating radar—an instrument that emits radar waves into the earth and records the returned echoes. Different echoes reveal distinct layers of soil and rock or, in this case, fossilized remains of dinosaurs. Paleontologists have excavated the remains of one of these plant-eating, ground-shaking creatures—called seismosaurs—in the desert of New Mexico.

Whether deployed in space or on the earth's surface, remote-sensing instruments are becoming standard archaeological tools. Many archaeologists, trained to use a pick and shovel and to hold the artifacts they describe, are not yet comfortable with these techniques. Nevertheless, those who use remote-sensing instruments have begun to accumulate a wealth of new and unusual evidence. Perhaps as important, some have been able to gather priceless knowledge without disturbing fragile sites—a requirement that is increasingly expected in this era of conservation.

A Very Recent History

Although aerial photographs have been available since the early years of this century, remote sensing of the earth was truly born in December 1968, when Apollo astronauts telecast the first view of the planet from the vicinity of the moon. An astonished audience watched the beautiful blue sphere rise above the lunar horizon in the black void of space. Astronauts on later earth orbital missions reported seeing the Great Wall snaking across the mountainous terrain of China and the Great Pyramid gracing the Giza Plateau west of the Nile River. A new way of looking at the earth began to emerge: researchers considered how to perceive structures and landscapes from afar with advanced technologies and how to uncover hidden details.

In 1972 the National Aeronautics and Space Administration initiated the Landsat program to scan and study agricultural areas. By recording the intensity of infrared rays reflected by vegetation, NASA scientists could estimate crop yields. The healthier the crop of wheat, for example, the more vigorous the reflection. The earth could now be viewed, within the electromagnetic spectrum, as a patchwork of luminous reds, yellows, blues and greens. Gradually, researchers realized that these images were of value to other disciplines, including geology, geography and archaeology. By the late 1970s a few archaeologists were employing Landsat images to help determine the location of Maya ruins in the dense jungles of the Yucatán Peninsula and ancient structures in the plains of what was once Mesopotamia.

In the 1980s archaeologists familiar with Landsat began to utilize pictures with even higher resolution. Thomas L. Sever, an archaeologist and remote-sensing expert at the NASA Stennis Space Center in Mississippi, and Payson D. Sheets, an anthropologist at the University of Colorado, were among those who pushed the technology to another level. By requesting the installation of infrared sensors on airplanes, they were able to record "an odd, twisting line" in the Tilarán area of northwestern Costa Rica. The infrared photographs showed that the mark ran across hills and valleys. Sever and Sheets noted at the time that they suspected it was not a natural feature but a prehistoric road. They were correct. Later fieldwork proved the existence of footpaths that were between 1,000 and 2,000 years old, linking cemeteries, villages and quarries.

Although ancient roads can be observed in satellite images—as in the case of the Empty Quarter of Arabia—the details unveiled by the infrared aerial pho-

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RADAR IMAGE details a region on the Arabian Peninsula surrounding what some researchers believe may be the site of the lost city of Ubar. Too small to be detected here, the site lies close to the center, where several red lines converge. The image, covering an area of about 50 by 85 kilometers (31 by 53 miles), was taken in 1994 by the space shuttle *Endeavour,* using Spaceborne Imaging Radar C (known as SIR-C).

Tracks appear as reddish streaks. The tracks have been used in modern times, but field investigation shows many were traveled thousands of years ago as well.

A major wadi, or dry streambed, appears white because of surface roughness that causes strong radar backscattering.

The green areas denote rough limestone, which forms a rocky desert floor.

Huge sand dunes spread across the magenta-colored areas.

tographs were even more precise. Thus, Sever and Sheets had little trouble finding the structures once they set out on foot. Sever went on to identify prehistoric roads in Chaco Canyon, N.M., showing that the Chaco civilization was hardly isolated but rather part of a vast trade network in the North American Southwest. This approach to finding ancient cities has become commonplace for archaeologists.

In 1986 the National Center for Space Study in France provided the next advance in satellite remote sensing: SPOT. Its multispectral images could capture objects or areas 20 meters wide, and the panchromatic data recorded objects as small as 10 meters. (In contrast, the first three Landsat sensors were able to detect objects 80 meters in size or larger; the later two missions could resolve items as small as 30 meters in size.) The SPOT images do not offer as much detail as aerial photographs do, but they cover much larger areas, allowing regional investigations. James R. Wiseman of Boston University was one of the first researchers to employ this technology. His team studied SPOT images of the landscape in northwestern Greece and discovered the ancient coastline of Ammoudhia Bay, the home of an important bygone port. The researchers were able to map inland tidal channels as well as former inlets.

Uncanny Promise

Perhaps the greatest tool for archaeology comes from so-called imaging radar. This technology's unique ability to penetrate underneath desert sands and to unveil ancient topography has astonished experts—including its designers, Charles Elachi and his colleagues at the Jet Propulsion Laboratory in Pasadena, Calif. Imaging radar was first used on board the maiden flight of the space shuttle in November 1981. The Shuttle Imaging Radar experiment (SIR-A) provided numerous images of the eastern Sahara. Three years later SIR-B also obtained images of the Arabian Peninsula, as did the radar's most recent incarnation—the Spaceborne Imaging Radar (SIR-C) in April and October 1994. SIR-C beamed the images in digital form to receiving stations on the ground for direct analysis by computer. By including both the horizontal and vertical polarizations, SIR-C brought out more details of the imaged regions [*see illustrations on pages 61 and 63;* also, see "Earth

Remote Sensing from Space…

Landsat Three of these digital-imaging satellites were launched in the 1970s into near-polar orbits. Multispectral scanners on the satellites measured the radiation in four bands of the electromagnetic spectrum reflected by various materials on the earth's surface. The scanners transmitted the data to ground stations.

Thematic Mapper This instrument was carried on Landsat 4 and Landsat 5 in the 1980s. Its sensor obtained 30-meter-resolution images in seven spectral bands: three in visible light (blue, green and red), one in near infrared, two in mid-infrared and one in thermal infrared. Thematic Mapper images could therefore detect a wider range of variations in the spectral response of surface materials.

SPOT Unlike the experimental Landsat, this series of imaging satellites was designed to be fully operational. Rather than scanning the scene with a moving mirror, as in the case of Landsat, SPOT sensors use linear-array "push broom" technology, which adds to the geometric fidelity of the images. Furthermore, the system has pointable optics to allow side viewing for stereo or three-dimensional imaging.

Radar Imaging radar instruments transmit microwaves toward the surface of the earth and record the echoes. Echoes from rocky terrain are generally strong, or "bright," in an image; those from smooth surfaces are weak, or "dark." Different combinations of wavelengths and polarization can be used to produce color images that emphasize particular features. In addition, radar images enhance such linear features as faults and escarpments. They showed, for example, several generations of a segment of the Great Wall of China that were not identified by other imaging systems.

Corona The U.S. government has recently declassified photographs obtained by "spy satellites" between 1960 and 1972. These black-and-white views have resolution as fine as one meter. Their ability to present scenes in stereo allows for simple measurements of surface elevations—important information for archaeological investigations. Commercial satellites may soon obtain images from space having one-meter resolution. Four industrial consortia plan to launch and operate systems to provide such data.

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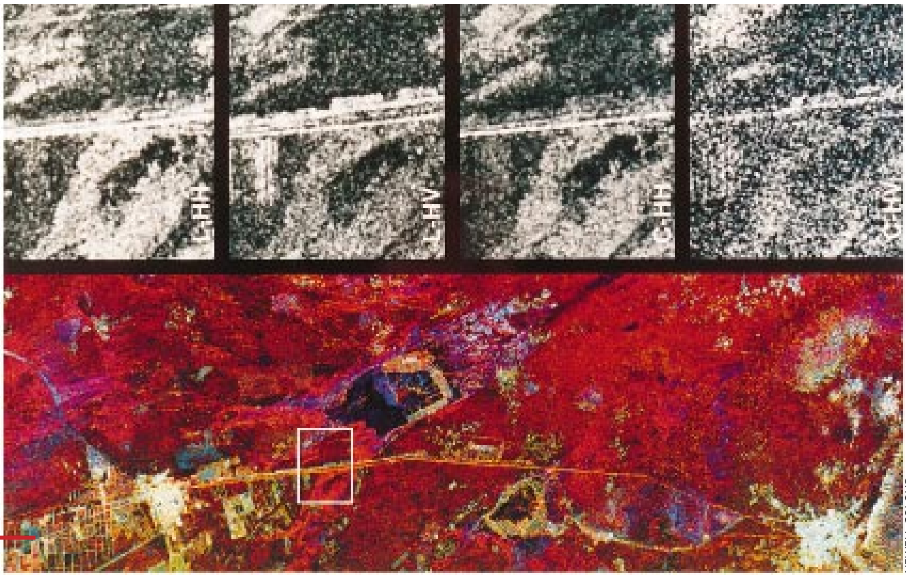
PHOTOGRAPHS BY A. C. ROOSEVELT

MOUND-BUILDING CHIEFDOM studied by Anna C. Roosevelt lies at the mouth of the Amazon River (*top left*). Portable remote-sensing tools (*three are pictured at right*) helped Roosevelt discern the location and nature of the mounds, allowing her to create a model of the site (*bottom left*).



NEWELL COLOUR

SEGMENT OF GREAT WALL OF CHINA appears as a thin orange band (*bottom*). The black-and-white images correspond to the area outlined by the white box and represent the four radar channels of SIR-C. The two left images provide the clearest view of two generations of the wall: the bright continuous line is the younger wall, built about 600 years ago; immediately above it, the bright discontinuous line is a remnant of an older version of the wall (about 1,500 years old). The wall is easily detected from space by radar because its steep, smooth sides provide a prominent surface for reflection of the radar beam. Detection of the old wall by radar is allowing Chinese researchers to trace the former location of the structure across vast and remote areas. Taken by *Endeavour* in 1994, the bottom image shows an area roughly 25 by 75 kilometers (15 by 46 miles).

...and on Earth

Electromagnetic Sounding Equipment These instruments measure differences in electrical or magnetic properties between surface and subsurface soil and other features, such as rocks or buried walls. They can sense to a depth of about six meters. Researchers use these devices to map layers of soil or subsurface cavities.

Ground-Penetrating Radar This low-frequency radar is capable of "seeing" into the ground. Conventional radar uses microwaves, which can penetrate only a few centimeters into most soils. Ground-penetrating radar, however, employs frequencies closer to those used by FM radio or television stations, allowing waves to travel, most commonly, down to 10 meters below the surface. When these pulses pierce the earth, they pass through various layers of soil, sand, clay, rock or man-made material. Each interface between these layers produces an echo. The deeper the boundary, the longer its echo takes to return to the surface—thereby indicating the depth of the buried object.

Magnetometers These instruments identify subsurface features that have a magnetization different from that of the surrounding soil. The "proton magnetometer"—the form most often used by archaeologists—can measure tiny variations in the magnetic field caused by changes in magnetization, particularly those caused by the presence of a hearth.

Resistivity Instruments These tools introduce electrodes into the ground and measure the difference in electrical potential between them. As researchers move the electrodes along a site, they record differences in resistivity—clues to buried artifacts.

Seismic Instruments Archaeologists use seismometers much like those that detect and record vibrations caused by earthquakes. These archaeological instruments, however, are sensitive to artificially generated sound waves. The motion and travel time of a wave and its echoes are recorded on charts, which cumulatively present a seismic picture of the subsurface. Various seismic instruments can reach much deeper than other sensors.

from Sky," by Diane L. Evans et al.; Scientific American, December 1994].

The SIR-A images of the Western Desert of Egypt, near the border with Sudan, had particular significance for my own research. This terrain is covered by a thick layer of sand, topographically distinguished only by low hills. But the radar unveiled the long-empty beds of three great rivers, which ranged from eight to 20 kilometers in width. The intervening hills appeared to have been islands created by fluvial erosion. Field excavation later showed that the radar waves had penetrated five meters into the sand to reveal the banks of these ancient waterways. Archaeologists then unearthed hand axes, proving that humans lived there some 200,000 years ago.

The discovery provided the data that teams of archaeologists, geologists and biologists needed to verify their hypothesis about the evolution of this part of the Sahara, just west of the Nile. The Western Desert is today the driest place on earth. Nevertheless, researchers suspected that between 5,000 and 11,000 years ago, the local climate was wetter; before that, a dry climate prevailed. These alternating cycles were thought to date back 320,000 years. Imaging radar clinched the case by revealing vast river courses from the wet periods.

The ability to determine the presence of invisible rivers, in turn, allowed archaeologists to develop a more complete picture of early Egyptian civilization. Fred Wendorf of Southern Methodist University, who has conducted many investigations in the Western Desert, concludes that about 11,000 years ago, rainfall increased from near zero to 100 to 200 millimeters a year. This shift permitted the growth of grasses and thorn trees—much like those thriving in such environments as California's Death Valley. Wendorf believes that although the climate was unstable and fraught with droughts, the indigenous people developed a complex economy based on herding.

The rainy era ended 5,000 years ago—the date that marks the initiation of Egyptian civilization. It is my opinion that the two events are inextricably related. Climate change gradually brought extreme aridity to the eastern Sahara, perhaps prompting a mass migration to the only dependable source of water, the Nile. The banks of the Nile, however, were already teeming with a sedentary population. It may have been the dynamic convergence of these two peoples that planted the seeds of ancient Egypt.

The ancient “river” people lived in harmony with the ebb and flow of the Nile. They measured the strength of annual floods and ingeniously lifted water from the river to channel it to their fields. Their thoughts were directed toward the earth, which they tilled with great expertise. Those who came from the west had “desert wisdom.” They learned how to live with erratic rainfall and where to seek greener pastures. To escape the scorching heat of the sun, they moved at night and were adept in astronomy. These nomadic people kept their sights turned upward, contemplating man’s place in the universe—a philosophical orientation that permeates the recorded history of Egypt.

The arrival of desert people on the banks of the Nile increased the regional population, requiring better social organization to produce enough food. The cultural interaction of the two groups created a vigorous new society; it was this cross-fertilization that ignited the spark of civilization in ancient Egypt.

Back Down to Earth

The least explored application of remote sensing for archaeology takes place on the ground: the use of handheld sensors. Typically, when archaeologists study a site, they divide it into a grid to guide digging, which often proceeds at each point of intersection. The approach leaves much to chance. Handheld sensors, however, can direct archaeologists to the exact location of an artifact, limiting the area that has to be disturbed and saving time.

Anna C. Roosevelt of the Field Museum in Chicago has used such tools to great advantage, experimenting with various combinations. Roosevelt has been at the forefront of this technological advance—and she has made important discoveries about the settlements and lifestyles of prehistoric peoples in the Brazilian Amazon.

One of the cultures Roosevelt studied was a mound-building chiefdom that subsisted on fishing and the cultivation and collection of plants on the island of Marajó, at the mouth of the Amazon River. She used a series of portable tools to discern the location and nature of the mounds [*see illustration on page 62*]. A proton magnetometer scan of several three-hectare-wide mounds that ranged in height from seven to 10 meters delineated the large, fired-clay hearths of many houses. Ground-penetrating radar revealed disturbed soil layers. Electromagnetic equipment indicated conductivity changes below the surface, marking locations of strata. In addition, instruments measuring electrical conductivity resistance mapped horizontal and vertical stratigraphic shifts caused by buried earth platforms, garbage fill and the hearths. Devices that measured the refraction of seismic waves detected several building stages and located the original ground on which the mounds were built.

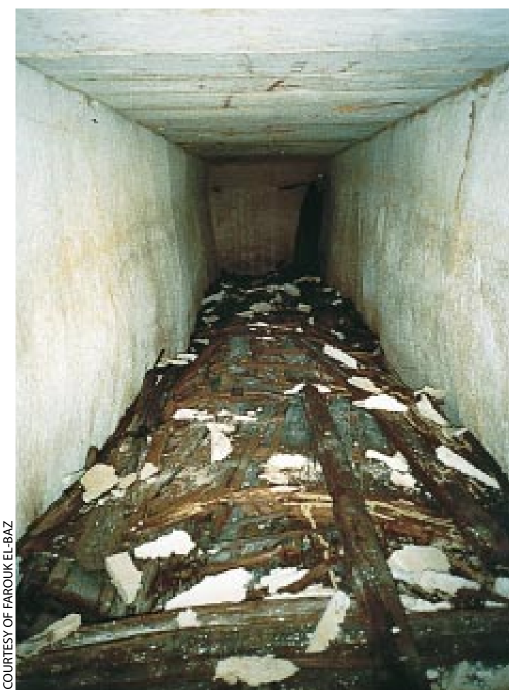
Taken together with excavations, the insights gleaned from these technologies allowed Roosevelt to form a picture of life along the banks of the Amazon between 500 A.D. and the arrival of Europeans in the mid-1500s. Marajoaran peoples lived in separate and warring chiefdoms, harvested fruits and food crops, and built their extensive mounds to raise their settlements out of the swamps. For centuries, they would build one house on top of an older one. Roosevelt has argued that the Marajoarans’ sophisticated culture was indigenous, thus challenging the long-standing theory that the lush life of the forest prevented Amazonian Indians from evolving complex societies.

Work near Santarém in northern Brazil led Roosevelt to another discovery that is overturning thinking about Amazon habitation. It has been an entrenched anthropological conclusion that Indians from Mexico or Peru introduced pottery making into the Amazon. But Roosevelt’s team uncovered evidence of a thriving pottery-using, fishing population in place 7,000 years ago. Ground-penetrating radar revealed numerous domestic features, and resistivity and seismic surveys detected the initial layers of occupation, which produced the early radiocarbon and thermoluminescence dates of the pottery. Because the Amazon pottery later found at several other sites predates other Western Hemisphere pottery by thousands of years, the research has changed the picture of early American cultural development.

The Craft of Conservation

Archaeological sites are easily destroyed once they have been excavated, because they become exposed to the elements, to visitors and, often, to looters. It is becoming disturbingly clear that cultural patrimony is under siege, as magnificent monuments—from Ang-

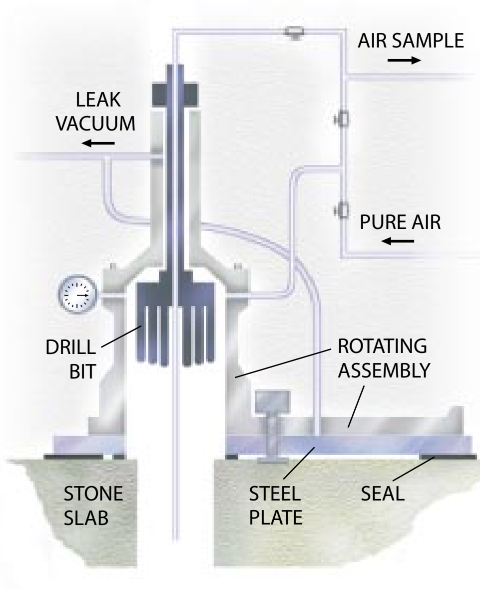
REMOTE INVESTIGATION was undertaken (*above*) on the second of two sealed pits containing disassembled royal barges of Pharaoh Khufu. The first boat, unearthed in 1954, was reassembled in a museum on the site (*below*). Environmental damage to the craft persuaded researchers to leave the second barge undisturbed and to investigate using remote sensing. Above at right, a worker prepares an airtight hole through which tools



COURTESY OF FAROUK EL-BAZ

PHOTOGRAPHS COURTESY OF FAROUK EL-BAZ

could be lowered. A specially designed air lock (*below*) prevented introduction of foreign matter into the pit. A steel plate was sealed to the stone; a rotating assembly could turn 90 degrees to align holes in the plate and stone for drilling or to cover the hole in the fixed plate, sealing the work surface so that drills or probing heads could be safely changed. A remote photograph eventually revealed the stacked timbers of the boat (*below, left*).



LAURIE GRACE

kor in Cambodia to Machu Picchu in Peru—crumble. Modern archaeologists must increasingly consider how to preserve sites they have unearthed or how to examine sites without touching them.

My first experience using remote sensing in this way came in 1987 during work on the Great Pyramid at Giza. Built by Pharaoh Khufu—or, as the Greeks called him, Cheops—some 4,600 years ago, the pyramid had two sealed chambers near its base. Excavation of one began in 1954, and archaeologists soon discovered inside it a disassembled barge, 43.4 meters long and 5.9 meters wide. It took 18 years to excavate and assemble this royal bark, which was ultimately housed in a special "Boat Museum" constructed on the site. Opened to visitors in 1982, the boat became a popular attraction.

It also diminished. By some estimates, the barge has shrunk about a half a meter since it was placed in the museum. Conservators believe this deterioration is caused by the environmental conditions inside the building, which differed from those of the sealed chamber. It was thought that a second, unopened chamber also contained a boat, so I was asked to develop a plan to study the sealed environment—and to determine how best to preserve the boat that was already on exhibit.

In 1987 the Egyptian Antiquities Organization, the National Geographic Society and the Center for Remote Sensing at Boston University agreed to apply remote-sensing techniques to study the second chamber. Because the first chamber had been hermetically sealed, it seemed logical that an air sample from the second one could produce data on the composition of the earth's atmosphere 4.6 millennia ago. I called on Bob Moores, a Black and Decker engineer who had worked on the lunar-surface drill used by the Apollo astronauts, to drill a hole without affecting the pristine environment. Moores designed an airlock that allowed cutting through the rock without mixing the air inside with the air outside. We used ground-penetrating radar to determine the shape of the chamber and to select a proper drilling site.

After two and a half days of drilling, we penetrated the 159-centimeter-thick rock cap. We then inserted a probe into the chamber and sampled air from three levels. Next, we lowered a camera into the enclosure, discovering hieroglyphs on the chamber walls and the anticipated second royal bark. The analysis of the air samples—as well as a view of moisture marks on the walls and of a desert beetle crawling about—testified to the fact that the modern environment was somehow reaching the chamber. But it was not necessary to excavate and further endanger the bark, and so we sealed the hole and left the royal history in the same state as we found it.

A team of archaeologists in England has recently been able to conduct a similar nondestructive study. Using remote-sensing instruments, the scientists are mapping a buried Roman city under the village of Wroxeter, locating streets, shops and what may be a church—all without disturbing the village and pastures that overlie the city. Computer models offer a compelling illustration of what this densely populated city must have looked like.

In the next century, remote sensing will continue to offer researchers a virtual archaeological reality, one that is needed to preserve the fragile environment of the earth and of historical sites. In exploring the mysteries that may lie beneath our feet, we may learn as much from what we do not touch as we do from what we hold in our hands. SA

The Author

FAROUK EL-BAZ is director of the Center for Remote Sensing at Boston University. He received his undergraduate degree from Ain Shams University in Cairo and his Ph.D. in geology from the University of Missouri. He has taught at Assiut University in Egypt and at the University of Heidelberg in Germany and has held positions at Bell-Comm, at the Smithsonian's National Air and Space Museum (where he established and directed the Center for Earth and Planetary Studies) and at Itek Optical Systems. His research focuses on the interpretation of satellite images, the application of space photography to desert studies and the use of remote sensing in archaeology and geology.

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GLANDULAR GIFTS

The way to a katydid's heart is through her stomach

by Darryl T. Gwynne

FEMALE SOFT-WINGED FLOWER BEETLE (*Malachius bipustulatus*) (*left*) feeds on fluid secreted by glands on the male's face during courtship, here conducted on a flowering head of timothy grass. In a remarkably high number of insect species, the male offers glandular secretions or body parts as a nuptial gift.

K. G. PRESTON-MAFHAM *Premaphotos Wildlife*; (magnification 20X)

In 1859, the year evolutionary theory burst onto the scene with the publication of Charles Darwin's *On the Origin of Species*, Captain John Feilner of the U.S. Cavalry was exploring northern California. He was eventually killed by Indians, but not before he had reported to the Smithsonian Institution his observations on the habits of grasshoppers. After the mating act, he noted, "a small bag—evidently the ovary—is attached to the body of the female close to the tail."

Almost half a century later, across the globe in France, pioneer ethologist Jean Henri Fabre filled in the details of this curious copulation. In *The Life of the Grasshopper,* a volume devoted to orthopteran insects in his *Entomological Memories* (*Souvenirs entomologiques*), Fabre correctly identified the bag as originating from the male. He wrote that an opalescent structure "similar in size and color to a mistletoe berry" was attached to the spermatophore, a separate sperm-filled package, and eaten by the female in a "final banquet" culminating the mating sequence.

SPERMATOPHYLAX, a food bag transferred with the sperm, is the most common gift among katydids (Tettigonidae) and related crickets. Shown eating them are three species (*left to right*): a North American meadow katydid (*Conocephalus strictus*); a Brazilian false-leaf katydid (unnamed); and an Australian pollen katydid (*Kawanaphila nartee*).

DAVID H. FUNK *Stroud Water Research Center*

Such extreme investments in mating are typically viewed by biologists as a mystery. Male animals usually commit only genetic material in their cheap gametes—the sperm. Their greatest reproductive benefit is thought to come from a strategy of multiple copulations rather than from putting much of their resources into any one. Females, on the other hand, produce expensive gametes—eggs containing both genetic and nutritive material—and often use up considerable effort in ensuring that each mating is productive. As a result, they choose their mates very carefully.

The roots of male investment may lie in either natural or sexual selection, the processes proposed by Darwin as the causes of biological evolution. Natural selection arises from the struggle to survive and reproduce. Sexual selection derives solely from competition for mates—or, as I shall explain in the case of glandular gifts, for inseminations.

The donations typical of many crickets and katydids are postcoital meals: females eat them after copulation, while the externally attached spermatophore is ejaculating with a syringelike action. Thus, in these species, ejaculation can occur after the pair has parted. In 1915 the fact that eating the nuptial meal coincides with sperm transfer led the Russian biologist B. T. Boldyrev to suggest a reason for such contributions as the katydid's food bag. He speculated that this bag, which he called the spermatophylax, served to distract the female from eating the spermatophore, which would probably supply some nutrition in itself. Any such delay should result in fertilization of more eggs, because more of the ejaculate would be transferred, helping the gift-giving male's sperm to outcompete numerically the sperm of other males already stored within the female. (Sperm storage is the rule in insects, and females have a special organ, the spermathecae, which evolved for this purpose.)

The hypothesis that the nuptial meal is a result of sexual selection was elaborated on by Nina Wedell of Stockholm University, who suggested that an evolutionary arms race had occurred between the sexes. Males had evolved the tempting spermatophylaxes to prevent females from eating their sperm. Females then evolved to mate many times—perhaps to get additional meals—prompting the males to provide ever more sperm to wash out their rivals' gametes. So a larger meal bag became necessary to protect the larger sperm bag.

Robert L. Trivers of Rutgers University offered an alternative hypothesis for nuptial gifts. He noted that the male investment may be a form of indirect paternal care: natural selection could have acted on males to induce them to give nutrients that would be incorporated into eggs, thereby providing benefits to their own progeny.

All in the Family

These ideas, it should be noted, are not mutually exclusive; a male's investment may procure dual returns. It is even possible that the trait evolved originally for one purpose but is today maintained for another. I decided to probe the latter possibility by looking closely at the historical record.

Scientists examine the origins of an adaptation by tracing it among different taxa (groups of related organisms). If, for instance, all the organisms at the tips of a phylogenetic tree—a family tree showing the relationships and descent of related organisms—have a certain trait, one may deduce that the an-

FLESHY HINDWINGS of the male sagebrush cricket *Cyphoderris strepitans* (Haglidae) are offered to the female (*seen on top*) during mating. In this sequence, however, the female also damages the male's forewings (*far right*).

DAVID H. FUNK

K. G. PRESTON-MAFHAM *Premaphotos Wildlife*

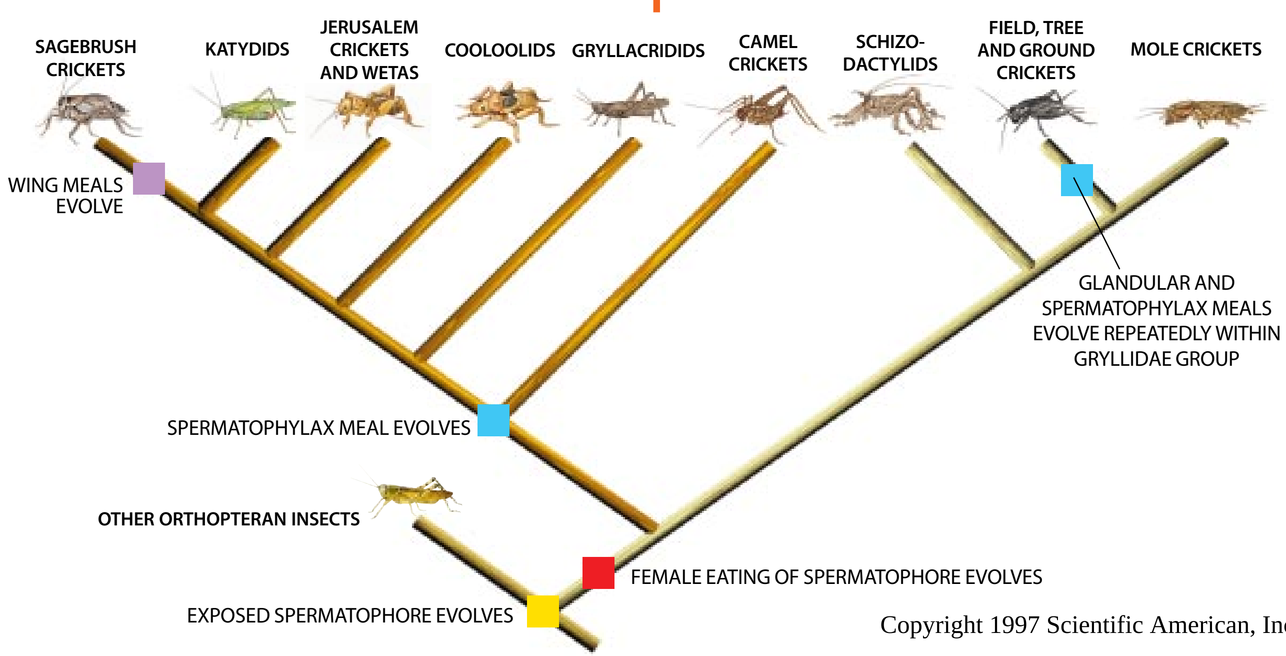
DARRYL T. GWYNNE

cestral organism had it as well. I used this logic to address the origin of male nuptial offerings within the cricket-katydid group.

As in short-horned grasshoppers, spermatophores of most insects are placed inside the female. So if male contributions originated to prevent interference with sperm transfer, they would have evolved only after the first appearance of both an externally located spermatophore and the female's consumption of this vulnerable package. My analysis supported this sequence of evolutionary events. In virtually all taxa of the cricket-katydid tree, the female eats the spermatophore, suggesting that the ancestral cricket at the base of the tree did so as well. In addition, virtually all taxa on the left-hand branch of the tree—and a few on the right-hand branch—offer a spermatophylax gift, indicating that this refinement developed somewhat later. Indeed, the comparisons reveal about a dozen independent origins of glandular and body-part meals, including three distinct origins of a spermatophylax. (Curiously, the most common nuptial offering in the animal kingdom—prey or other food items harvested by the male, as opposed to its tissues or secretions—does not exist in the Orthoptera at all.)

Several experimental studies show that males typically supply no more food than necessary to allow time for safe transfer of sperm, suggesting that the ancestral protective role for glandular meals is also the present role in most katydid and cricket species. Moreover, effective sperm transfer, allowed by an ample meal, does seem to bring a reward in terms of increased paternity. Wedell mated two males of *Decticus verrucivorus* (literally, the "wartbiter" katydid) to the same female. She found that the proportion of offspring sired by a male directly relates to the size of the meal it donates as compared with its rival's.

EVOLUTIONARY TREE of crickets and katydids (orthopteran suborder Ensifera) indicates that exposed, vulnerable spermatophores evolved first (yellow). Nuptial meals, in the form of a spermatophylax, or meal bag, followed (blue). The sequence suggests the banquets evolved to prevent the female from eating the sperm.



ROBERTO OSTI

MIGRATING MORMON CRICKETS near St. Anthony, Idaho, can find very little food. In order to get spermatophylax meals, females aggressively seek to mate, as do female Australian pollen katydids (*far right*). Two females jostle for position over an available male.

DARRYL T. GWYNNE

Another analysis of paternity revealed a remarkably similar pattern in a quite different arthropod—one in which the meal ends the male's reproductive career. The tiny male Australian redback spider is cannibalized in about two thirds of all matings because it somersaults into the jaws of its much larger mate during insemination. One explanation offered for this morbid meal is that the male's complicity evolved as a final act of paternal nutritive investment. Experiments conducted by Maydianne C. B. Andrade, then at the University of Toronto, have shown, however, that male self-sacrifice is instead like most other mating meals: it helps to prolong coitus rather than to provide nourishment.

This suicidal snack distracts the female, thus extending the time for sperm transfer and increasing the number of eggs fertilized. Furthermore, although both the spider's somatic gift and the wartbiter's meal must contain some nutrition, it is not of any detectable reproductive or survival value to the female. Thus, these males' extreme offerings do not violate the rule that the male's mating effort is an aid for fertilizing as many eggs as possible, rather than for nurturing the offspring.

The Australian redback is one of the black widow spiders (genus *Latrodectus*). Females of other black widow species sometimes consume the male after mating. But for the most part, this cannibalism does not appear to be an instance of gift giving, as males show no complicity in the act. The same is true of many other perilous copulations, such as those of some praying mantises, where the males try hard to escape their mate's clutches.

Sexual selection therefore appears to be the general rule in nuptial feedings. Some of these meals improve the genetic fitness of females, perhaps because the ancestral females preferred more nutritious gifts. The mating meals of some katydids are known to boost not only the number but also the size of the eggs; increased weight enhances the chances of an egg surviving the winter. And work by William Brown of the University of Toronto showed that secretions lapped by the female from a tiny "soup bowl" gland on the male's back contain a Methuselah substance—glandular material of unknown composition that enhances the female's longevity.

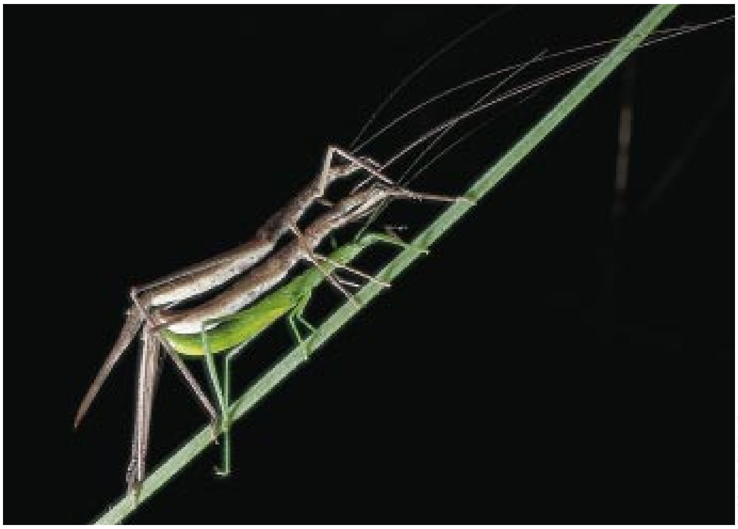
Such positive effects do not by themselves confirm the paternal hypothesis, however: a meal that serves as a sexually selected distraction may also be a nutritious one. To support a paternal function, there should also be a clear pattern of the male nurturing its own offspring, rather than those of a rival. In two species of Australian katydids, males appear to be confident of their paternity because the eggs are laid before the female takes a second mate; moreover, these eggs are fatter when the nuptial meal is more substantial.

Male fire-colored beetles (*Neopyrochroa flabellata*) may also have evolved to in-

METATHORACIC GLANDS on the male's back provide a postcopulatory meal (*right*) for the female two-spotted tree cricket, *Neoxabea bipunctata* (Gryllidae). The vulnerable sperm bag can be seen hanging near the tip of the female's abdomen. The female Allard's ground cricket (*Allonemobius allardi*) feeds on a glandular secretion from a modified tibial spur on the male's leg (*below*).

DAVID H. FUNK

DAVID H. FUNK



DARRYL T. GWYNNE

vest in offspring—not with food but with a chemical secretion that protects the progeny from predators. Thomas Eisner and his colleagues at Cornell University examined the beetles' use of cantharidin, the active chemical in the (rather dangerous) aphrodisiac "Spanish fly." After eating cantharidin, the male stores some in a gland in its head; but most goes to specialized abdominal glands. During courtship, females taste the head glands and mate with males that have eaten cantharidin, rejecting the others. The males subsequently ejaculate most of their reserve of cantharidin into the females, who incorporate it into their eggs. Thus, the males are honest advertisers—they give away their cache of cantharidin instead of saving it to attract more females. So the chemical meal might have more of a nurturing, paternal function than an exploitative sexual one.

Changing Roles

One of the two katydids in which the spermatophylax appears to have changed from its ancestral distractive role to a more nurturant function is Western Australia's garden katydid (*Requena verticalis*). A male *Requena* provides a larger meal than necessary to distract its mate and ensure full insemination. Even so, the pressures of sexual selection never quite go away. Leigh W. Simmons and his colleagues at the University of Western Australia showed that males save the best banquets for matings with healthy young females. A young female is no more than a week past molting into adulthood; an old one has spent three weeks as an adult and will most likely have stored sperm from rival males. In matings with older females—the paternity of whose offspring is questionable—males show a subtle form of discrimination by transferring smaller spermatophylax meals.

The idea of males choosing mates brings me to a final twist to the story of seminal gifts. The evolution of a large, nutritious spermatophylax in several species has, somewhat paradoxically, caused a complete turnaround in the more familiar patterns of sexual selection, in which males compete for mates and females choose. One such katydid is the Mormon cricket, a pest in parts of the American West, and almost certainly the grasshopper that Captain Feilner observed "in such numbers as actually to cover the ground." At these densities, very little food is available, and starvation has curious effects. Males mate less often because they can no longer produce many meals; females, in contrast, become more libidinous, with an increased urge to forage for mating meals. These changes dramatically reverse the more typical sexual behavior.

If Feilner had survived to spend more time observing his grasshoppers, he might well have noted this consequence. It is the females, not the males, that grapple for access to mates. Meanwhile the coy males become quite choosy about which female to provide with their costly, edible gifts. SA

ANDREW C. MASON *Cornell University*

MALE AUSTRALIAN REDBACK SPIDER offers its entire body to the female (*larger*). After inserting its copulatory palpus, it somersaults into the female's jaws; the female feeds during the transfer of sperm. The sacrifice—of negligible nutritive value—increases the duration of mating and therefore the number of eggs fertilized.

The Author

DARRYL T. GWYNNE studies the evolutionary and behavioral biology of insects and spiders. He received his Ph.D. from Colorado State University in 1979. After research stints in New Mexico and Australia, Gwynne joined the faculty of the University of Toronto in the department of zoology. He is a Fellow of the Animal Behavior Society.

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The Top-Secret Life of Lev Landau

KGB archives reveal that the Soviet genius co-authored an anti-Stalin manifesto

by Gennady Gorelik

The theories of Lev Davidovich Landau built the backbone of 20th-century condensed-matter physics. They described superfluidity, tenets of superconductivity, and diverse corners of astrophysics, particle physics and many other disciplines. To this day, Landau levels, Landau diamagnetism, Landau spectrum, Landau-Ginzburg theory and other Landau discoveries remain essential tools. His texts taught generations of scientists: the library at Harvard University contains four times as many titles by this Soviet physicist as by the renowned American physicist Richard Feynman.

For his achievements, Landau won the Nobel Prize in 1962. His admirers saw him as an ivory tower theorist—bold, impudent and charming but detached from the humdrum of everyday existence. They ignored two political aspects of his life: his year in Joseph Stalin's prisons in the late 1930s and his contributions to the dictator's nuclear bomb a decade later.

Only now do we know Landau had a political persona that made him permanently suspect to the KGB, the Soviet secret police. This revelation was partly accidental. In 1989 Maia Besserab, the niece of Landau's wife, published the fourth edition of her biography of the scientist. Glasnost (or "openness") had arrived, and the author claimed she could finally announce the full story behind his 1938 arrest. A disgruntled former student by the name of Leonid Pyatigorsky, Besserab stated, had denounced Landau as a German spy. This during Stalin's Great Terror, when many millions were executed on fanciful charges.

Unfortunately for the biographer, Pyatigorsky was still alive. It was indeed true that Landau had expelled him from the theoretical group at the Kharkov institute in Ukraine. "Dau," as the great man was called by his adoring students, could be very hard on them: a sign outside his office door warned, "Beware! He bites!" But Pyatigorsky nonetheless continued to revere Landau, and shocked by the accusation, he brought Besserab to court in the summer of 1990.

Inside the KGB

The judge for the case asked the KGB to check Landau's files. They contained no mention of Pyatigorsky, and Besserab published an apology. It was at this time, I believe, that the KGB discovered that the pride of Soviet science was no innocent victim of Stalinist insanity but a genuine anti-Soviet criminal. In 1991 the KGB published almost the entire contents of Landau's file in a short-lived magazine designed for glasnost called the *Bulletin of the Central Committee of the Communist Party.*

As it happened, I had seen Landau's file just a few weeks before its publication. Soon after perestroika (or "restructuring") began in the late 1980s, I obtained a research position at the Institute for the History of Science and Technology in Moscow. The institute's director was the son of former defense minister Dmitriy Ustinov. Realizing that his name could lower enormous barriers, I decided to try my luck at getting into the KGB archives.

With utmost care, I composed a letter pointing out that almost nothing was known about the fate of many important Soviet physicists who had been arrested in the 1930s. Listing two dozen names, I asked if historians could study their files. After two weeks of contemplation, Ustinov signed this letter; to my great fortune (I was later told), it landed next on the desk of an exceptionally liberal deputy to the KGB head.

Two months later the agency informed me I could examine the files—inside its headquarters, located in the Lubyanka building, where countless prisoners had spent their initial terrified hours. At the door a guard searched me with intimate and embarrassing thoroughness. There was no reading room, only a very small room for prisoners' relatives. Explaining that it would be uncomfortable for me to work in a room full of weeping people, my hosts gave me the office of someone who was out sick. This room, still covered in 1930s wood paneling, may even have been the one where Landau was interrogated. Through the window, I could see the inner prison where he had been incarcerated.

I, too, was interrogated. Two officials asked me why the files of dead physicists might contain anything in-


COURTESY OF GENNADY GORELIK

teresting. As I answered their questions, I began to wonder why I had been permitted to enter the KGB headquarters at all. Surely my interrogators were aware that my Jewish parents had just left Russia for the U.S.—were they trying to trap me? It took me some time to calm down, to understand that the KGB was simply trying hard to soften its public image. When they finally asked me if Andrei Sakharov was indeed a good physicist or merely an overhyped dissident, I accepted that the two men were also just curious.

After a few hours, they left me with five files on the desk. The files were dated from 1930 to 1952; some were extremely haphazard. Landau, who was arrested near the end of the Great Terror—when some sanity was returning—had a very neat file. Opening it, I first asked myself if it was a 1990s forgery. Eventually I decided that all the documents, including any fabrications, were made back in the 1930s. Unfortunately, I had no way of copying anything, except by hand.

Physicists Yuri B. Rumer and Moissey Koretz were arrested the same night as Landau. Rumer was one of the pioneers of quantum chemistry. Koretz, though not a famous man, was Landau's close friend and ally, someone he turned to for advice on the practical side of life.

In Rumer's file I found three reports by unnamed informers. One was undated and bizarre—it stated that an acquaintance of Rumer's was the son of a rabbi, lived in Berlin and worked for Adolf Hitler's Gestapo. The second report, from March 1938, described a conversation between Rumer and Landau about Soviet officials, in which Landau opined that nothing good could be expected from people who were born subhuman. In the third, from April 19, the informer disclosed that Landau and Rumer were aware of an anti-Soviet leaflet that had been prepared for distribution. The original, handwritten, copy of this extraordinary leaflet was supposed to be in Koretz's file—which, I was told, was in the office of the attorney general. But Landau's file contained a typewritten copy.

A 1934 SNAPSHOT shows Lev Landau (*front, right*) and his colleagues on the steps of the Physico-Technical Institute in Kharkov, Ukraine. Landau's attempts to save pure physics at the institute were soon to land him in trouble.

The pamphlet was designed to be duplicated and discreetly distributed during the May Day parade. Here is its wording:

> Comrades!
>
> The great cause of the October revolution has been evilly betrayed.... Millions of innocent people are thrown in prison, and no one knows when his own turn will be....
>
> Don't you see, comrades, that Stalin's clique accomplished a fascist coup! Socialism remains only on the pages of the newspapers that are terminally wrapped in lies. Stalin, with his rabid hatred of genuine socialism, has become like Hitler and Mussolini. To save his power Stalin destroys the country and makes it an easy prey for the beastly German fascism....
>
> The proletariat of our country that had overthrown the power of the tsar and the capitalists will be able to overthrow a fascist dictator and his clique.
>
> Long live the May day, the day of struggle for socialism!
>
> —The Antifascist Worker's Party

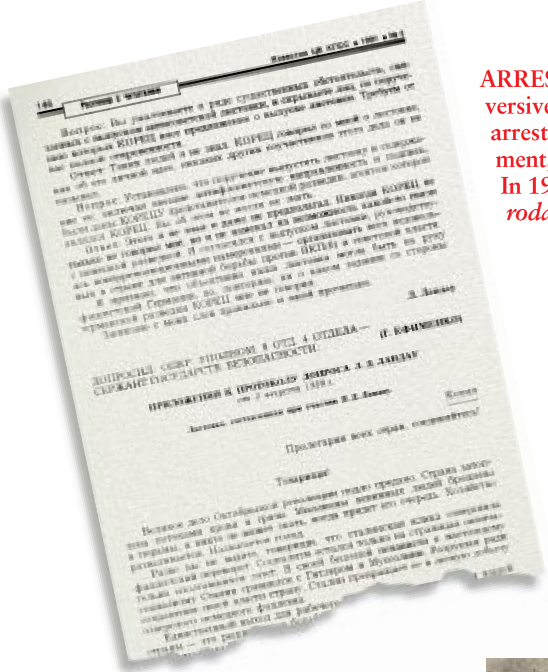
To my knowledge, this manifesto is one of only three explicit denunciations of Stalin made by a Soviet citizen during the Terror. Another, an open letter, was published in 1939 by a Soviet diplomat who escaped to Paris; soon after, he died under mysterious circumstances. The third was an entry in the personal diary of Vladimir Vernadsky, the director of the Radium Institute. Writing, and especially planning to disseminate, such a denunciation took incredible courage, perhaps foolhardiness. To understand why the KGB did not instantly shoot the perpetrators requires some background.

Ideological Impertinence

Born on January 22, 1908, in the oil town of Baku in Azerbaijan, Landau was the son of Jewish parents. His father was an engineer with the local oil industry, and his mother a doctor. Landau was only nine years old at the time of the Soviet revolution of 1917. At 14 he entered Baku University, transferring two years later to Leningrad State University. Graduating in 1927, Landau continued his studies at the Leningrad Physico-Technical Institute, the cradle of Soviet physics.

In 1929 Landau won a fellowship to visit foreign scientific institutions. After working for a year with Niels Bohr in

ARREST AND INTERROGATION by the KGB in 1938 were precipitated by a defiantly subversive pamphlet written by Landau and Moissey Koretz. This typeset version (*left*) and the arrest warrant (*below*) were published by the KGB in 1991. After two months of imprisonment, Landau wrote a confession (*right*) detailing his disillusionment with the Soviet system. In 1991 the KGB supplied Landau's prison mug shot (*at bottom*) to the Soviet magazine *Piroda;* it declined, however, to provide the profile, on the grounds that it was too depressing.

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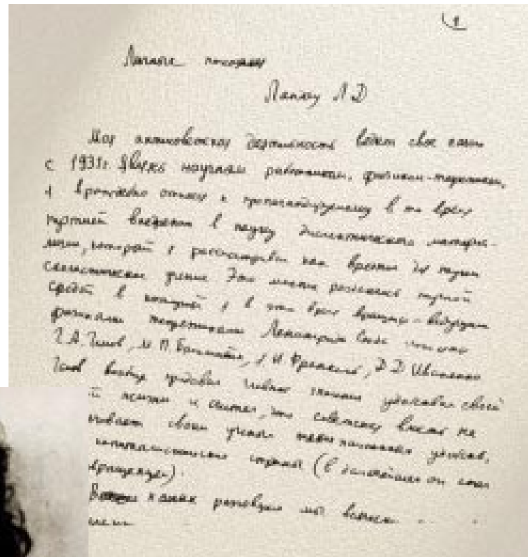


ALL DOCUMENTS COURTESY OF GENNADY GORELIK

AIP EMILIO SEGRÈ VISUAL ARCHIVES

Copenhagen, he came to think of Bohr—already famous for his contributions to the new quantum physics—as his mentor. In England he met Pyotr Kapitsa, an influential Soviet experimentalist who had been working in the Cavendish Laboratory in Cambridge since 1921. In response to one of Kapitsa's questions, Landau developed the theory of diamagnetism of electrons in a metal, his first major scientific contribution.

In 1932 Landau went to Kharkov to head the theoretical division of the Ukrainian Physico-Technical Institute. There he began his seminal studies on phase transitions of the second kind—subtle changes in a system, which, unlike the freezing of water, do not involve the emission or absorption of heat. In addition, he worked on ferromagnetism, the process by which magnets form.

An able and enthusiastic teacher, Landau also began to write, along with his student Evgenni Lifshitz, the nine-volume classic *Course of Theoretical Physics* (Pergamon Press, 1975–1987). His institute soon acquired a reputation for creating world-class scientists adept at tackling almost any problem in theoretical physics.

Hendrik Casimir, a physicist who met Landau in Copenhagen, recalls him as an ardent communist, very proud of his revolutionary roots. The enthusiasm with which Landau went about building Soviet science was part of his socialistic fervor. In 1935 he published an odd piece entitled "Bourgeoisie and Contemporary Physics" in the Soviet newspaper *Izvestia.* Apart from attacking bourgeois inclinations toward religious superstition and the power of money, he praised the "unprecedented opportunities for the development of physics in our country, provided by the Party and the government." A committed classifier, Landau designated himself and his friends as "communists," those he hated as "fascists," and faculty elders as simply *wisent*—the Russian bison, nearing extinction.

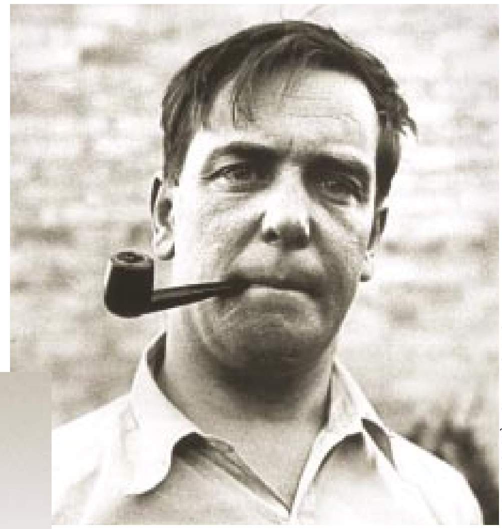
Despite his faith in the Soviet system, Landau suffered attacks from some socialist writers. In the late 1920s a newly discovered nuclear decay, in which some energy could not be accounted for, caused quite a stir. Landau and others initially supported Bohr in his idea that this experiment violated the conservation of energy. Later, however, Landau discovered that this hypothesis contradicted Albert Einstein's theory of gravity and abandoned the concept. (Wolfgang Pauli's explanation—that an unknown neutral particle, later named the "neutrino" by Enrico Fermi, had carried off the missing energy—won the day.) Unfortunately, the co-founder of Marxism, Friedrich Engels, had declared in the 19th century that the law of conservation of energy was to be forever fundamental to science, and Landau was severely castigated in the local papers for his (temporary) blasphemy.

In any case, his social views were soon to undergo a phase transformation of their own. In 1934 the Kharkov institute acquired a new director—with a mandate to redirect the research into military and applied ventures. Landau fought fiercely to save pure science. He suggested that the institute be split, so that one branch could be dedicated to physics. On the institute's bulletin board, which featured animated arguments on the future of the institute, Koretz authored a vigorous defense of Landau's plans. And Pyatigorsky, who did not know that opposition to official directives was to be construed as sabotage of the Soviet military enterprise, confirmed this plan to administrators (for which offense Landau expelled him). In November 1935 Koretz was arrested.

Landau tried valiantly to defend his friend, appealing to the KGB head in

COURTESY OF GENNADY GORELIK

LANDAU'S ASSOCIATES Koretz (*left*) and Yuri B. Rumer (*below*) were arrested on the same night. Koretz spent 20 years in the Gulag; Rumer spent 10 years in a penal science institution, or *sharashka*. Pyotr Kapitsa (*right*) saved Landau, by claiming that only he could explain a great new discovery. It turned out to be superfluidity.



AIP EMILIO SEGRÈ VISUAL ARCHIVES

COURTESY OF GENNADY GORELIK

Ukraine. And amazingly enough for those times, Koretz was released "because of lack of evidence." (A few months later the KGB official in Kharkov shot himself. He may have been one of the many idealists who could not live with the increasingly evident gap between communist ideals and reality.) But a note in Koretz's file warned that the KGB should keep an eye on he whose "guilt had not been proved" but who "was a member of a counterrevolutionary wrecking organization headed by Landau."

In 1937 the KGB arrested several German physicists working at Kharkov and an assortment of other scientists. Before being shot, Landau's friends Lev Shubnikov and Lev Rozenkevich "confessed" that Landau headed a counterrevolutionary organization. Landau felt he had to flee to some other, possibly safer, place. In Moscow, Kapitsa offered Landau a position as head of the theoretical division of the Institute of Physical Problems, and there he went in February. Koretz soon followed him to Moscow; Rumer was already there. Within a year, on April 28, 1938, Landau and his two friends were arrested.

In Prison

Landau's students and colleagues were scolded for supporting Landau in his preachings "against dialectical materialism, and even against the theorem of energy conservation." They believed Landau had been denounced by an enemy for his past impudence. Certainly Landau had enemies, for he liked to step on toes. One April Fools' Day, for instance, he had posted an official notice classifying the Kharkov institute's faculty by ability and rescaling their salaries accordingly—a joke that did not sit well with superiors.

The charges against Landau were in fact much graver than scientific heresy. He was accused of heading a counterrevolutionary organization; the confessions extorted from his associates "proved" that charge to the KGB's satisfaction. The leaflet merely determined the date of arrest—a week before the traditional May Day parade.

Rumer, it turned out, was not involved in the leaflet at all. Both Landau and Koretz testified to that, and he was relieved of this accusation. But the fanciful charges of espionage for Germany forced Rumer to spend 10 years in a *sharashka*—a scientific and engineering institute run like a prison.

Landau was taken to the Lubyanka prison. A hastily scribbled note in his file, apparently made by a KGB officer, records that Landau was forced to stand for seven hours a day and threatened with transfer to the even more horrific Lefortovo prison. After two months he broke and wrote a six-page confession, the most eloquent document in his file. (Every prisoner signed an oath of secrecy on leaving prison, and Landau never talked about this phase of his life.)

The confession states: "At the beginning of 1937, we came to the conclusion that the Party had degenerated and that the Soviet government no longer acted in the interests of workers but in the interests of a small ruling group, that the interests of the country demanded the overthrow of the existing government, and creation in the U.S.S.R. of a state that would preserve the *kolkhozes* [agricultural farms] and State property for industry, but build upon the principles of bourgeois-democratic states."

Although such confessions cannot be taken too seriously given the circumstances under which they were extracted, this statement is so unusual that I believe it to be true. The two physicists had somehow reached a conclusion that eluded most of their countrymen for the next half century. It was Koretz who had convinced Landau of the need for practical action and whose handwriting was on the leaflet. But the political intelligence behind it was Landau's. Landau was known for his "graphophobia," and most of his writing was actually done by his colleagues, including the famous *Courses*. (The confession was the longest piece of handwriting Landau accomplished in his life.) The two conspirators had signed the manifesto with the name of a fake organization so that people would take it more seriously.

Koretz spent 20 years in the Gulag, returning to Moscow in 1958, where I met him a few times before he died of cancer in 1984. He was enthusiastic about science and worked for a popular science magazine. Wonderfully lively and vigorous despite his travails, he told me many stories about Landau—but never the circumstances of their arrest. Nor was Koretz ever rehabilitated (that is, officially acknowledged as having been unjustly accused). This was a hint that unlike most victims of the Terror, his arrest was for some real reason.

Kapitsa saved Landau. By virtue of having invented a new technique for production of oxygen—vital for metallurgy and therefore industry—Kapitsa had acquired very good relations with the government. He was also extraordinarily gifted in communicating with officialdom and in his lifetime wrote more than 100 letters to the Kremlin on matters of science policy, as well as to save physicists such as Vladimir Fock, the quantum-field theorist.

In 1938 the head of the KGB "disappeared," and Lavrenti Beria succeeded him. After two years of carnage, Stalin had achieved his purpose—to destroy all rivals, real and imaginary. Sensing an opportunity, Kapitsa wrote to Prime Minister Vyacheslav Molotov, saying that he had just made a discovery "in the most puzzling field of the modern physics" and that no theorist other than Landau could explain it. And on the eve of May Day, 1939, after a year of imprisonment, Landau was freed on bail. In a few months, he had explained Kapitsa's superfluidity using sound waves, or phonons, and a new excitation called a roton. It earned both of them a Nobel Prize a few decades later.

In 1939 Landau married K. T. Drobanzeva, and in 1946 they had a son, Igor. The marriage was unusual. Apparently Landau believed in free love and urged his students and his distraught wife to practice it as well.

A few years after Landau's release, Stalin instituted the Soviet atomic project; after Hiroshima, it was pushed full-steam ahead. Kapitsa's institute was recruited for this purpose, and Stalin appointed Beria as the supreme officer overseeing the effort. Kapitsa was not a pacifist but found it unbearable to work under Stalin's chief gendarme in an atmosphere of deep secrecy. He wrote to Stalin, charging that Beria was unfit to be heading such a project.

Enter the Hydrogen Bomb

This was an exceedingly dangerous ploy. General Andrei Khrulev, a friend of Kapitsa's, related to him a conversation he overheard between Beria and Stalin. Beria wanted Kapitsa's head, but Stalin told him that although he could dismiss Kapitsa from all positions, he could not kill him. Apparently Stalin respected Kapitsa's worldwide reputation as a physicist: he was a member of the British Royal Society.

Kapitsa escaped execution—although he remained under a kind of house arrest until Stalin's death. Landau was, however, engaged in the top-secret affair. His bomb duty was numerical mathematics rather than theoretical physics. Along with the physicists he directed, Landau calculated the dynamics of the first Soviet thermonuclear bomb, called *sloyka*—or "layer cake"—filled with lithium deuteride. (According to Hans Bethe, one of the creators of the American bomb, the Americans had considered this compound, along with other fillers, for the original "alarm clock" design, which was analogous to the *sloyka*. Unlike Landau's calculations, however, those of the Americans could not predict the yield.)

Part of the mathematics developed to this end was declassified and published during the first nuclear thaw in 1958. The resulting paper on numerical inte-

Landau's Science

In 1927 Lev Landau became one of the first to introduce the density matrix, a mathematical tool for dealing with mixed quantum states. He went on to describe the behavior of an electron gas, finding that electrons in a magnetic field are confined to orbits of discrete energy, now called Landau levels. In the realm of astrophysics, he postulated the existence of neutron cores, which have come to be known as neutron stars. And simultaneously with an American group, he explained how cosmic rays produce electron showers.

Landau's greatest contributions involve phase transitions of the second kind, in which a substance changes from an ordered to a disordered configuration without absorbing heat. One such transition is that of helium from a normal to a superfluid state. Landau described superfluidity by means of a roton, an excitation that has since been discovered but whose true nature remains mysterious. He also introduced the order parameter, a kind of large-scale wave function. Applied to superfluid helium, the order parameter described the behavior of atoms in their common quantum state; applied to superconductors, it revealed such properties as how current flows around an intruding magnetic field; applied to superfluid helium 3, it described a host of complex configurations.

In 1950, with his student Vitaly Ginzburg, Landau developed a framework in which the universal phenomenon of broken symmetry—by which, for example, quarks are believed to acquire mass—can be simply described, again by means of an order parameter.

Landau also studied how ferromagnets—the magnets of ordinary experience—divide into domains in which the microscopic components point in different directions. He worked on plasma physics and in 1956 developed the theory of Fermi liquids, which contain strongly interacting electronlike particles. His interests encompassed particle theory as well: he developed a statistical picture of a nucleus, challenged the consistency of quantum electrodynamics and, along with others, postulated the principle of charge-parity conservation. And this is only a partial list of his achievements.

—*The Editors*

COURTESY OF GENNADY GORELIK

TEN COMMANDMENTS of Landau, an engraved list of his major discoveries, were drawn up by Landau's students to celebrate the physicist's 50th birthday in 1958. Landau created a "school" of physics—a style of describing the natural world—which he passed on through his teachings.

gration looks rather strange in Landau's *Collected Works*. Also in this volume is perhaps his most far-reaching publication ever, co-authored with Vitaly Ginzburg in 1950 in the midst of bomb research. The paper describes a simple and powerful framework in which an enormous variety of systems—superconductors, elementary particles, chemical mixtures and so on—can be described. It anticipates the generic phenomenon of symmetry breaking, vital to particle theorists, among others.

For his contributions to the atomic and hydrogen bombs, Landau received, ironically enough, two Stalin Prizes, in 1949 and 1953. In 1954 he was awarded the title "Hero of Socialist Labor."

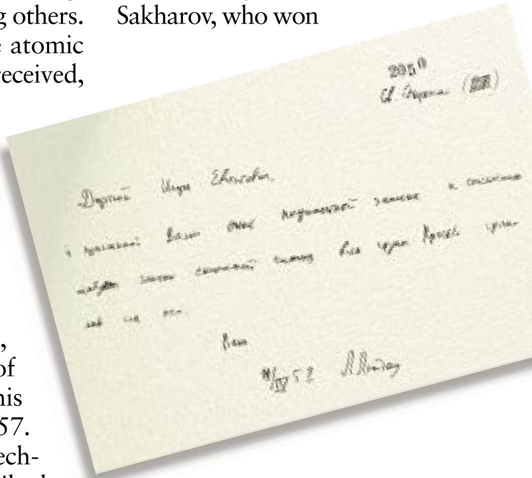
In 1957, I believe Landau asked the central Communist Party for permission to go abroad. At the party's request, the KGB produced transcripts of Landau's conversations with his friends between 1947 and 1957. These drew on "special techniques"—as the KGB described them—and informants' reports. The document was found in the archives of the Communist Party; it is revealing.

In the transcripts, Landau describes himself as a "scientist slave." Given his rebellious nature, that is not surprising; besides, his experiences of the 1930s had turned him against Stalin. But the documents reveal a deeper political transformation. On one occasion a friend remarked that if Lenin were suddenly to revive, he would be horrified by what he saw. "Lenin employed the same kinds of repression," Landau retorted.

Later, he said: "Our regime, as I have learned since 1937, is definitely a fascist regime, and it could not change by itself in any simple way.... I believe that while this regime exists, it is ridiculous to hope for its development into some decent thing.... The question about a peaceful liquidation of our regime is a question about the future of humankind.... Without fascism there is no war." Finally, he concluded, "It is quite clear that Lenin was the first fascist."

It is important to realize how extraordinary these views were. Almost all Landau's colleagues were profoundly pro-Soviet—including Igor Evgenyevich Tamm, who won the first Soviet Nobel Prize for Physics, and Andrei Sakharov, who won the first Soviet Nobel Prize for Peace. Those who did recognize Stalin's sins saw him as a criminal who had betrayed Lenin's cause; still, Lenin remained a hero.

So far as I know, there were only two physicists who expressed their distaste for working on Stalin's bomb. One was Landau, and the other was Mikhail Leontovich, who in 1951 became the head of theoretical research in the Soviet fusion program. Landau served on the bomb project because it shielded him from the authorities. He tried to limit his participation and at one time cursed the physicist Yakov Zeldovich (as "that bitch") for attempting to expand it. After Stalin died, Landau commented to a friend and pupil, Isaac M. Khalatnikov: "That's it. He's gone. I'm no longer afraid of him, and I won't work on [nuclear weapons] anymore." And he quit the bomb project.



COURTESY OF GENNADY GORELIK

TOP-SECRET NOTE by Landau asks Igor Evgenyevich Tamm to send data on particle velocities, needed for calculations on the first Soviet hydrogen bomb.

An obvious question remains. Given that Landau was reluctant to work on the bomb, how is it that his contributions were so substantial? Khalatnikov, who became the director of the Landau Institute for Theoretical Physics, created in 1965, offered me an answer: Landau was simply unable to do a shoddy piece of work.

Thus, Landau was exceptional in being able to understand the true nature of the Soviet system and for being courageous enough to express himself. Among the Soviet bomb physicists, his position was curiously poignant, because he realized with full clarity for whose hands he was creating the mighty weapon.

In 1962 Landau suffered a car accident. He survived, but with severe brain injuries that, tragically, changed his personality and robbed him of his scientific genius. Landau seemed to be well aware that he had changed. He died on April 1, 1968; his student Alexander I. Ahkiezer recalls that on receiving the news, he assumed it was just another of Dau's April Fools' jokes.

After just two weeks of studying the KGB files, I found myself unable to continue. The multitude of broken lives recorded in them overwhelmed me emotionally. After the fall of the Soviet Union in 1991, the KGB was restructured, and so far as I know, no historian has had regular access to the archives since then. Unquestionably, the files still conceal many amazing stories—perhaps even a few more about this extraordinary physicist. SA

The Author

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The Machinery of

Studies of the brains of monkeys and, more recently, of humans are revealing the neural underpinnings of working memory, one of the mind's most crucial functions

by Tim Beardsley, *staff writer*

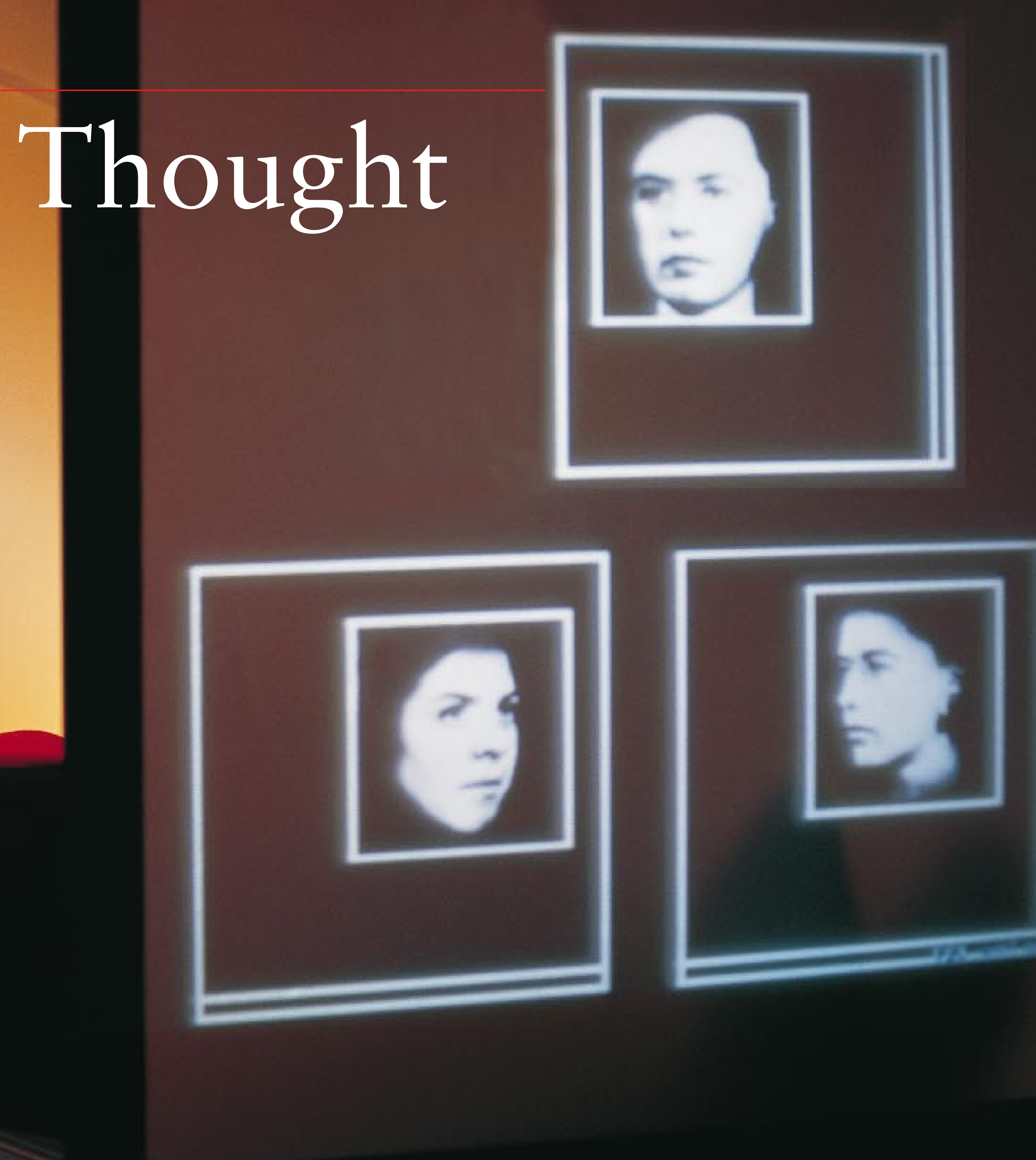
KAY CHERNUSH PHOTOGRAPHY

In a darkened basement laboratory on the campus of the National Institutes of Health in Bethesda, Md., volunteers earn $100 by lying for two hours with their head inside a huge magnetic resonance imaging (MRI) machine while they gaze at a screen reflected in a mirror. The screen periodically displays black-and-white pictures: some are faces, others scrambled blocks of light and shade. When a face appears on the screen, the subject signals by pressing buttons whether the face is a new one or the same as one that was shown a few seconds earlier as a "target" to be remembered.

As the test proceeds, the MRI machine bombards the volunteer's brain with radio-frequency waves that excite hydrogen atoms in the bloodstream, causing the atoms to emit signals of their own. Later, the machine transforms the resulting electromagnetic cacophony into color-coded maps of oxygen consumption levels throughout the subject's brain. Because increased oxygen consumption results from heightened neural activity, researchers can analyze these brain maps to learn what parts of the brain work hardest when a person recognizes a face.

With experiments such as these, researchers are beginning to fathom the neural processes underlying "working memory"—the limited, short-term store of currently rele-

Thought

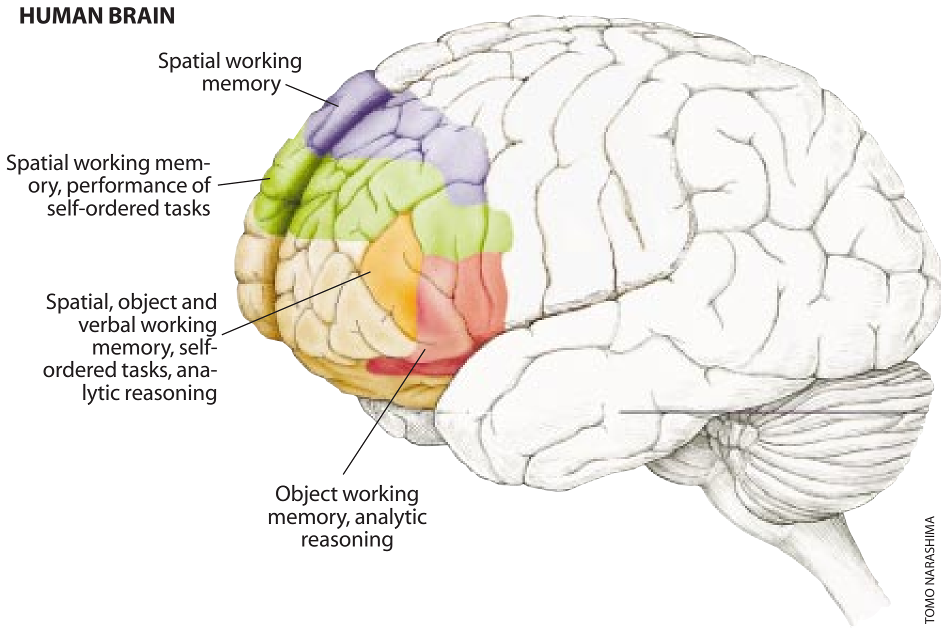


VOLUNTEER research subject in a study of brain activity lies in a magnetic resonance imaging (MRI) machine at the National Institutes of Health. By looking in a mirror, she can see a screen displaying a selection of visual cues—in this case, faces. When the subject recognizes cues that meet set criteria, she responds by pressing one of two buttons. The MRI machine records which parts of her brain are most active as she seeks and then recognizes cues.

vant information that we draw on when we comprehend a sentence, follow a previously decided plan of action or remember a telephone number. When we bring to mind the name of Russia's president, for instance, that information is temporarily copied from long-term memory into working memory.

Psychological studies have demonstrated that working memory is fundamental to the human ability to reason and make judgments that rely on remembered contextual information. There are compelling humanitarian reasons for understanding working memory. Schizophrenia, one of the most devastating mental illnesses, is believed to be caused in part by a defect of this system. Studies of the molecular basis of working memory "have implications for drug treatment in mental illness," says Patricia Goldman-Rakic of Yale University, one of the most prominent investigators of working memory.

An intensive research effort has started to produce detailed information about the areas of the brain involved when we engage this vital intellectual faculty and is illuminating the patterns of neural activity that allow it to operate. The important role of specific brain chemicals in working memory is also becoming clear. Yet for all the progress, researchers have still to agree on how working memory is controlled and organized.



PREFRONTAL CORTEX is vital for maintaining in humans and in monkeys the temporary store of information known as working memory. Different tasks excite subregions within the prefrontal cortex, although details are controversial.

From Electrodes to Fast MRI

The prototypical test for working memory involves what is called delayed choice. An animal or a person signals where some specific cue was previously seen, before an imposed period of waiting. Thus, a monkey might be given a choice of two jars in separate positions and be rewarded for pointing to the one in which it previously saw food placed.

The task provides no clue to the correct response at the time of testing, so the monkey must rely on its recollection of the correct location. A related challenge rewards an animal for remembering which of several images it saw presented initially as a target. The NIH volunteers who were recalling faces were engaged in a variant of this test.

Technological advances have greatly enhanced researchers' ability to probe the neural underpinnings of such capacities. Investigators began studying cerebral activity in working memory some 40 years ago by inserting electrodes into individual neurons within the brains of monkeys. This method has its limits, however. Although monkey brains have clear anatomical similarities to human brains, the animals' behavior is vastly simpler, making detailed comparisons with human thinking problematic. Lacking language, the animals must be patiently trained over a period of weeks to master tasks that a person would pick up in a minute.

Electrode-recording techniques are also ethically unacceptable for use on people. Researchers try to learn which parts of our species' brain do what by studying the effects of damage caused by injury, disease or therapeutic surgery. Yet patients have different medical histories—and their brains vary in exact shape—so interpreting this clinical data is tricky at best.

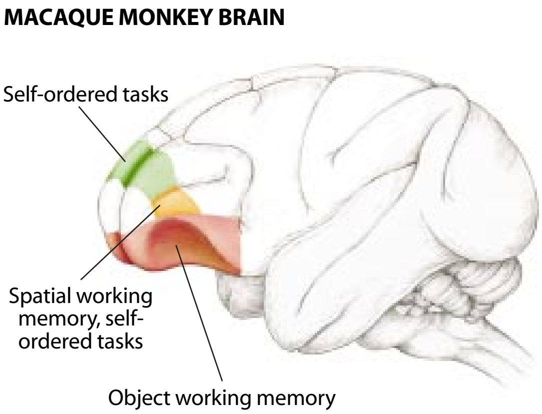
Earlier this decade, positron emission tomography, or PET scanning, made enormous strides by showing which parts of the human brain are busiest when performing different tasks, such as hearing words or speaking. But PET requires exposing the human subjects to radioactive tracers, and to keep radiation doses within acceptable levels, researchers have to use techniques that can resolve brain areas only about a centimeter apart. Also, during a delayed-choice task, PET scans are too slow to distinguish between the neural activity pattern of a target being held in mind and the pattern that follows a few seconds later when the target is recognized.

The new technique used at NIH and elsewhere, called functional MRI, can resolve the position of active neurons to about two millimeters and is fast enough to study activity before and after the brain recognizes a cue on a screen. The rapidly improving technique has over the past two years become the state of the art for functional brain imaging.

Monkey Puzzle

Experiments involving electrodes implanted in monkeys still provide crucial information, however, because they reveal in fine detail and on a millisecond-by-millisecond timetable what happens as these primates respond to cues and rewards. When animals perform such feats of working memory, several brain regions can play a role, but as Joachín M. Fuster of the University of California at Los Angeles showed in the 1970s, one area that is always involved is the prefrontal cortex.

The prefrontal cortex is a layer of tissue that lies just behind the forehead. With neural connections to almost all the areas of the brain that process sensory information, it is well situated to maintain a flexible store of information relevant to any task at hand. It is also the part of the brain that has grown the most in humans, as compared with monkeys. Monkeys missing some parts of their prefrontal cortex preserve their



long-term memory but perform miserably on delayed-choice tests. Humans similarly afflicted suffer a reduced attention span and ability to plan.

Fuster and, separately, Kisou Kubota and Hiroaki Niki of the Kyoto Primate Center made electrical recordings from a variety of neurons in the monkey prefrontal cortex, including some that apparently were active only while the animals were holding information in working memory. Subsequently, Goldman-Rakic and her colleagues have explored working memory in monkeys with more sophisticated tests. They established that prefrontal neural activity during a delayed-choice task indeed corresponds well to the functioning of working memory.

Goldman-Rakic and her associate Graham Williams have taken the analysis all the way to the subcellular level, showing that receptors for the neurotransmitter dopamine pivotally influence the responsiveness of cells in the prefrontal cortex and their actions in working memory. "There is no other example I know" of research that spans the gulf between behavior and subcellular function, Goldman-Rakic notes. She and her colleagues have recently shown that administering antischizophrenic drugs to monkeys for six months leads to specific changes in the numbers of two different types of dopamine receptors in that region, further evidence that schizophrenia—or its treatment—alters normal function there.

Research by other scientists supports the view that the prefrontal cortex could sustain working memory. Robert Desimone of the National Institute of Mental Health, along with Earl K. Miller, Cynthia Erickson and others, has discovered in the monkey's prefrontal cortex neurons that fire at different rates during the delayed-choice task, depending on the target the animal saw previously. Neurons in other parts of the brain generally "forget" the target when a distracting stimulus appears—their rate of firing changes. Prefrontal neurons detected by Desimone and his colleagues, in contrast, maintain their rate of activity during a delayed-choice task even after the animal is presented with irrelevant, distracting stimuli.

Activity in some prefrontal neurons, then, appears to embody directly the temporary working memory of the appearance of a target the animal is seeking. Other researchers have found prefrontal neurons that seem to maintain locations in working memory: Giuseppe Di Pellegrino of the University of Bologna and Steven Wise of the National Institute of Mental Health have found prefrontal neurons that are busiest when an animal has to remember where it saw a cue. Stimuli fail to excite the same frenzy unless they are in the location that is the current target for the task.

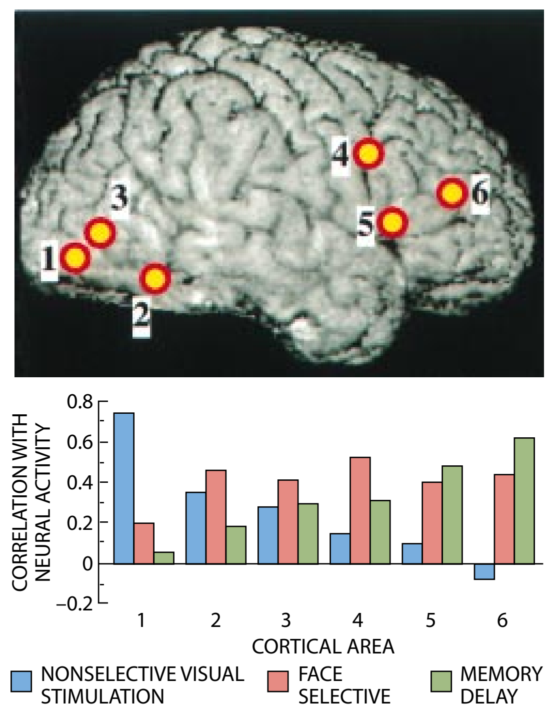
Neurons in the prefrontal cortex could thus apparently control how animals respond in a delayed-choice task. Fuster, one of the pioneers in the field, says the prefrontal cortex "serves the overarching function of the temporal organization of behavior" by driving networks that maintain currently important information in an active state. And neurons in the prefrontal cortex might exert their influence in more subtle ways, too.

Besides controlling directly the responses in delayed-choice tests, Desimone believes, the prefrontal cortex might tune the visual and possibly other perceptual systems to the task at hand. "What's loaded into working memory goes back to sensory processing," he suggests. Hundreds of experiments with both animals and people have shown that organisms are far more likely to perceive and react to cues relevant to their current needs than to irrelevant stimuli. This effect explains why we are more likely to notice the aroma wafting from a neighbor's grill when we are hungry than just after eating. If Desimone is right, the prefrontal cortex could be responsible for focusing an animal's attention and thus possibly steering awareness.

Imaging studies with PET and functional MRI corroborate the evidence from brain injuries that the human prefrontal cortex, like that of monkeys, is central to working memory. Several research groups have now imaged activity in the prefrontal cortex when people remember things from moment to moment. Different tasks may also require various other brain regions closer to the back of the head, but for primates in general, the prefrontal cortex always seems to be busy when target information is kept "in mind."

The Devil in the Details

Having shown that the prefrontal cortex is crucial to working memory, investigators naturally want to understand its internal structure. Goldman-Rakic and her associates at Yale have found evidence that when an animal retains information about a spatial location, the prefrontal activity is confined to a specific subregion. A separate area below it is most active when an animal is remembering the appearance of an object. These findings, together



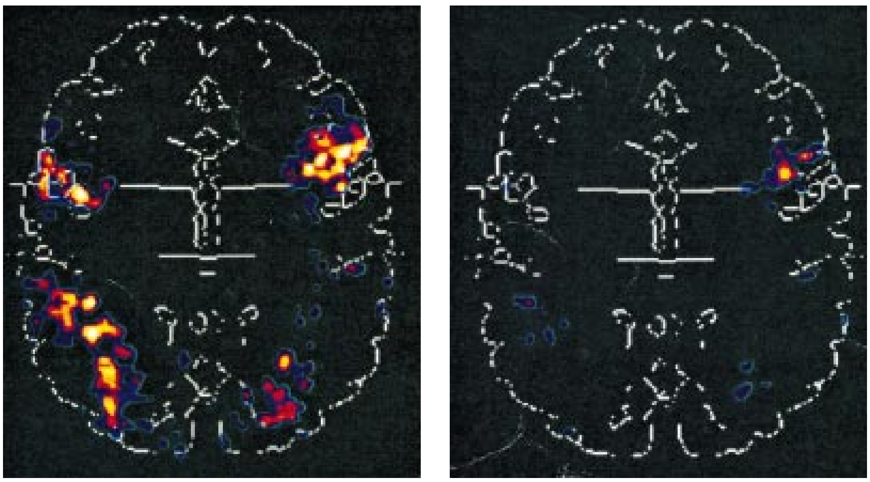
NATIONAL INSTITUTE OF MENTAL HEALTH

JOHNNY JOHNSON

MRI shows that parts of the prefrontal cortex (*4, 5, 6*) are active while a face is remembered. Other areas (*1, 2, 3*) respond to seen faces and patterns.

with observations of the anatomy of neural pathways, led Goldman-Rakic to propose that the prefrontal cortex is organized into regions that temporarily store information about different sensory domains: one for the domain of spatial cues, one for cues relating to an object's appearance and perhaps others for various types of cues.

There are, moreover, some indications that the human prefrontal cortex may be organized along similar domain-specific lines. A PET study reported last year by Susan M. Courtney, Leslie G. Ungerleider and their colleagues at the National Institute of Mental Health found that in humans, as in the monkeys studied earlier by Goldman-Rakic, certain brain areas are especially active during exercises that challenge working memory for visual details and for locations. Moreover, the most active brain regions lie in similar relative positions in both species.



JOHN D. E. GABRIELI

BOTH SIDES of the prefrontal cortex (*top*) are very active when volunteers perform hard analytical tasks (*left image*). During more moderate reasoning, the activity is reduced and concentrated on the right side (*right image*).

Goldman-Rakic's proposal about the organization of the prefrontal cortex argues against the standard view of the various components of working memory. The British psychologist Alan Baddely proposed in 1974 that working memory has a hierarchical structure, in which an "executive system" in the prefrontal cortex allocates processing resources to separate "slave" buffers for verbal and spatial information. The memory buffers were supposed to be well behind the prefrontal cortex. But Goldman-Rakic is unconvinced that the brain's executive processes are confined to any particular location. Moreover, in the traditional model, memories organized by domain would lie somewhere behind the prefrontal cortex, not within it.

The high-speed imaging capability of functional MRI is now able to help resolve the question. A study that Courtney and Ungerleider and their colleagues published in April in *Nature* pinpoints the part of the brain that is liveliest while working memory holds an image of a face. That region—the middle part of the prefrontal cortex—has been fingered as the crux of working memory in a variety of studies.

Yet the face-recognition task Courtney and company used does not involve any obviously executive functions, Ungerleider notes. Their findings thus contradict the view that only executive functions reside within the prefrontal cortex, but they do fit with Goldman-Rakic's scheme. Similarly, Jonathan D. Cohen of Carnegie Mellon University and his co-workers found a region of the prefrontal cortex partly overlapping the one identified by Courtney that is active while subjects remember letters seen in a sequence. The more the subjects had to remember in the Cohen experiment, the more active their prefrontal regions. So Cohen's result also suggests that working memories are actually stored, in part, in the prefrontal cortex. Domain-specific organization "is the dominant view" of the prefrontal cortex, Wise says.

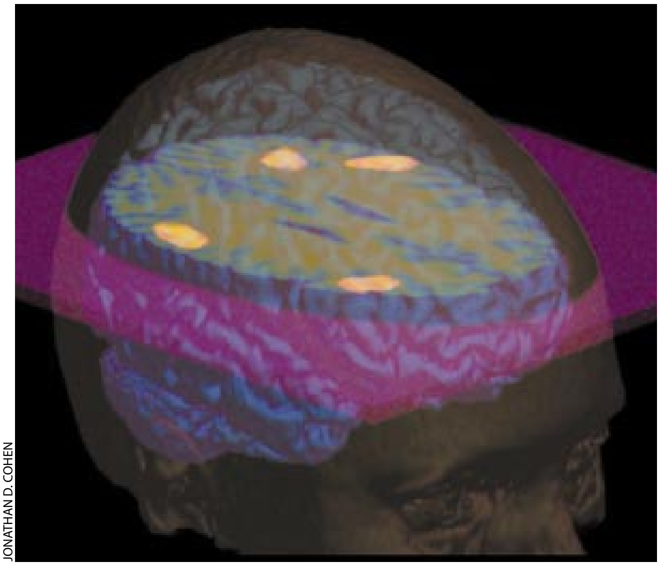
Wise himself does not subscribe to that dominant view, however. He points, for example, to a study reported in *Science* in May by Miller and his associates at the Massachusetts Institute of Technology. The researchers recorded from neurons in the prefrontal cortex of monkeys while they solved delayed-choice tasks that required them to remember information about both the appearance and spatial locations of objects. Over half the neurons from which Miller recorded were sensitive to both attributes, a result not expected if domain-specific organization prevails. "It argues against Goldman-Rakic's view that identity and location are processed in different parts of the prefrontal cortex," Miller says.

Goldman-Rakic responds that she and her colleagues have recently found hundreds of cells in part of the prefrontal cortex that respond selectively even in untrained animals to objects or faces—further evidence, she asserts, that the information in that area is organized in part by sensory domain. "We do feel the evidence is overwhelming that the functions of neurons in the prefrontal cortex are dictated in large part by the neurons' sensory inputs," she says. Moreover, Goldman-Rakic believes technical problems cast doubt on Miller's experiment. She maintains the targets he used were too close to the center of the visual field, which could produce spurious firings.

Keeping Self-Control

Michael Petrides of McGill University, another leading figure in the field, has mounted a different challenge to the standard view. Petrides's studies point to two distinct levels of processing, both within the prefrontal cortex. In his view the levels are distinguished primarily not by whether they maintain information about place or objects, as Goldman-Rakic holds, but rather by the abstractness of the processing they perform. The lower level in the hierarchy—physically lower in the brain as well as conceptually lower—retrieves data from long-term memory storage elsewhere. The higher "dorsolateral" level, in contrast, monitors the brain's processes and enables it to keep track of multiple events. This higher monitoring level is called on when subjects are asked, for example, to articulate a random list of each number from 1 to 10, with no repetition: a subject has to remember each digit already chosen.

Petrides finds that both humans and monkeys with lesions in the dorsolateral part of the prefrontal cortex are crippled in their ability to monitor their own mental processes: they perform



JONATHAN D. COHEN

BRAIN REGIONS show more activity as subjects have to remember more letters in a memory task. One such region (*closest to the viewer*) is in the right prefrontal cortex.

badly on special tests he has devised that require subjects to remember their earlier responses during the test. He also cites PET studies of healthy humans that find heightened activity in the same region when subjects are performing the tasks he uses. The finding is the same whether the tasks involve spatial cues or not. "The material does not seem to matter—the process is crucial," Petrides says.

Other researchers have found evidence to support the notion that the higher parts of the prefrontal cortex are key for self-monitoring. In an experiment by Mark D'Esposito and his associates at the University of Pennsylvania, volunteers performed either one or both of two tasks that, separately, did not require working memory. One task required subjects to say which words in a list read aloud were the names of vegetables, whereas the other asked them to match a feature of a geometric figure seen in different orientations. Functional MRI showed that the dorsoventral prefrontal cortex became active only when subjects attempted both tasks simultaneously. And in April at a meeting of the Cognitive Neuroscience Society, D'Esposito presented a meta-analysis of 25 different neuroimaging studies. The analysis supported Petrides's general notion that tasks involving more computation involve higher regions of the prefrontal cortex. "It was amazing that this came out," D'Esposito says.

D'Esposito's analysis also confirmed earlier indications that humans, far more than monkeys, represent different types of information in different halves of the brain. The meta-analysis did not, however, detect the upper/lower distinction between spatial and object working memory that Goldman-Rakic espouses.

Asymmetry of the human hemispheres is becoming apparent to other researchers as well. John D. E. Gabrieli and his colleagues at Stanford University have used functional MRI to study the brains of volunteers who were solving pictorial puzzles such as those often found on intelligence tests. The puzzles were of three types. One group was trivial, requiring the subject simply to select a symbol identical to a sample. A second group was a little harder: people had to select a figure with a combination of features that was absent from an array of sample figures. The third group contained more taxing problems that required analytical reasoning.

Gabrieli's study sheds some light on the debate over the organization of the prefrontal cortex. When volunteers pondered the intermediate class of tasks, which most resembled the tasks other investigators have used when studying working memory, the right side of the higher part of the prefrontal cortex was prominently active. Moreover, the activity was in areas that other researchers have found to be used when cues about spatial location are stored. This result fits Goldman-Rakic's idea that working memory for spatial location is stored in the higher regions of the prefrontal cortex, because these intermediate tasks all demanded that subjects visualize features in different locations.

When the volunteers in Gabrieli's experiment worked on the hard problems, however, the prefrontal cortices of the subjects became even more active, on the left as well as the right side. The added complexity produced a pattern of activation like that Petrides has found during his tests of self-monitoring.

Gabrieli's data thus provide some support for Petrides's theory of a higher executive level in the prefrontal cortex, as well as for Goldman-Rakic's view that domain-specific regions exist there. "There are definitely domain-specific places," Gabrieli says. "And there are others that rise above that." In other words, both sides in the debate over domain-specific organization of the prefrontal cortex may have a point. Yet in June, Matthew F. S. Rushworth of the University of Oxford and his colleagues reported in the *Journal of Neuroscience* that monkeys with large lesions in their lower prefrontal cortex could still perform well on delayed-choice tests. The finding casts new doubt on the theory that object working memory resides there and seems to support Petrides.

It may take years before the outstanding questions about the prefrontal cortex are settled and the operation of the brain's executive functions are pinned down to everyone's satisfaction. "If you put a theory out, people will attack it," Goldman-Rakic muses. "Everyone is contributing." And the modus operandi of the brain's decision-making apparatus is slowly becoming visible. "We are getting," Goldman-Rakic observes, "to the point where we can understand the cellular basis of cognition." SA

Further Reading

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DOWN-REGULATION OF THE D_1 AND D_5 DOPAMINE RECEPTORS IN THE PRIMATE PREFRONTAL CORTEX BY CHRONIC TREATMENT WITH ANTIPSYCHOTIC DRUGS. Michael S. Lidow, John D. Elsworth and Patricia S. Goldman-Rakic in *Journal of Pharmacology and Experimental Therapeutics,* Vol. 281, No. 1, pages 597–603; April 1997.

TEMPORAL DYNAMICS OF BRAIN ACTIVATION DURING A WORKING MEMORY TASK. J. D. Cohen, W. M. Perlstein, T. S. Braver, L. E. Nystrom, D. C. Noll, J. Jonides and E. E. Smith in *Nature,* Vol. 386, pages 604–608; April 10, 1997.

TRANSIENT AND SUSTAINED ACTIVITY IN A DISTRIBUTED NEURAL SYSTEM FOR HUMAN WORKING MEMORY. S. M. Courtney, L. G. Ungerleider, K. Keil and James V. Haxby, *ibid,* pages 608–611.

INTEGRATION OF WHAT AND WHERE IN THE PRIMATE PREFRONTAL CORTEX. S. Chenchal Rao, Gregor Rainer and Earl K. Miller in *Science,* Vol. 276, pages 821–824; May 2, 1997.

THE AMATEUR SCIENTIST

by Shawn Carlson

Getting a Charge out of Rain

One of my best friends in college was a burly, carrot-topped Irishman named Michael North, affectionately known to us as Red. He was a forestry major, a brilliant chess player and one of the physically strongest men I have ever known. Red spent his summers working for the U.S. Forestry Service as a logger and occasional fire lookout in tall towers on the high peaks of the Sierra Nevada in California. One afternoon he took a nap that nearly cost him his life. By the time the thunder woke him, it was too late to escape. The black base of the thunderhead's anvil was already poised directly overhead, only a few hundred feet above the tip of the pointed, all-metal tower. With only seconds to act, he grabbed four glass beer steins and set them on the metal floor. He hurriedly positioned a small wooden stool onto the glasses and crouched his 250-pound body atop the stool. Within moments the first bolt hit, sending the tower reeling and temporarily knocking him off his insulated perch. Over the next three hours, by Red's count, lightning struck the tower 30 more times.

The power of lightning, as I'm sure Red agrees, is one of the most awe-inspiring phenomena in nature. (If you're not already convinced, see the articles on lightning beginning on page 50.) Yet despite both the fascination and terror it evokes in most people, scientists still do not understand exactly how lightning comes about. It is clear that cosmic rays liberate large quantities of both positive and negative charge in the atmosphere by ripping away electrons from atoms in the air. These charges collect on the water droplets that make up the thundercloud. But even the experts are not sure just how these drops routinely acquire tens of millions of excess positive or negative charges to become highly charged themselves. And it is still quite a mystery how these charged droplets manage to separate from one another, forming distinct positive and negative regions within the cloud that are intense enough to generate thunderbolts.

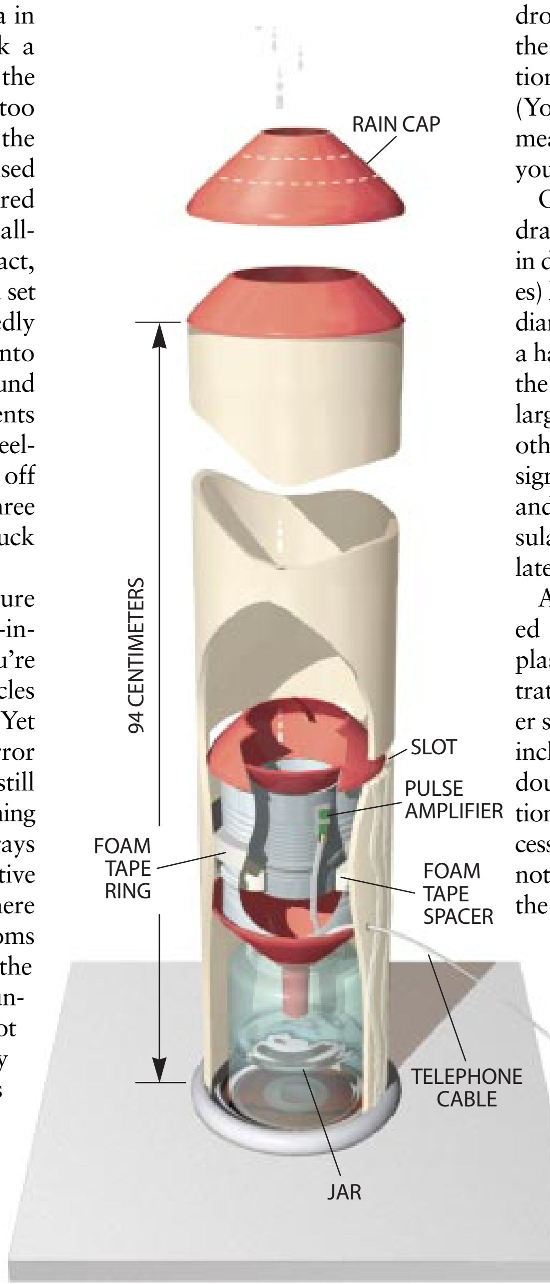
Lightning is simply too dangerous an animal to be let loose inside the amateur laboratory. But it is only one electrical component of a storm. Raindrops carry their charge with them as they fall, removing it from the cloud and depositing it into the earth. Although lightning is more dramatic, rainfall may actually transport more charge to the ground. The device described here will let you measure the charge on individual raindrops as they fall.

This instrument works on the principle of electrical induction. A charged drop falling through a metal cylinder will momentarily change the electrical potential of the cylinder. A positively charged drop will raise the potential, whereas a negatively charged drop will lower it. The size of the change reveals the magnitude of the charge on the raindrop. Furthermore, the drop escapes the apparatus unscathed, and so additional measurements of it can be made. (You might, for example, want to try to measure the mass of each drop. Can you figure out how?)

Our instrument is made of a plastic drainpipe 10 centimeters (four inches) in diameter and 94 centimeters (37 inches) long, some plastic funnels of the same diameter, two nested metal cylinders and a handful of electronic components. For the cylinders, I used two soup cans, one large enough to fit comfortably over the other. Electrically connect wires for the signals to the outside of the smaller can and the inside of the larger can; then insulate the cans by dipping each one in latex-based enamel paint.

After the paint dries, secure the painted metal cans inside the center of the plastic drainpipe, as shown in the illustration on this page. I wrapped the outer soup can about two centimeters (one inch) from one end with three layers of double-sided foam tape (3M Corporation, part no. 051131-06439). This process builds up a flexible ring of foam. Do not remove the protective backing from the last layer of tape. Rather leave it attached so you can slide the assembly into position and have friction hold it in place.

The two inverted funnels above the soup cans act as baffles to keep everything dry. And hav-



SOUP CANS, funnels and plastic drainpipe help to measure the electrical charge on a single raindrop.

BRYAN CHRISTIE

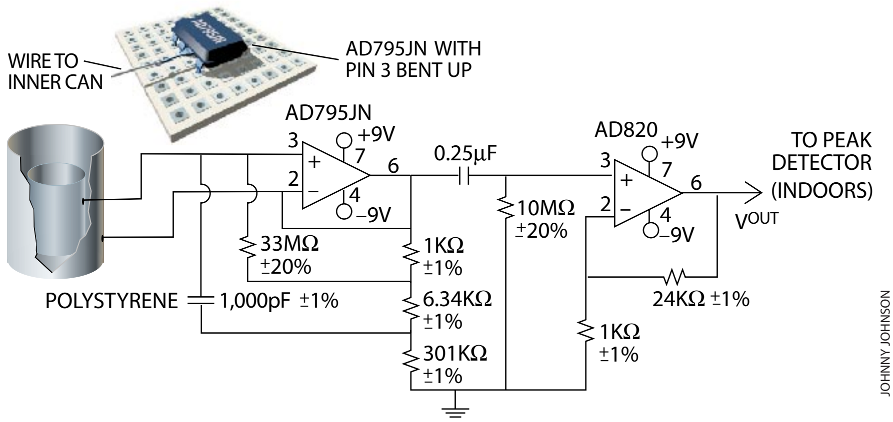
ing a set of funnels to act as "rain caps" is convenient. Select a cap that will let drops enter the instrument at a manageable rate. Use a small aperture cap in a downpour and a larger aperture cap during drizzle. The bottom funnel lets you collect the drops for any chemical analysis you may wish to do.

Cut the two inverted funnels so that their openings are about two centimeters narrower than that of the inner can. To fix the funnels into place above and below the cans, you'll need two rings for the inside of the drainpipe. Carefully slice two short segments from the end of some extra drainpipe and remove a centimeter or so from each ring; when compressed, the rings should fit snugly inside the drainpipe. Use Plastix (Loctite Company, item no. 82565) to rejoin the cut ends and to glue the compressed rings to the funnels. You will also need to cut slots into the pipe as shown. Use these openings to swab inside the pipe thoroughly with epoxy. Then push the funnel into position.

When the epoxy sets, carefully dope the joints with silicon aquarium cement to create a waterproof seal. You want any drops that strike this funnel to exit through the slots, not drip farther into the instrument. The bottom funnel should be epoxied in place similarly. The instrument stands on a plastic flange that is fixed to a weatherproof base. Just push the assembly over the flange; do not attach it permanently.

Measuring the tiny charge on a single raindrop might seem impossibly difficult. Barrie Gilbert of Analog Devices in Beaverton, Ore., devised an extraordinary solution especially for this project, which, I believe, sets a new standard for these instruments. His circuits use some clever tricks that render the device intrinsically calibrated (see the SAS Web page for details). Further, by using two nested cans and driving the outer can from the amplifier's output, Gilbert's scheme converts the charge on the raindrop to a substantial voltage, while reducing external electrical interference.

Position this circuit between the two cans, as shown in the illustration on the opposite page. The four-wire telephone cable runs inside your home where you can remain warm and dry. If at all possible, read this signal directly into your computer using an analog-to-digital converter. This capability isn't as exotic as it sounds. For $310, the Multipurpose Lab Interface, made by Vernier Software (Portland, Ore., telephone: 503-297-5317), will serve nicely.



PULSE AMPLIFIER puts out a voltage spike when a drop passes through.

Alternatively, you could feed the signal into Gilbert's other nifty circuit, shown below. This dual peak detector saves exactly half the maximum voltage, which can be read with a handheld digital voltmeter. A positively charged drop results in a positive final voltage, whereas a negatively charged drop yields a negative final voltage.

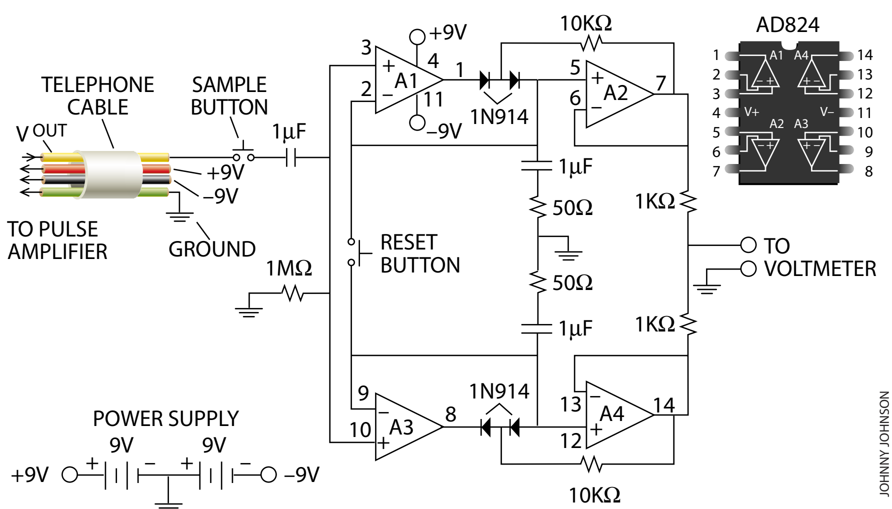
Using the peak detector requires good reflexes. Momentarily depress the reset button and then push down on the "sample" button. The output voltage of the peak detector will jump when a charged drop passes though the instrument. Quickly release the sample button to prevent another drop from upsetting the measurement. Record this voltage with your voltmeter. When you're ready, press the reset button, hold down the sample button, and await the next drop.

Charged drops typically give readings of about 0.3 volt. Because larger charges produce larger voltage spikes, measuring the maximum voltage provides an estimate of the charge on the drop:

$$\text{Charge} = \frac{K \times V^{\max}}{\sqrt{1 + (D/L)^2}} \times 10^{-12} \text{ coulomb}$$

where $K = 1$ using pulse amplifier alone
$K = 2$ using dual peak detector
D = diameter of inner can
L = length of inner can

The electronic components required for these circuits can be purchased from Future Electronics in Bolton, Mass.; call (800) 655-0006. For more information about this project, check out the Society for Amateur Scientists's World Wide Web site at www.thesphere.com/SAS/ or call (619) 239-8807 or (800) 873-8767. You may write the society at 4735 Clairemont Square, Suite 179, San Diego, CA 92117. SA



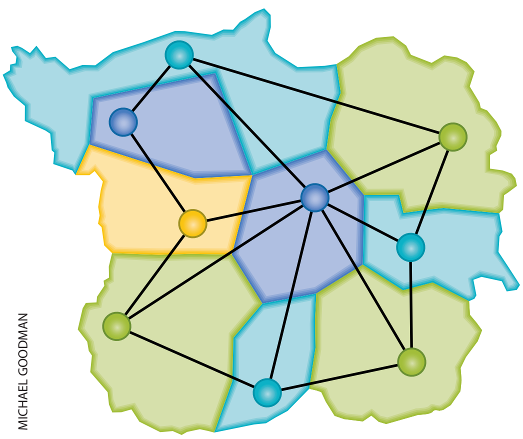
DUAL PEAK DETECTOR allows measurement with a handheld digital voltmeter.

MATHEMATICAL RECREATIONS

by Ian Stewart

Empires on the Moon

On the face of it, the Earth-moon problem is just a bit of harmless fun. Earth has been carved up into separate nations, each owning one connected region of territory—land and sea. Moreover, each earthly nation has annexed a region of the moon, to create an empire that consists of two pieces: one on Earth, the



MICHAEL GOODMAN

ANY MAP can be represented as a "graph" by marking a node—say, the capital city—in each country and connecting those cities whose territories have a common border. The coloring problem then requires finding a different color for any two connected cities.

other on its satellite. What is the smallest number of colors that will cover any such map, so that both countries in any particular empire receive the same color but no two adjacent regions receive the same color—either on the moon or Earth?

The problem, which I first described in the April 1993 column, is highly artificial. A typically useless product of ivory tower intellectuals?

Not at all. In October 1993 Joan P. Hutchinson of Macalester College in St. Paul, Minn., published a thorough survey of such questions, "Coloring Ordinary Maps, Maps of Empires, and Maps of the Moon," in *Mathematics* magazine (Vol. 66, No. 4). In one section she described an application to the testing of printed circuit boards, discovered by researchers at AT&T Bell Laboratories in Murray Hill, N.J. The connection is not at all obvious. This month, I'll tell you about maps, empires and graphs; many moons later, we'll take a look at electronic circuit boards.

A map is an arrangement of regions, either in the plane or on a surface such as a sphere. Each region is a single connected part of the plane or surface, and the regions make contact along common boundaries, which are curves.

A graph is a diagram formed from a number of blobs, called nodes or vertices, which are joined together by a number of lines, known as edges. Graphs are simpler and more abstract than maps. Any map can, however, be represented as a graph by assigning a node to each region and joining two such nodes by an edge—if and only if the corresponding regions share a common stretch of border.

Imagine the nodes as capital cities and the edges as highways that join cities in adjacent countries, crossing at their common border. This is the map graph. It represents which regions share a common boundary with others but removes various distractions, such as the shapes.

A graph is said to be planar if it can be drawn in the plane without any edges crossing. If we start with a map in the plane, its map graph is obviously planar. More surprisingly, if a map is drawn on the sphere or on several disconnected planes and spheres—as is the case for Earth-moon maps—the resulting graph is still always planar. To see why, imagine a map drawn on a sphere. Put a node in each region, and whenever two regions have a common boundary, connect the corresponding nodes with edges. The result is a graph that can be drawn on a sphere without any edges crossing.

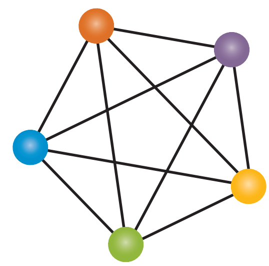
But any such graph can be opened up and spread out on a plane. To do this, imagine cutting a small hole in the sphere, which does not meet any of the nodes or edges of the graph. Now imagine that the sphere is made from elastic sheeting. You can pull that tiny hole, making it bigger and bigger. The rest of the sphere stretches and deforms, carrying the graph with it. By pulling it far enough, you can flatten it out into a disk. Lay the disk on the plane, and you've now drawn the map graph on a plane without any edges crossing.

If the map is drawn on several spheres, we just do the same for each of them and lay all the resulting disks out in the same plane without overlaps. The resulting graph will be disconnected—it will fall into several separate pieces, one for each sphere—but that is quite a common feature of graphs.

One important graph is the complete graph K_n. It has n nodes and an edge joining every pair of distinct nodes. If n is five or larger, graph K_n is not planar.

A map—on a plane, sphere, several spheres, whatever—is said to be k-colorable if its regions can be colored, using no more than k colors, so that areas that share a common boundary receive different colors. (Regions that meet only at a point or at finitely many points can, if necessary, receive the same color.) The analogous property for a graph runs along very similar lines. A graph is k-colorable if its nodes can be colored, using no more than k colors, so that nodes joined by an edge receive different colors.

COMPLETE GRAPH K_5 has five nodes, all of which connect to all others. So the graph requires five colors.



MICHAEL GOODMAN

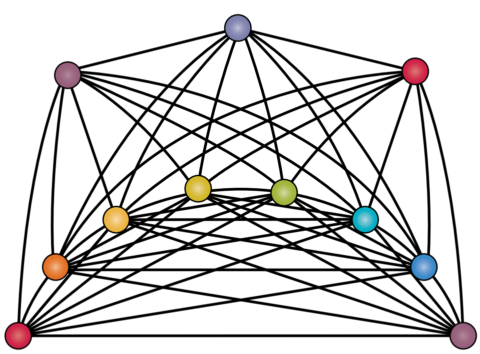
It is easy to see that a map is k-colorable if and only if its map graph is k-colorable. Just color each capital city, each node of the graph, with the color of the corresponding country. The smallest such k is called the chromatic number of the graph. It tells us the minimum number of different colors needed for that graph—hence also for the corresponding map. Evidently K_n has chromatic number n, because each node is joined to every other node, so no two nodes can be colored the same.

A problem closely related to Earth-moon maps was introduced by British mathematician Percy John Heawood in 1890. The scene is set only on Earth, but now each country is part of an empire consisting of a maximum of m countries, and the same color must be used for every country in a given empire, again with adjacent regions having different colors. (Countries in a given empire are assumed not to touch one another.) Such a map is punningly known as an m-pire. Heawood proved that an m-pire can always be colored with $6m$ colors, for all m equal to two or more—no matter how many empires there are.

Because an m-pire is a particular type of map, it has an associated map graph with one node per country. It is, however, no longer true that every legal coloring of the map graph corresponds to a coloring of the empire. The reason is that the standard coloring rules for a graph do not necessarily lead to nodes from the same empire receiving the same color. It is difficult to handle this condition using the map graph. Instead the construction of the graph is modified so that the coloring rules are automatically correct.

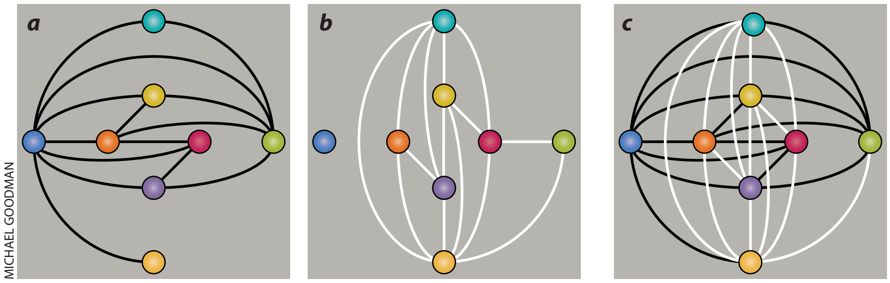
Here's how. The m-pire graph associated with a given m-pire map has one node for each empire—not one for each region. If you find this confusing, think of the node as representing the emperor. Two nodes are joined by an edge if and only if the corresponding empires include at least one pair of adjacent countries. You might think of the m-pire graph as the "invasion graph" of emperors whose empires can go to war across a common border: one node per emperor, one edge for every possible two-sided war.

Conceptually, the m-pire graph is obtained from the ordinary graph by iden-



MICHAEL GOODMAN

ROLF SULANKE'S GRAPH of thickness two requires nine colors. Its lower part consists of the complete graph K_8.



EARTH-MOON GRAPH for eight empires has two disconnected pieces (a *and* b) *that are planar (having no crossing lines). The corresponding two-pire graph* (c) *is created by superposing the nodes belonging to the same empire. This figure is actually the complete graph* K_8 *and requires eight colors.*

tifying all the nodes in a given empire—that is, by drawing them in exactly the same place. This construction often leads to multiple edges: superfluous edges are removed to leave just one. Identifying all the nodes in a given empire automatically forces them to receive the same color, so the number of colors needed for an m-pire is the same as the chromatic number of its m-pire graph.

In 1983 Bradley W. Jackson of San Jose State University and Gerhard Ringel of the University of California at Santa Cruz used this approach to prove that the number $6m$ in Heawood's theorem cannot be reduced. They did this by demonstrating that you can find an m-pire whose m-pire graph is the complete graph K_{6m}. Because K_{6m} definitely needs $6m$ colors, there is an m-pire that cannot be colored with fewer than $6m$ colors.

An Earth-moon map can be viewed as a particular kind of two-pire, with a slightly curious underlying geometry—two spheres—which splits all the two-pires into two pieces. Its graph consists of two disjoint planar graphs; one possible arrangement is drawn in the illustration above. (The rounded shape has nothing to do with Earth or the moon: it's just easier to draw.)

Suppose we now think of this Earth-moon graph as a two-pire graph, so that nodes belonging to the same empire are identified to create the last graph in the figure. We see that the resulting graph need no longer be planar; indeed, this one is not. The graph is, however, almost planar. The way it is constructed shows that its edges can be separated into two subsets, each of which forms a planar graph on the original set of nodes. The two subsets are just the edges in the two preceding graphs.

Such a graph is said to have thickness two. In general, a graph has thickness t if its edges can be separated into t subsets, and no fewer, in such a manner that each subset forms a planar graph.

So every Earth-moon map is made up of two planar maps—one on the moon, the other on Earth—and has a thickness of two. Conversely, every graph of thickness two corresponds to an Earth-moon map (although there may be regions unclaimed by any of the empires).

Because an Earth-moon graph is a special kind of two-pire graph, Heawood's theorem implies that 12 colors are sufficient for any Earth-moon graph. But we cannot conclude that 12 colors are also necessary. The reason is that not every two-pire corresponds to an Earth-moon map: some empires in a two-pire might have both territories on Earth.

In fact, none of the known two-pire graphs that actually require 12 colors can be turned into Earth-moon maps. It therefore remains possible that fewer than 12 colors might always be enough for an Earth-moon graph. For instance, the complete graphs K_9, K_{10}, K_{11} and K_{12} are all two-pire graphs, but they have thickness three and so cannot be Earth-moon graphs. The thickness of K_n is three if $n = 9$ or 10 and is the greatest integer not exceeding $(n + 7)/6$ otherwise.

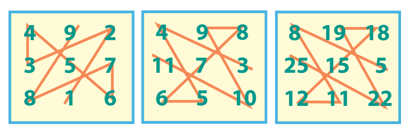
The last graph in the illustration (*c*) is in fact the complete graph K_8, so K_8 has thickness two. This means it can be represented as an Earth-moon graph—proving that at least eight colors are needed in the Earth-moon problem. Rolf Sulanke of Humboldt University in Berlin increased this lower limit to nine by demonstrating that the graph shown on the preceding page has thickness two and chromatic number nine. So the answer to the Earth-moon problem is not settled: it is either 9, 10, 11 or 12.

You might like to think about Earth-moon-Mars maps where every emperor has three territories, one on each world. These maps are particular kinds of three-pire maps, and their three-pire graphs always have thickness three.

Map-coloring problems of this kind are great fun, but they have little obvious practical significance. We shall see next month, however, how the concept of thickness applies to the testing of electronic circuits. SA

FEEDBACK

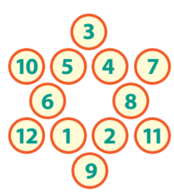
The January column on alphamagic squares elicited a number of intriguing tidbits. Delia T. Lewit of Huntington Park, Calif., noticed a curious pattern in all the examples of 3 x 3 magic squares. If the numbers are connected in ascending order, the same polygonal shape occurs in all of them. Can anyone explain or disprove this for any 3 x 3 magic square?



CURIOUS PATTERN appears in 3 × 3 magic squares.

Lee Sallows himself wrote from Nijmegen in the Netherlands to send me his latest thoughts on magic squares. He also mentioned Martin Gardner's 1996 challenge problem from the magazine *Quantum:* construct a 3 x 3 magic square composed of nine distinct perfect squares or prove it to be impossible. The prize is $100. The best-known attempt right now seems to be a near miss with a magic total of 147^2—itself a perfect square—for all rows, all columns and one of the main diagonals (but not the other). And Julius Telesin of Ben-Gurion University in Israel sent a fascinating analysis of "magic Davids." In the one shown, every straight line of four numbers sums to 26. —*I.S.*

127^2	46^2	58^2
2^2	113^2	94^2
74^2	82^2	97^2



NEAR MISS of a magic square (above) *and a magic David* (right).

MICHAEL GOODMAN

THE FUTURE OF THE PAST

Review by Ben Davis

Rome Reborn
http://www.aud.ucla.edu/~dabernat/rome/index.html

Forum of Trajan
At the Getty Museum in Los Angeles; exhibit opens December 1997

Virtual Los Angeles
http://www.gsaup.ucla.edu/bill/LA.html

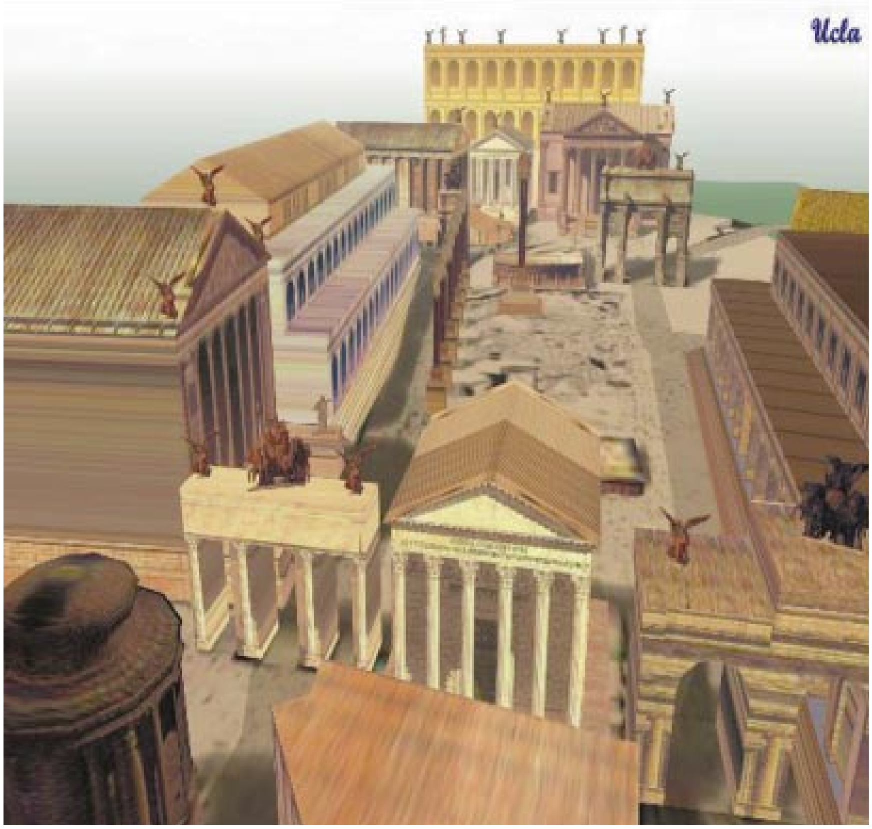
Learning Sites
http://www.learningsites.com

Ancient Egypt Research Associates
http://www.pbs.org/wgbh/pages/nova/pyramid/excavation/lehner.html

Giza Plateau Mapping Project
http://www.oi.uchicago.edu/OI/PROJ/GIZ/Giza.html

Qin: Tomb of the Middle Kingdom
CD-ROM for Windows or Macintosh
Time Warner Interactive, New York, 1997 ($29.95)

Dynamic Timelines
http://robin.www.media.mit.edu/people/robin/thesis/



UNIVERSITY OF CALIFORNIA, LOS ANGELES

COMPUTER RE-CREATION OF ANCIENT ROME, part of Rome Reborn, shows the city as it appeared at the time of Augustus.

Scientific people...know very well that Time is only a kind of Space," wrote H. G. Wells in *The Time Machine*. He defended his argument by observing how data from a barometer, when plotted over time, produce a spatial image. Now, a century later, electronic computers offer a ubiquitous and far more sophisticated means of manipulating time and information into graphic form. Three-dimensional computer visualizations have become a mainstay of modern science, vastly expanding our understanding of the world around us. Intriguingly, the computer-mediated blending of time and space is also being applied inward, to help us understand ourselves. In museums, in computer software and on the Internet, a new technique of "cultural data visualization" is beginning to take shape.

In some cases, researchers are using visualization software, originally intended for scientific and architectural modeling, to re-create the past with a high degree of authenticity. Ironically, much of the current work on virtual reconstructions is taking place in Los Angeles—a city noted for its ephemeral structures and constant development. One of the most notable projects is Rome Reborn, a collaboration among researchers at the University of California at Los Angeles and a raft of U.S. and Italian sponsors. This ambitious project will yield a multilayered, 3-D, interactive virtual-reality simulation of Rome from the ninth century B.C. to the fourth century.

Aimed primarily at high school and college students, Rome Reborn would be distributed along high-speed Internet lines and might include virtual guides speaking both English and Latin. The entire project will not be finished until 2020, but the Roman Forum and architecture from the Age of Augustus (50 B.C. to 14 A.D.) should be ready in time for bimillennial celebrations.

Other such architectural-historical recreations will be done sooner. The J. Paul Getty Trust is supporting the construction of a simulated Forum of Trajan in Rome; the result will be on display at the opening of the new Getty Museum in Los Angeles in December 1997. The exhibition will display the virtual forum along with actual statuary from the site so that the visitor can get a sense of how the real objects fit in their historical environment.

Both these ancient Rome projects draw on a software program called uSim (Urban Simulation System), developed at U.C.L.A. In Rome Reborn, each of the 14 political districts of the ancient city will be mapped over 14 centuries. A four-dimensional database (spatial coordinates and time) models architectural changes over the recorded life span of the city. Every time a user switches to a different moment in history, the program quickly redraws that part of the city to conform to its appearance at that period. The database can be accessed either locally at U.C.L.A. or globally through the World Wide Web. When Rome Reborn is complete, an architecture professor could have his or her stu-

BRIEFLY NOTED

VIRTUAL ARCHAEOLOGY: RE-CREATING ANCIENT WORLDS, *edited by Maurizio Forte and Alberto Silotti. Harry N. Abrams, New York, 1997 ($49.50).*
For those who lack access to the World Wide Web, here is a fine paper introduction to the ways that computers are being used to visualize the art and architecture of long-lost civilizations (see accompanying review by Ben Davis). The book's 50 case studies colorfully illustrate this meeting between old and new and offer a wealth of archaeological information.

INVENTION BY DESIGN, *by Henry Petroski. Harvard University Press, Cambridge, Mass., 1996 ($24.95).*
This is something of a greatest-hits collection from the man who managed to make a book about the pencil a riveting read. Henry Petroski delights in picking apart the design details of everyday objects; his targets this time include the paper clip, the zipper and the fax machine. These examples are deftly chosen to illustrate the normally invisible process in which inventors and manufacturers continuously battle one another, with the winners subtly reshaping our modern world.

CLAUDE NURIDSANY AND MARIE PÉRENNOU

MICROCOSMOS: THE INVISIBLE WORLD OF INSECTS, *by Claude Nuridsany and Marie Pérennou. Stewart, Tabori & Chang, New York, 1997 ($35).*
The gorgeous, innovative photography that made the film *Microcosmos* such a treat is now available in book form. Some poetry is lost along with the motion, but these stills allow a more leisurely contemplation of the diverse appearances and behaviors of our ubiquitous six-legged neighbors. Many of the images—such as the puss-moth caterpillar rearing up to face a predator, above—are probably the finest ever committed to film.

dents meet at the virtual Pantheon of 129 A.D. and conduct the class entirely from inside the model. The virtual Rome, like the real one, will not be built in a day, but conceivably this project could let the interested user visit hundreds of years in a few hours.

William Jepson, director of computing in the department of architecture and design at U.C.L.A., anticipates that the project's database will change as new architectural discoveries are made and authenticated. Researchers' understanding of the past changes as time goes by; someday it may be possible to see parts of Rome not only as they were at different times but also as they were thought to have been by different generations of reconstructors.

Jepson is also working on another project, Virtual Los Angeles, that focuses on contemporary buildings, both real and imagined. The Virtual Los Angeles effort, which started a few years ago, now embraces about 25 square kilometers (10 square miles) of the most densely developed areas of the city. Many of the models for Virtual Los Angeles were commissions from development corporations to explore structures that were never physically built. All the models incorporated in this project are time-stamped, so that anything built in virtual reality automatically has a historical annotation. As a result, the records of a Los Angeles that never actually materialized coexist with those of the real thing—only their annotations distinguish them.

These visualization time machines straddle not just space and time but also academia and business. In the late 1980s researcher William Riseman of the Boston Museum of Fine Arts used a computer-aided design (CAD) program to assist in problems of archaeology. Then, in 1992, Riseman met Donald H. Sanders, an archaeologist and teacher who was looking for visually effective ways to present the past to his students. The meeting led to the creation of Learning Sites, a company that now designs and develops interactive 3-D databases and rendering software to make the data visible. Learning Sites makes a profit selling products and services that employ visualizations as teaching tools, research aids and information banks.

Eventually these tools and models may be linked via the Internet to create

UNIVERSITY OF CALIFORNIA, LOS ANGELES

VIRTUAL LOS ANGELES will depict architectures both real and imagined.

3-D virtual libraries. Some of the sites that are already available include the Mastabas at Giza in Egypt; the Temples of Gebel Barkal in Nubia; the Sun Temple at Meroë in the Sudan; King Aspelta's tomb at Nuri in the Sudan; the Fortress of Buhen in Egypt; the Sanctuary of King Antiochus I at Nemrud Dagi in Turkey; and the Vari House in Greece.

The Vari House is a farmhouse in Attica, located in southeastern Greece. In the summer of 1966 a group of British archaeologists published a thorough analysis of this house, which showed that it was built sometime between 325 and 275 B.C., apparently by a family of beekeepers. Drawing on that analysis, Learning Sites constructed a virtual-reality model of the house using virtual-reality modeling language and Java technology. The company then assembled a curriculum aimed at teenage students. Each section of the model is attended by study questions such as "What kinds of materials would tend to survive thousands of years of exposure to the weather?" At the end of the questions, the student receives brief answers and is invited to go to the model and investigate the topics further. The technology can also simulate an architectural dig to give a sense of how physical history is actually recovered.

Learning Sites is one of several new companies working with museums, schools and archaeologists to create 3-D models for exhibitions and education programs, CD-ROM publications, kiosks and digitizing services for the preservation of documents and images.

This commercial approach is fostering the birth of a new "virtual archaeology" that is more sensitive to conservation issues and the preservation of cultural heritage. By contracting with institutions as well as individuals, companies such as Learning Sites are making the collection, study and dissemination of archaeological data broader and more efficient.

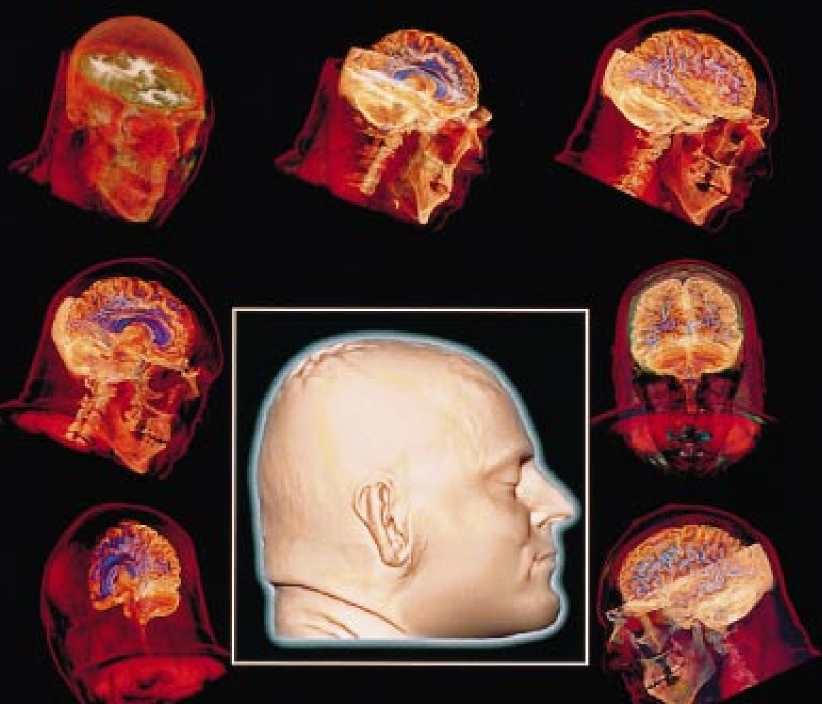
One organization that has done particularly comprehensive studies of virtual architectural reconstructions is Ancient Egypt Research Associates (AERA). The association was founded in 1986 by Mark Lehner, an Egyptologist at the Oriental Institute of the University of Chicago and Harvard University's Semitic Museum, and by composer and producer Matthew McCauley. It does extensive field study of the Giza Plateau in Egypt and has produced detailed models of the Khufu Pyramid Complex; the Khafre Pyramid Complex; the Menkaure Pyramid Complex; and the Sphinx Temple.

AERA, working with Zahi Hawass in Egypt and such researchers as John Sanders of the University of Chicago's Oriental Institute, Peggy Sanders of Archaeological Graphic Services in Chicago and Tom Jaggers of Jerde Partnership in Venice, Calif., has developed a network of archaeologists, technologists and digital artists. One of AERA's intentions is to further the notion that the great archaeological structures are emergent phenomena, arising—according to complexity theory—from simple local rules. This approach goes hand in glove with digital visualization technology, wherein small files of data can be linked to produce ever larger visual structures.

The modeling of the Giza Plateau and its architectural monuments, for instance, required compiling maps, published surveys and excavation reports into a 3-D graphics database. AERA produced a contour map with a resolution of down to one meter (three feet), amplified from its own survey-control network at Giza. This map was then processed to extract the spatial coordinates for every line segment of each contour, producing a file containing more than 100,000 points that describe a 2.5-by-three-kilometer, 3-D plot of the plateau. Atop these data, using AutoCAD software, researchers built 3-D wireframe models of the 10 Giza pyramids, mortuary and valley temples, causeways, the Sphinx and 150 mastaba tombs.

With the computer model of the Giza Plateau and its pyramid complexes completed, animation software could process the entire database to permit a viewer to fly in, around and through the model. One result was a 45-second video sequence for PBS television station WGBH in Boston, which aired the segment as part of the "This Old Pyramid" episode of *NOVA* on November 4, 1992. A more detailed model is now being built using a texture-mapping technique to apply realistic-looking materi-

THE ILLUSTRATED PAGE



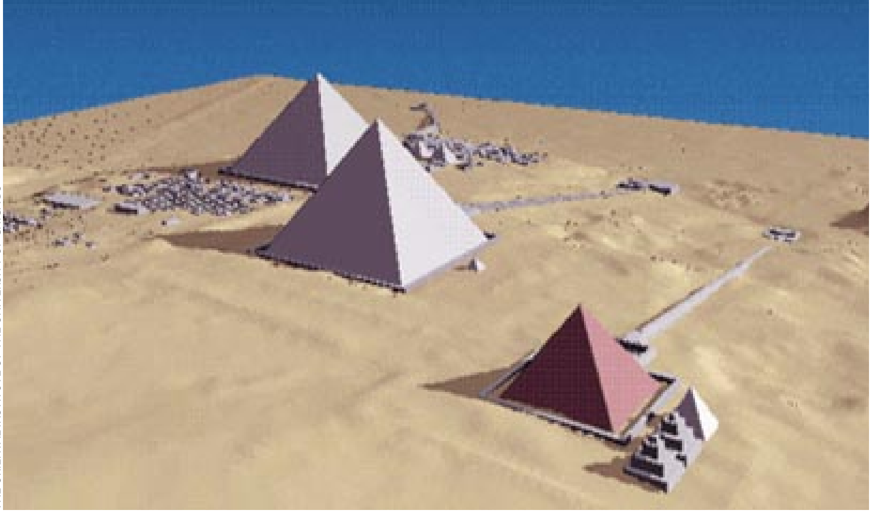
ALEXANDER TSIARAS

Body Voyage
CD-ROM for Windows and Macintosh
Time Warner Electronic Publishing, New York, 1997 ($39.95)

Body Voyage
BY ALEXANDER TSIARAS
Warner Books, New York, 1997 ($35)

Human Anatomy in Full Color
BY JOHN GREEN
Dover Publications, Mineola, N.Y., 1996 ($4.95)

The National Library of Medicine's Visible Human Project is a landmark in anatomical imaging—a set of scans of a sliced cadaver that, collectively, builds up a three-dimensional map of the entire human body. *Body Voyage* reworks those data to dazzling effect. This is one case in which CD-ROM easily trumps paper. The unusually well designed disk allows instant views of virtually any vertical or horizontal slice through the body. Other features include automated "fly-throughs" of the body and illustrated medical anecdotes. Although the book contains much of the same material, it lacks the interactive features that make this anatomy lesson come alive. (Note for parents: the images and background information may be disturbing to young children.) A much better paper companion is the bargain-priced *Human Anatomy in Full Color*, which fills in many of the medical specifics left out of the CD-ROM. —*Corey S. Powell*



THE ORIENTAL INSTITUTE OF THE UNIVERSITY OF CHICAGO

GIZA PLATEAU MODEL
offers a 3-D view of the pyramids at the time of their construction.

als, inscriptions and wall reliefs onto the Giza structures.

This last "mapping" process is important for gaining a deeper understanding of the structures and their relation to ancient Egyptian culture. AERA has been aggressively collecting information on architectural details and materials. Drawing on new ideas from complexity theory, McCauley (co-founder of AERA) hopes to use these data to investigate the powerful self-organizing forces brought into play by simple local rules in ancient Egypt.

Historical visualization can form the basis of another commercial enterprise: computer games. Learn Technologies Interactive, or LTI, has created Qin: Tomb of the Middle Kingdom, a CD-ROM game that combines archaeological and historical data into an imaginative simulation of the tomb of Qinshihuang, the first emperor of China. The Qin legends and stories are some of the most exciting in Asian history. They were suddenly tied to reality in 1974, when Chinese archaeologists discovered an army of terra-cotta figures—thousands of life-size soldiers and horses that guard Qin's tomb. Although the Chinese government has refused to release images of the tomb near the famous Terra-cotta Army in Xi'an, researchers at LTI were able to draw on other scholarly material to design a simulation that is startling in its graphic immediacy and its serious educational intent. Taking scholarly research and making it into a computer game is risky business; the Qin project is notable because it makes such a careful attempt to use fictionalized visualization to stimulate a genuine interest in history.

Luyen Chou, co-founder and director of LTI, and his team of designers incorporated an impressive amount of information about the tomb and the surrounding terra-cotta figures—an effort that clearly shows when one plays the game. Put in the role of amateur archaeologist, the user falls into the tomb and must navigate through rooms and artifacts. To give the images a genuine sense of eastern Asian and Chinese aesthetics, the designers researched and photographed authentic materials and fabrics and then texture-mapped these onto surfaces generated by computer graphics programs.

One of the more interesting aspects of Qin: Tomb of the Middle Kingdom is that the user must learn to interpret clues from objects found in the tomb. The clues are given in Chinese, but there is a translator character who will translate the information into English. An encyclopedia on the disk serves as a helpful reference. LTI thus makes historical research into a labyrinth from which only the intellectually passionate can return. This approach gives the game's young audience an insight into real history, where legend and fact mingle, and simple answers are seldom forthcoming.

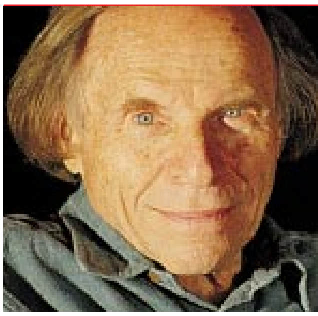
The Qin game holds a more sobering message for academic applications of visualization techniques. They may work well for 3-D objects but fall short for presenting other kinds of information, such as bibliographical or historical annotations. The kind of encyclopedia and translator used in Qin may make a useful gaming device, but these techniques are probably not appropriate for more serious work. Yet 3-D representations of data could be helpful to cultural researchers in making sense of the massive amounts of such data that they often confront.

Ronald L. MacNeil of the Massachusetts Institute of Technology's Media Laboratory and others have tackled this conundrum by making traditional databases three-dimensional. Working with MacNeil and the late Muriel Cooper of the Visible Language Workshop, Robin Kullberg, now at the Art Technology Group in Boston, authored a data visualization program called Dynamic Timelines. She combined visual techniques from graphic design and cinema (such as zoom, animation and transparency) with 3-D interactive rendering, to synthesize a dramatic information "space." The software lets a user take a simulated flight through 265 annotated images from the collection of the George Eastman House that represent the history of photography from 1830 to 1950.

Kullberg's 3-D virtual world depicts abstract historical information rather than concrete representations of physical architecture. She describes her program as an atlas of history, a map of events in time. A physical point of reference (such as a photograph) exists as an island in a virtual ocean of related data. By diving into the 3-D space, a researcher can move toward or away from a specific topic without losing visual contact with related information; both content and context are always visible.

Dynamic Timelines and similar data visualization tools provide a seamless interface between physical representation and abstract information. The graphical skills that researchers have applied to architectural reconstructions and scientific visualization can now be applied to database architecture as well. This potential is fostering a blending of scientific methodology and cultural content. The ability of the computer to transmute one form of information into another—data into pictures, pictures into scenarios—affords an amazing new mechanism for remembering the past. In a world constantly besieged by new technology, it is important to recall that the survival of culture ultimately depends on memory.

BEN DAVIS is program manager of communications at the Getty Information Institute in Los Angeles, Calif.



COMMENTARY

WONDERS

by Philip Morrison

1997: Subatomic Centenary

DUSAN PETRICIC

Around 1875 James Clerk Maxwell, on whose superb work our physics still rests, described atoms as "foundation stones of the material universe…unbroken and unworn. They continue to this day as they were created—perfect in number and measure and weight."

In 1899, 20 years after Maxwell's untimely death, Joseph John Thomson, third director of Maxwell's own laboratory at the University of Cambridge, told quite a different story. For Thomson had found the electron. Any electrical phenomenon, Thomson explained, "essentially involves splitting up of the atom, a part…getting free and becoming detached from the original." To "split the atom" by transferring electrons was a commonplace of electrical and chemical processes, just as requisite for salting your soup.

Back in the 1830s Michael Faraday had passed direct current between two copper plates through a blue-green solution of copper sulfate and noted that the negative plate, the cathode, grew heavier as the positive one dwindled. Positive charge had traveled along with the atoms of metallic copper. Faraday called these traveling charges "ions." The ions always transferred a charge strictly proportional to the weight of the atoms transferred, corrected for different valences by a factor of two or three. (Wires, however, are not at all like fluid electrolytes. Heavy current can flow indefinitely in a copper wire, yet no detectable atoms of copper come along. Whatever travels inside a wire, it is no atom of the metal.)

Maxwell's equations showed the necessity for a fieldlike contribution, without local charges, to complete one major case of conserved current flow. That fed his shadowy view of charge, which cast doubt on whether currents are simply the flow of charged matter. In 1873 Maxwell wrote of one "molecule of electricity," but at once he termed the phrase "gross…and out of harmony," good mainly as a mnemonic device!

By the mid-1880s chemists had mapped many molecules without any form of imaging. Their purely "chemical logic" firmly disclosed atoms linked in space. In 1881 Herman von Helmholtz, lecturing in Britain, emphasized just what Maxwell had evaded: "If we accept…atoms, we cannot avoid concluding that electricity itself is divided into…atoms of electricity." In 1891 George Stoney even dubbed Faraday's atom of electrical charge, before it had ever been isolated, as the electr[i]on.

By the mid-1880s chemists had mapped many molecules without any form of imaging.

The explosive sensation that opened 1896 was Wilhelm Roentgen's demonstration of x-rays—penetrating electromagnetic radiation secondary to high-voltage cathode rays. The cathode rays themselves had been identified by Philipp Lenard the year before as swift negative particles. At the Cavendish Lab, J. J. Thomson had long since developed the best cathode-ray beams, the best evacuated tubes and a deep understanding of electromagnetic forces. Yes, the cathode rays did bend like charges in magnetic fields—everyone saw that—and they felt electrical fields as well.

Then Thomson directed strong fields, electrical and magnetic, across an evacuated glass tube, down whose long axis flowed the cathode-ray beam. What the magnet pushed aside, the electrical field could restore. At the right settings the beam's path, well revealed by the visible fluorescent glow where the rays struck artfully positioned patches of phosphor, passed undeflected. At balance, the ratio of the two fields fixed the ratio of particle charge e to its mass m.

To learn either charge or mass by itself, you needed to know the particle speed. Thomson found that by indisputable means: he measured the heating of a little metal cup that caught the stream of rays. That gave the kinetic energy brought in; the electrons could be counted by the charge they carried. From these data their mass and their charge both followed.

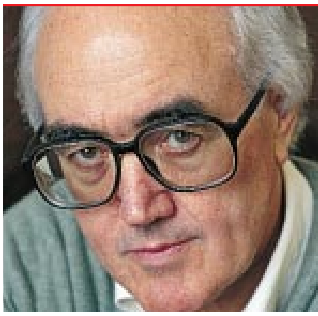
Thomson reported his work widely in lectures that spring of 1897. The charge e was close to Faraday's value, equal though opposite to that of the positive hydrogen ion. The mass m was low, less by 1,000-fold than that of hydrogen, lightest of atoms. Two years later Thomson closed the final logical gap. These electrons were no strangers but parts of ordinary atoms. He had made his beams anew by accelerating electrons released at low voltage. Their charge and mass values matched the cathode rays at high voltage. Any atom could now be parted into electrons and a positive residue. The uncuttable had been cut.

I was disappointed when I realized that Thomson's long direct path had not interested students as eager and able as Albert Einstein or the slightly younger Max Born. Their letters and papers over the next few years admire electrons, but they slight Thomson, and his atom-splitting prowess goes unmentioned. Why?

These budding theorists seem to have regarded Thomson's subatomic electron as merely a confirming result, long expected and indeed anticipated by a year or more. Einstein at age 67 recollected that Maxwell's theory was "the most fas-

Continued on page 95

COMMENTARY



CONNECTIONS
by James Burke

Lucky He Missed

DUSAN PETRICIC

I was at the London Zoo the other day, staring at a buffalo and thinking about the fact that such places all started as a "get inside God's head" attempt to reproduce the two-by-two conditions on board Noah's Ark. For one, there was the work of an obscure, middle-of-nowhere-North-of-England country vicar called William Paley, who wowed everybody with the 1802 equivalent of chaos theory. Paley's was an *order* theory, and he explained it all in a large book entitled *Natural Theology*. What gripped the public imagination was his idea that every bit of nature was like a watch: designed with a purpose. Thus, cranes can't swim because they haven't got webbed feet, but they do have long legs to let them wade. So if zookeepers managed to collect all the animals in existence into one location, you'd get an idea of what He (they didn't think of Him as a She) was thinking at Creation and maybe work out the Heavenly Watchmaker's Grand Design.

The fellow who hoped to put this theory into practice by setting up the London Zoological Society was a big fan of Paley, and while briefly British governor of Java he had spent most of his time in the jungle, scooping up anything that walked, crawled, flew or sat there long enough. Sir Stamford Raffles (for it was he) also deviously obtained a forever lease on Singapore for the Brits and thus became one of the Great and the Good back home. He got the London Zoo job in 1826 because of another G&G name—Sir Humphry Davy, who lobbied successfully for Raffles as zoo prez.

Davy was about as big a science wheel as you could get: so eminent a savant that he was able to collect a medal from Napoléon's French Institute despite the minor inconvenience of Britain and France being in a state of war at the time. At the tender age of 23, Davy had made so much of an impression with his chemistry experiments that he was offered the job of assistant lecturer at the Royal Institute in London. His first talks on galvanism (a.k.a. electricity) won him rave reviews and swooning ladies.

By 1806 he had become the hottest thing in electrochemistry. And because that kind of guy always knew everything, in 1812, when a mining disaster killed 92 people, Davy was approached to solve the problem of firedamp. This explosive mixture of air and methane was often found underground, and if you happened to come across it with your lighted candle you tended to get taken seriously dead. In no time at all Davy had the answer, in the form of a lamp whose flame was surrounded by a fine-wire gauze. The flame burned, but the surrounding gases didn't. As a result, Davy was awarded a humongous money prize by his pals in the Royal Society.

The Morse code coming ashore in Newfoundland was music to his . .- .-. ...

But George Stephenson, an uneducated collieryman nobody who claimed to have done the same thing only better, didn't get a penny. Fortunately, he had other fish to fry. Mine owners, ticked off by the way the Napoleonic Wars were causing the cost of horse feed to spiral, were desperate for alternative hauling power. So by 1829 our slighted lamp maker came up with a traveling steam-power gizmo called a locomotive and instantly became a railroad biggie, feted by royalty everywhere. Better late than never. As were his trains.

George's son, Robert, picked up where his father had left off and became a famous engineer, in 1850 opening his revolutionary Britannia Bridge, which crossed the Menai Strait in Wales by means of two giant cast-iron tubes through which trains passed. The bridge was a Guinness record before Guinness. No fewer than 2,190,000 rivets were used, banged into holes put there by an ingenious automatic machine working on punched-card control. This struck Robert's friend Isambard Kingdom Brunel as an absolutely riveting idea, because he had a plan of his own that would need three million of them.

In 1866 the plan, by this time hailed as the *Great Eastern*, the biggest ship in the known universe, was inching into Heart's Content Bay, Newfoundland, hauling one end of the first successful transatlantic telegraph cable (the other end was anchored to Valencia Island, Ireland) and making the day for a certain Cyrus Field. A retired American millionaire papermaker, Field owned all 2,500 miles of the cable (and a further 1,000 miles of another one, broken off earlier and now lying at the bottom of the sea), so the Morse code coming ashore in Newfoundland was music to his . .- .-. ...

Samuel Morse himself was one of Field's advisers, having had experience in laying cable ever since 1844, when he had done it between Baltimore and Washington, so as to transmit the first telegraph message—"What hath God wrought"—and stupefy Congress. Not stupefied enough, though, to finance his idea. Fortunately, his business manager was an astute type called Amos Kendall, a former U.S. postmaster general, over whose land Morse's cable had crossed. Kendall suggested to Morse that he'd do better setting up a private telegraph company instead of pressing for government support.

In return for this blindingly obvious idea, Kendall got 10 percent of the first $100,000 Morse would make and 50 percent of the rest. So by 1864 (guess what?), he was a very rich man. Because he was married to a deaf woman (as was Morse), Kendall decided to give some of his well-gotten gains to help found the first National Deaf Mute College (now Gallaudet University).

The mid-19th century witnessed a great deal of American interest in speech and hearing impediments, as well as arguments about how they should be treated. Several schools for stammerers were established by another self-made man, who had amassed a fortune in communications. This was Henry Wells, a stammerer himself, who started life as a freight agent in New York and went on to partnership with William Fargo in a courier company they set up in 1850, called American Express. That year, 55,000 people had gone west to California. Of these, 36,000 had made the trip by sea, as did most of the mail, because dying of thirst or sunstroke, plus objections placed in your way by Native Americans, all tended to make the overland route somewhat iffy.

As ever, it was money that would surmount these minor inconveniences. In 1858 gold was discovered in Colorado and Kansas, and two years later the miners were getting their letters hand-delivered by individuals lathered in sweat and dust because they'd done the last 100 miles at full gallop. Wells and Fargo ran the western end of this extravagant and brief-lived delivery service, known as the Pony Express. Extravagant because it lost a huge amount of money, and brief because 18 months after it started it stopped, when, in October 1861, the coast-to-coast telegraph link was completed.

By that time, however, one particular rider had already left to provide meat for the Union Pacific Railroad, because apart from his ability to ride hell-for-leather he was also a crack shot. Well, fortunately, not quite crack. Although his killing record of 4,280 animals in eight months (69 in one day alone) was so impressive it earned him his nickname, "Buffalo" Bill Cody can't have been that good, or I wouldn't have been able to admire that magnificent beast the other day in the London Zoo.

Must shuffle off now. SA

Wonders, continued from page 93

cinating subject" of his student years. Like most careful readers he found in it a certain strangeness: matter, not space, was both the source and seat of fields. Instead it was the work of the great Leiden physicist H. A. Lorentz that the young ones had mastered. He had celebrated and validated Maxwell's equations but over the years shifted their physical emphasis, adding one explicit equation, the "Lorentz force" felt by point charges. For Lorentz, fields existed only in the vacuum. Matter was atomic and bore the essential charges, plus and minus, that by placement and motion created all field patterns.

Experiments that made those charges real were done by novice Pieter Zeeman and at once interpreted by senior theorist Lorentz. Their lab in Leiden had, like others, just received from Henry Rowland of Johns Hopkins University an exquisitely ruled new diffraction grating that improved by an order of magnitude the power of spectroscopy. Zeeman read Maxwell's admiring essay on Faraday and was moved to repeat 30-odd years later, with the grating, the same spectroscopic experiment that had shown no effect through Faraday's prisms. A Bunsen flame held between the poles of an electromagnet heated a piece of asbestos soaked in salty water; the yellow glow of hot sodium vapor was dominated by one narrow double spectral line.

As never before, the lines could be seen to widen as soon as the strong magnetic field came on. Lorentz knew that electrons moving in any lasting orbit would slowly rotate faster (or slower, depending on the field direction) once an outside magnetic field was imposed. He could calculate the charge-to-mass ratio of the moving atomic electron from the small wavelength shifts Zeeman measured. Polarized light was predicted and found; it fixed the sign of the radiating electron, negative like the cathode rays.

Clearly, Lorentz's theory could not be final. He had no map of the atom. Yet before 1896 had ended, the Leiden researchers had found the first key: electrons of known charge and mass radiate spectral light as they move within ordinary atoms. When Max Planck introduced the idea of quantized energy in 1901, the dizzying journey of quantum physics began. SA

WORKING KNOWLEDGE

OPTICAL FIBERS

by John MacChesney

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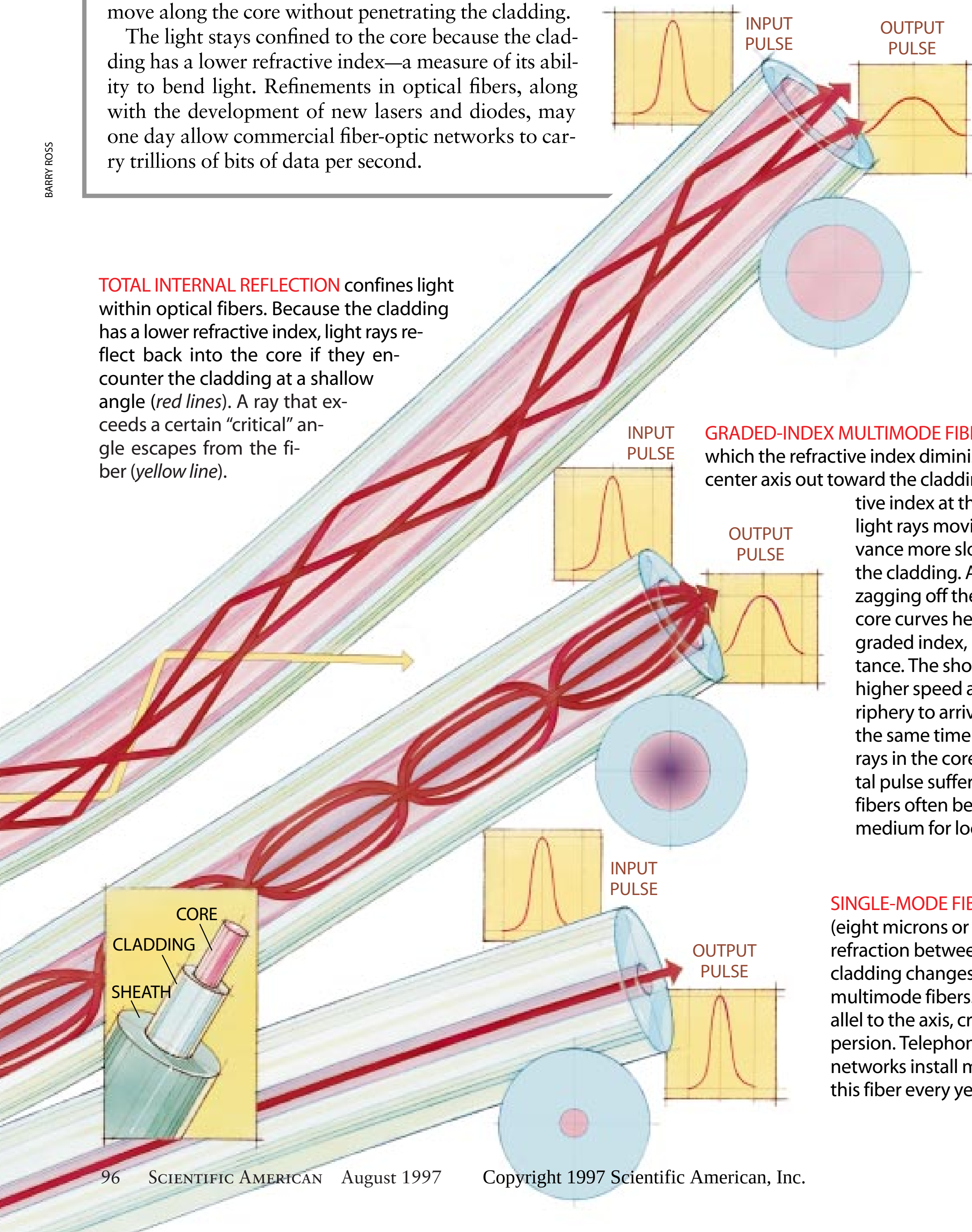
Some 10 billion digital bits can be transmitted per second along an optical fiber link in a commercial network, enough to carry tens of thousands of telephone calls. Hair-thin fibers consist of two concentric layers of high-purity silica glass—the core and the cladding, which are enclosed by a protective sheath. Light rays modulated into digital pulses with a laser or a light-emitting diode move along the core without penetrating the cladding.

The light stays confined to the core because the cladding has a lower refractive index—a measure of its ability to bend light. Refinements in optical fibers, along with the development of new lasers and diodes, may one day allow commercial fiber-optic networks to carry trillions of bits of data per second.



BARRY ROSS

STEP-INDEX MULTIMODE FIBER has a large core, up to 100 microns in diameter. As a result, some of the light rays that make up the digital pulse may travel a direct route, whereas others zigzag as they bounce off the cladding. These alternative pathways cause the different groupings of light rays, referred to as modes, to arrive separately at a receiving point. The pulse, an aggregate of different modes, begins to spread out, losing its well-defined shape. The need to leave spacing between pulses to prevent overlapping limits bandwidth—that is, the amount of information that can be sent. Consequently, this type of fiber is best suited for transmission over short distances, in an endoscope, for instance.

TOTAL INTERNAL REFLECTION confines light within optical fibers. Because the cladding has a lower refractive index, light rays reflect back into the core if they encounter the cladding at a shallow angle (*red lines*). A ray that exceeds a certain "critical" angle escapes from the fiber (*yellow line*).

GRADED-INDEX MULTIMODE FIBER contains a core in which the refractive index diminishes gradually from the center axis out toward the cladding. The higher refractive index at the center makes the light rays moving down the axis advance more slowly than those near the cladding. Also, rather than zigzagging off the cladding, light in the core curves helically because of the graded index, reducing its travel distance. The shortened path and the higher speed allow light at the periphery to arrive at a receiver at about the same time as the slow but straight rays in the core axis. The result: a digital pulse suffers less dispersion. These fibers often become the physical medium for local-area networks.

SINGLE-MODE FIBER has a narrow core (eight microns or less), and the index of refraction between the core and the cladding changes less than it does for multimode fibers. Light thus travels parallel to the axis, creating little pulse dispersion. Telephone and cable television networks install millions of kilometers of this fiber every year.

