Surprisingly Modern Neandertals • National Medal of Technology

SCIENTIFIC AMERICAN

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QUARK SOUP

CERN cooks up a new state of matter

see page 16

QUANTUM Teleportation

The Future of Travel? Or of Computing?

Of Mice and Mensa

Genetic formula for a smarter mouse

Brown Dwarfs

Stars that fizzled fill the galaxy

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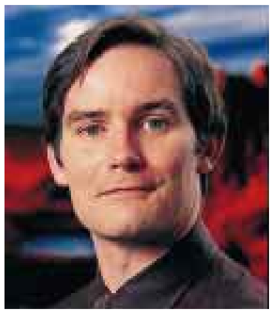
EDITOR_ JOHN RENNIE

Quantum Bits and Reliable Boats

Quantum teleportation and the Aleutian kayak, both forms of transportation described in this issue, could not be more different. The former is futuristic and derived from applications of quantum physics, about which we are still learning. The latter is a historical curiosity based on principles of boat design centuries-old, many of which have been forgotten. Quantum teleportation can in theory move people and things from one place to another without taking them through intervening points, and it can do so at the speed of light. The kayak carried hunters through rough seas at a possible top speed of about 10 knots. Quantum teleportation involves exotic stuff called "entangled matter." The kayak was built of animal skin and wood.



ERICA LANSNER

Which of these will be more important as a form of transportation? I think it's obviously the kayak.

Let me reemphasize the words *as a form of transportation*. The Aleutian kayak can fall back on its record: it was a mainstay of the Aleuts' livelihood for perhaps thousands of years. It helped them tame the forbidding seaways around the Bering Strait. George B. Dyson's fascinating article on these craft begins on page 84.

Kayaks beat teleporters for transportation.

Quantum teleportation, though ingenious, is still unproved for shipping anything other than photons. In science fiction, teleportation is a great convenience for advancing plots in either wonderful (see *Star Trek*) or horrible (see either movie version of *The Fly*) directions. Of course, those imaginary teleporters disassembled people's atoms, zapped them through the ether and reassembled them elsewhere. Measurement uncertainties and the sheer overload of information required would make that feat impossible. Quantum teleporters do not disassemble anything, so their mishaps could never produce anything quite like poor fly-headed David Hedison.

But at least for now, quantum teleportation works only one out of four times—and that 25 percent probability applies distinctly to each particle in the subject's body. What comes out at the far end of a quantum teleporter therefore still might make even a genetically fused Jeff Goldblum blanch. Then there's the philosophical quandary of whether someone who steps into a quantum teleporter is really the same person who steps out at the other end or just a duplicate, perfect down to the memories. (Somehow this never comes up in kayaking.)

For all these reasons, quantum teleportation's application to moving matter may always be limited. On the other hand, as an extension of quantum computation, a radically different way of processing information, its potential may be unlimited. As you'll learn in Anton Zeilinger's article beginning on page 50, it even offers a way for quantum computers to start processing information that they haven't received yet.

No messages have reached me yet about this, but I know my answer to them: yes, we have redesigned some departments in the magazine. We hope the changes help you identify the articles interesting to you that much more easily and generally enhance your reading enjoyment of *Scientific American*.

John Rennie

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LIVING LONGER

In "Can Human Aging Be Postponed?" Michael R. Rose suggests that we could postpone aging via natural selection by delaying childbirth. This is already being followed by the current generation of Americans, albeit for other, more immediate reasons. Marriage age has increased dramatically, and the smaller family size is probably the result of starting childbearing later, rather than stopping earlier, as couples pursue careers that demand longer educations and longer working hours. It's interesting that we are, as a result of our affluence and technological sophistication, adopting the very strategy that will lead to longer life spans.

ERIC GOLDWASSER
Yorktown Heights, N.Y.

We don't need a genetic miracle to prolong healthy life. For average people not smoking, regular exercise, effective stress management, lean weight and a heart-healthy diet can mean 20 to 25 healthy years beyond the age of 60.

THOMAS PERLS
Harvard Medical School

Rose sees no limit to the length of time human life can be extended by turning on antiaging genes or preparing drug cocktails to combat aging. But I see a problem. Any assistance provided by new therapies can backfire on us over the long run. As we provide our own antiaging remedies, natural selection will begin to lose its feedback-control mechanism: early death resulting in the weeding out of deleterious genes. In a parallel (with a twist) to the current problem of excessive antibiotic use, which results in natural selection of resistant bacterial strains, I foresee a reduction of the natural-selection mechanism as drugs take over the longevity job. We will become more and more dependent on drugs just to hold our ground. In other words, be careful about fooling Mother Nature.

ROBERT P. HART
East Hampton, Conn.

DISSECTING THE MIND

Reading Antonio R. Damasio's article "How the Brain Creates the Mind" reminded me of something the comic Emo Phillips once said: "I used to think the brain was the most important organ in the body, until I realized who was telling me that."

LUKE E. SOISETH
St. Paul, Minn.

Damasio supplies a bullish account of how neuroscience is moving toward a satisfactory account of consciousness, and he falls straight into a well-known trap: a failure to distinguish the "hard" problem of consciousness from other, less troublesome issues. Damasio writes that neuroscience is identifying more and more places in the brain where particular kinds of representation are computed. Among those representations, he reports, are some that model the self and some that model the fact that the self is doing some representing of the world. But then he inserts a non sequitur: further elaboration of these lines of inquiry will lead to a resolution of all questions of consciousness.

Yet it does not follow that the subjective life of the mind could, in principle, be explained by an account that confines itself to biological or computational mechanisms. What, for example, could a complete map of the visual pathways ever tell us about the subjective redness of the color red? The distinction between the hard problems of consciousness and the lesser issues was invented recently to eliminate the kind of confusion injected into the debate by contributors such as Damasio, who assert that the problem is not as difficult as everyone makes it out to be and then go on to attack the wrong problem.

RICHARD LOOSEMORE
Canandaigua, N.Y.

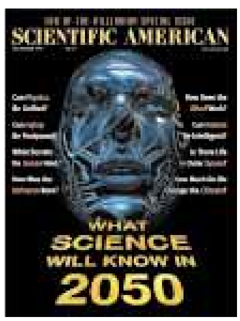
SLIM FILMS

SELF-AWARENESS emerges within what Antonio Damasio calls the movie-in-the-brain.

Damasio replies:

As stated in my article, I propose a means to generate, in biological terms, the subjective feeling that accompanies our image-making. Loosemore does not have to accept my proposal, but the aim of my effort is clear: to understand not just how, say, the color red is mapped but also how we have a subjective perspective of redness. I am neither bullishly claiming that we know all nor that

THE_MAIL



READERS HAD STRONG OPINIONS about our December 1999 issue on "What Science Will Know in 2050," and none more forceful than the protests that this "End-of-the-Millennium Special Issue" came a year early. We sympathize with their point of view, but in answer: It may be more mathematically rigorous and precise to start the 21st century in 2001, but it is a meaningless precision given the caprices with which calendars have been modified over the years. Moreover, when people refer to periods like "the 20th century" or "the next millennium," our understanding is that they are typically less concerned with the precise demarcations than with the overall historical character and significance.

As such, "the 20th century" is a label akin to "the Renaissance" or "the Victorian era." The bottom line is that if most of the world thinks that a new millennium has begun, then for all practical purposes, it has. Additional reader comments concerning articles in the December issue are featured.

we will know all, although I am convinced we will know a lot more. I do claim, however, that the assumed hardest part of the hard problem—subjectivity—may not be so hard after all.

ROBOT REFLECTIONS

Regarding Hans Moravec's robot dreams ["Rise of the Robots"], I've been a science-fiction writer for more than 40 years, and I like to create robot characters. Most are miners on airless moons or builders and land-shapers on new worlds. Some are self-aware, and sometimes they malfunction, go crazy and behave in evil ways. A few are human-shaped and tend to pose around admiring themselves. None of them takes out the garbage. I would hope that 50 years from now we would find something better to do with garbage—convert it into fuel, for instance—than have a robot lug it to the curb. Although Moravec admits that all attempts by roboticists to create a human level of intelligence in machines have failed, he still envisions within 50 years a species of superintelligent robots that leaves the human species with nothing to do but putter around. (This quaint vision harks back 70-odd years, where it flourished for a while in Hugo Gernsback's magazines of "scientifiction.") If I thought that kind of sluglike existence was in store for my grandchildren in their middle age, I would truly despair.

PHYLLIS GOTLIEB
Toronto, Canada

Moravec concludes that by 2050 robots will outperform their human creators "in every conceivable way, intellectual or physical." One can only hope that the robots will outperform us in the moral and ethical arena as well—it is frightening to contemplate from whom the robots may learn their ethical standards. Once we have become, in effect, their pets, let's hope the scenario is more like Isaac Asimov's *I, Robot* than *Terminator 2: Judgment Day*.

JEFFRY A. SPAIN
Cincinnati, Ohio

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Einstein, the H-Bomb and Whale Harpoons

APRIL 1950

HYDROGEN BOMB: A WARNING—"We have to think how we can save humanity from this ultimate disaster. And we must break the habit, which seems to have taken hold of this nation, of considering every weapon as just another piece of machinery and a fair means to win our struggle with the U.S.S.R. —Hans A. Bethe"

GRAVITY EQUATION—"The skeptic will say: 'It may well be true that this system of equations is reasonable from a logical standpoint. But this does not prove that it corresponds to nature.' You are right, dear skeptic. Experience alone can decide on truth. Yet we have achieved something if we have succeeded in formulating a meaningful and precise equation. The derivation, from the questions, of conclusions which can be confronted with experience will require painstaking efforts and probably new mathematical methods. —Albert Einstein"

ATOMIC SPY—"The celebrated case of Klaus Fuchs, atomic spy, came to a swift end last month. Fuchs, a German Communist who went to England in 1933 and was head of theoretical physics at the British atomic energy research center at Harwell, pleaded guilty to having transmitted atomic secrets to agents of the U.S.S.R. Fuchs received the maximum sentence of 14 years in prison. A strange feature of the case was that the U.S.S.R. repudiated Fuchs' confession."

APRIL 1900

ANTARCTIC PIONEER—"The steamer 'Southern Cross,' with C. E. Borchgrevink, a Norwegian, and the survivors of the South Polar expedition, fitted out in 1898 by British publisher Sir George Newnes, has arrived at Wellington, New Zealand. Herr Borchgrevink reports that the magnetic pole has been located." [*Editors' note: Carsten E. Borchgrevink led the first expedition to winter over on the Antarctic mainland.*]

SUNLESS SEA—"Sir John Murray addressed the Geographical Section of the British Association on some interesting facts as to the temperature of the ocean at great depths. The data obtained up to the present time shows that at a depth of 180 meters the temperature of the water remains nearly invariable at all seasons. Nearly all the deep water of the Indian Ocean is below 1.7° C, but in the North Atlantic and the greater part of the Pacific the temperature is higher. As the depths of the sea constitute an obscure region where the solar rays cannot penetrate, it follows that vegetable life must be absent upon 93 per cent of the bottom."

SOFT ARMOR—"The armored train has played an important part in the South African war. One memorable incident was the attack on the armored train at Chieveley in which Winston Churchill was captured. As is well known, railway iron and boiler plates are the usual protection, but the locomotive shown in our engraving was made safe in an unique manner. Rope mantlets were used for the protection of the engine on the Colenso line. The work was done by sailors, and it has been found that the rope protection is a most admirable one. It is probable that the engine is run entirely by bell signals, the fireman and engineer being entirely protected. Its appearance is most grotesque, looking not unlike a gigantic French poodle dog."

OLD HARPOONED WHALE—"A whale has been found with a harpoon in its body which, by its markings, showed that it must have been hurled at the whale at least thirty-six years ago."

APRIL 1850

NEW WHALE HARPOON—"Capt. Robert Brown, of New London, Conn., has invented a most important improvement for shooting and capturing whales. It is well known that some whales of the Pacific cannot be approached with the harpoon in a boat, and at best the harpooning and lancing of whales is a very dangerous and difficult business. The idea of firing the harpoon out of a gun has been often advanced, but Capt. Brown's harpoon, with the line attached, can be fired as accurately as a musket ball. The invention may be termed, 'Whaling made successful and easy by a Yankee Captain.'"

AGE OF STEAM—"It is said that according to the late census of England, the number of horses in that country has been found to have diminished from 1,000,000 to 200,000 within the last two years—in other words, the Railroad have dispensed with the use of 800,000 horses, and these animals, as well as oxen, are now scarcely used for transportation."

SCIENTIFIC AMERICAN

NEW APPLICATION for soft armor: a locomotive for the South African war, 1900.

FROM SCIENTIFIC AMERICAN

PHYSICS_ELEMENTARY PARTICLES

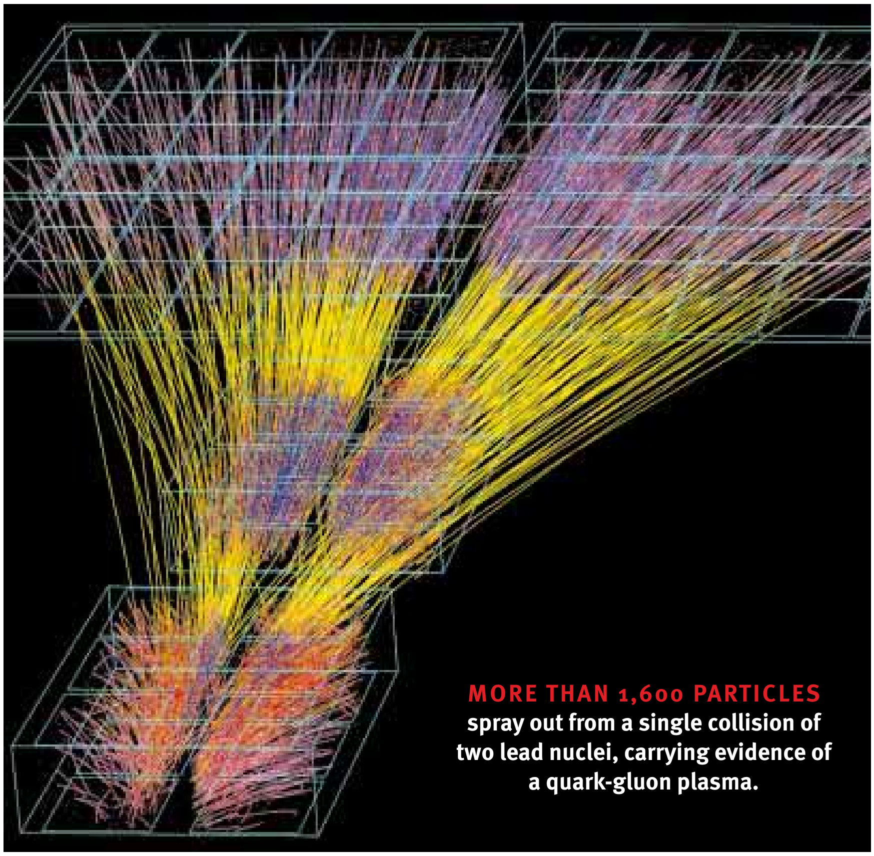
Fireballs of Free Quarks

CERN appears to have spotted the long-sought quark-gluon plasma—last seen during the big bang

Not every scientific discovery is heralded by a clear cry of "Eureka!" A case in point is the study of an exotic state of matter known as a quark-gluon plasma (QGP), in which hundreds of ordinary protons and neutrons melt together and form a fiery soup of free-roaming quarks and gluons. The universe consisted of such a quark stew 10 microseconds after the big bang, about 15 billion years ago.

Seven experiments have been gathering data for the past six years at CERN, the European laboratory for particle physics near Geneva. Although the accumulated evidence is not as direct and clear-cut as had been hoped for when the program began, scientists conducting the experiments felt sufficiently confident to make their February 10 announcement. "We now have compelling evidence that a new state of matter has been created," said CERN theorist Ulrich Heinz. And that state, he continued, "features many of the characteristics" predicted for a quark-gluon plasma.

Most modern high-energy particle physics experiments smash together the smallest convenient particles—electrons or protons—because the simpler the protagonists, the cleaner the data. The CERN experiments, in contrast, use relative behemoths: lead nuclei composed of 208 protons and neutrons. These nuclei are hurled at almost the speed of light at a thin foil, also made of lead. On occasion, one of the projectiles strikes a target nucleus, producing a spray of thousands of particles that travel on to the experimental detectors. From these particles, physicists try to determine whether the collision momentarily created a seething fireball of debris, hot and dense enough to set quarks loose.



MORE THAN 1,600 PARTICLES spray out from a single collision of two lead nuclei, carrying evidence of a quark-gluon plasma.

ANDRES SANDOVAL *CERN*

Quarks, glued together by particles aptly named gluons, are the basic constituents of matter, making up the familiar protons and neutrons as well as more exotic creatures seen only in cosmic rays and particle accelerators. Ordinarily, quarks are locked away inside their parent particles by a phenomenon called confinement. Individual quarks carry a kind of charge that is somewhat analogous to electric charge but comes in three varieties called colors. Confinement requires that quarks group together in sets of three whose colors blend to make "white" or in pairs of quark and antiquark whose colors similarly cancel out. Separating the component quarks of a particle takes a large amount of energy, and instead of exposing their bare color charges to the world, the energy generates new quarks and antiquarks, which pair up with any potential lone quarks to keep their colors balanced. This pairing process kicks in when a quark gets farther than about a femtometer (10^{-15} meter) from its companions—the approximate size of particles such as protons and neutrons.

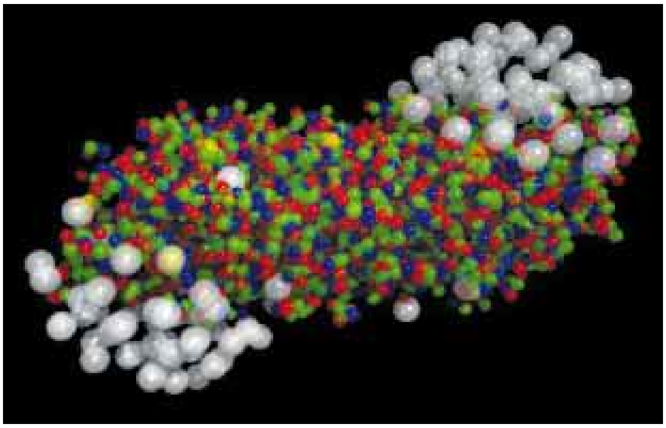
In the CERN experiments, when the two lead nuclei collide, the interactions between their component protons and neutrons generate a swarm of new particles out of the available collision energy. At lower energies, most of these particles will be new hadrons, particles made up of confined quarks and antiquarks. At sufficiently high energy densities, however, the newly generated particles are so tightly packed together that confinement stops being relevant; each quark has numerous companions within a femtometer. Instead of being a hot swarm of numerous hadrons colliding together and reacting, the fireball becomes one large cloud of quarks and gluons. The tremendous energy and pressure of the quark-gluon plasma causes it to explode outward. The temperature and density fall and soon become too low to sustain the plasma state. The quarks then rapidly pair off again, forming colorless hadrons. The fireball, now composed of hadrons, continues expanding and cooling, and ultimately the hadrons fly on to the detectors.

Physicists have been eager to create the QGP in part because it provides clues about the origin of the universe. The process of the quark fireball cooling to form hadrons (and later to form atoms) mimics what happened during the big bang. Our understanding of the universe's expansion has been tested by experiment back to the third minute, when ordinary atomic nuclei formed; with the quark-gluon plasma, "we have extended our knowledge back to 10 microseconds after the big bang," says Reinhard Stock of the University of Frankfurt, who led one of the CERN experiments. The explosive pressure at that time was comparable, he remarks, to the weight of "150 solar-masses acting on an area the size of a fingernail." (Apocalyptists take note: the presumed creation of the QGP did not create a mini–black hole or other Earth-destroying phenomenon, as some press reports suggested it might last year.)

CERN researchers cite several lines of evidence that strongly indicate they created the quark-gluon plasma. First are the relative numbers of various hadrons, which indicate the temperature and energy density that must have prevailed when they formed. The result is consistent with the levels theoretically required to produce a plasma. The energy density is about seven times that of ordinary nuclear matter, and the fireball is expanding at 55 percent of the speed of light when the hadrons "freeze out" of it.

The next observed effect is enhancement of strangeness, which refers to a type of quark. Altogether there are six different species, or "flavors," of quark, going by the whimsical names of up, down, strange, charm, bottom and top. The lion's share of ordinary matter is composed of the lightweight up and down quarks: two ups and one down quark make a proton; one up and two downs, a neutron. Strange particles, produced in particle physics experiments, contain at least one strange quark or antiquark.

Strange quarks are heavier than ups and downs, making them more difficult to produce. In the early 1980s theorists predicted that they should be unusually abundant in the QGP, where energy levels are so high that strange quark-antiquark pairs are produced essentially as easily as pairs of ups and downs are. The CERN experiments saw several features of enhanced strangeness. When conditions were ripe for a plasma, overall strangeness was two times higher, and a particle called omega, containing three strange quarks, occurred 15 times more often. Such extra enhancement of "multistrange" particles is characteristic of a plasma.



STEW OF QUARKS (*colored balls*) is set free from protons and neutrons (*gray balls*) when two nuclei collide.

Whereas strangeness is enhanced in a QGP, certain charm particles, containing the next heavier variety of quark, are suppressed, as predicted in 1986. Attention focuses on the J/psi meson, which consists of a charm quark and a charm antiquark. Charm quarks are so massive that these charm-anticharm pairs can be produced only during the initial extremely high energy proton-neutron collisions and not during the subsequent fireball. How many of the pairs remain together to be detected as J/psi mesons depends on whether they had to endure a QGP: a hot, seething plasma separates a charm quark from its partner charm antiquark, so they end up detected as a different species of hadron. The observed pattern of J/psi suppression in the CERN experiments "rules out the available conventional [explanations] based on confined matter," asserts Louis Kluberg of the Laboratory of High Energy Nuclear Physics in Palaiseau, France.

All this evidence comes down on the side of a quark-gluon plasma. Why, then, in the words of Heinz, is this evidence "not enough to prove beyond reasonable doubt" that a quark-gluon plasma has been created?

The problem is that the evidence is indirect, involving detection of particles produced when the plasma changes back to ordinary hadrons. If there were a complete and consistent dynamical theory that described the collisions, such indirectness might be less of a concern. But such a theory does not exist: theorists must resort to various approximation schemes and computer models, incorporating guesses about which processes are most significant to try to re-create the observed data. Indeed, some theorists will now be playing devil's advocate, doing their darnedest to concoct a model involving only hadron collisions that can explain all the CERN data.

A way to shortcut such efforts is to obtain untainted evidence *directly* from the plasma—by studying particles that do not interact strongly with quarks and gluons and so can escape from the QGP while it is still a plasma. They would carry direct signals of the extant conditions. For example, the formation of a QGP should greatly increase the number of photons emitted. Alas, CERN's photon data are inconclusive, almost swamped by the large background of photons that are explicable without a QGP. "There are intriguing indications of direct photons, but they are marginal," Heinz says.

Such direct evidence will have to wait for the Relativistic Heavy Ion Collider, or RHIC (pronounced "rick"), at Brookhaven National Laboratory in Upton, N.Y., which will start examining head-on collisions of two beams of gold ions in the summer [see "A Little Big Bang," by Madhusree Mukerjee, Scientific American, March 1999]. The usable collision energies will be 10 times those of CERN's program, which ought to produce a QGP with a higher temperature and longer lifetime, allowing much clearer direct observations. RHIC's plasma should be well above the transition point between a QGP and ordinary hadronic matter, allowing numerous more advanced studies of the plasma's properties, not merely an uncertain demonstration that it exists at all.

In 2005, CERN's Large Hadron Collider will come on-line and slam ions at 30 times the energy level of RHIC. "We have now scratched the surface," Heinz says. The higher energies of RHIC and the Large Hadron Collider are needed to "complete the picture." —*Graham P. Collins*

With reporting by Uwe Reichert of Spektrum der Wissenschaft *in Geneva.*

HENNING WEBER *University of Frankfurt*

Outbreak Not Contained

West Nile virus triggers a reevaluation of public health surveillance

The appearance of West Nile virus in New York City last summer caught the U.S. by surprise. That this virus—which is known in Africa, Asia and, increasingly, in parts of Europe—could find its way to American shores and perform its deadly work for many months before being identified has shaken up the medical community. It has revealed several major gaps in the public health infrastructure that may become ever more important in this era of globalization and emerging diseases.

Because it is mosquito-borne, West Nile has reinforced the need for mosquito surveillance—something that is only sporadically practiced around the country and something that could perhaps help doctors identify other agents causing the many mysterious cases of encephalitis that occur every year. And because it killed birds before it killed seven people, the virus made dramatically clear that the cultural divide between the animal-health and the public-health communities is a dangerous one. "It was a tremendous wake-up call for the United States in general," says William K. Reisen of the Center for Vector-Borne Disease Research at the University of California at Davis.

No one is certain when, or how, West Nile arrived in New York. The virus—one of 10 in a family called flaviviruses, which includes St. Louis encephalitis—could have come via a bird, a mosquito that had survived an intercontinental flight or an infected traveler. It is clear, however, that West Nile started felling crows in New York's Queens County in June and had moved into the Bronx by July, where it continued to kill crows and then, in September, birds at the Bronx Zoo.

By the middle of August, people were succumbing as well. In two weeks Deborah S. Asnis, chief of infectious disease at the Flushing Hospital Medical Center in Queens, saw eight patients suffering similar neurological complaints. After the third case, and despite some differences in their symptoms, Asnis alerted the New York City Department of Health. The health department, in turn, contacted the state and the Centers for Disease Control and Prevention (CDC), and the hunt for the pathogen was on. It was first identified as St. Louis encephalitis, which has a similar clinical profile and cross-reacts with West Nile in the lab.

BOB CHILD *AP Photo*

AVIAN AUTOPSY: Closer attention to crow deaths might have better prepared public health officials for the outbreak last year.

Understandable as it is to many health experts, the initial misidentification remains worrisome. As Reisen points out, diagnostic labs can only look for what they know. If they don't have West Nile reagents on hand, they won't find the virus, just its relatives. "In California we have had only one flavivirus that we were looking for, so if West Nile had come in five years ago, we would have missed it until we had an isolate of the virus as well," Reisen comments.

This is true even though California, unlike New York State, has an extensive, \$70-million-a-year mosquito surveillance and control system. The insects are trapped every year so that their populations can be assessed and tested for viruses. Surveillance has allowed California to document the appearance of three new species of mosquito in the past 15 years. In addition, 200 flocks of 10 sentinel chickens are stationed throughout the state. Every few weeks during the summer they are tested for viral activity.

In 1990 sentinel chickens in Florida detected St. Louis encephalitis before it infected people. "Six weeks before the human cases, we knew we had a big problem," recalls Jonathan F. Day of the Florida Medical Entomology Laboratory. After warning people to take precautions and spraying with insecticides, the state documented 226 cases and 11 deaths. "It is very difficult to say how big the problem would have been if we hadn't known," Day says. "But without our actions I think it would have been in the thousands." (Day says surveillance in his county costs about \$35,000 annually.)

New York City, home to perhaps about 40 species of mosquito, has no such surveillance in place, even though some of its neighbors—Suffolk County, Nassau County and every county in New Jersey—do. And it is not alone. Many cities do not monitor for the whining pests unless they are looking for a specific disease. "We have clearly forgotten about mosquito-borne disease," says Thomas P. Monath, vice president of research and medical affairs at OraVax in Cambridge, Mass., and formerly of the CDC. "We have let our infrastructure decay, and we have fewer experts than we had 20 or 30 years ago."

Tracking mosquitoes could potentially help not just with exotic arrivals but with the plethora of encephalitis cases reported every year. Indeed, the particular strain of West Nile that hit New York was ultimately identified by Ian Lipkin of the University of California at Irvine and his colleagues because they were collaborating with the New York State Department of Health on an encephalitis project. Two thirds of the cases of encephalitis that occur every year have an "unknown etiology." A few states, including New York, California and Tennessee, have recently started working with the CDC to develop better tests to identify some of these mysterious origins. As a result, Lipkin—who says he has developed an assay that can quickly identify pathogens even if they are not being looked for—was given samples from the patients who had died in New York City.

Some health experts, including Mahfouz H. Zaki of the Suffolk County Department of Health Services, predict that better mosquito surveillance would lead to a better understanding of encephalitis in general. As Zaki has noted, most of the unknown-etiology cases occur in September—just when insect-borne diseases tend to peak. Three hundred of the 700 such cases in New York State every year occur in New York City.

Even if surveillance can't catch what it doesn't know, it can tell public health researchers that a new mosquito species has appeared—say, one that can transmit dengue or yellow fever—or it can indicate that something is wrong with the birds and should be investigated. The sentinels in the case of West Nile were, in fact, the city's crows and, later, birds at the Bronx Zoo. Through careful analysis of the crows and other species, Tracey McNamara, a veterinary pathologist at the Wildlife Conservation Society (which runs the Bronx Zoo), quickly determined that the pathogen was not St. Louis encephalitis—despite the CDC claims—because that disease does not kill birds. And she knew that it was not eastern equine encephalitis, because emus weren't dying. "We owe a debt of gratitude to the emu flock," McNamara says.

DEATH ON WINGS: West Nile virus, carried by mosquitoes, may reemerge this summer. Officials are concerned that birds carried the virus south.

But despite her recognition that something new, unusual and deadly was afoot, McNamara could do little herself—except hound people in the human-health community to take a look at the wildlife. "The thing that was so frustrating was that we lack the infrastructure to respond," she says. "There was no vet lab in the country that could do the testing." Because none of the veterinary or wildlife labs had the ability to deal with such pathogens, McNamara was forced to send her bird samples to the CDC and to a U.S. Army lab. The Wildlife Conservation Society recently gave $15,000 to Robert G. McLean, director of the U.S. Geological Survey's National Wildlife Health Center, so he could study the pathogenesis of West Nile virus in crows and the effectiveness of an avian vaccine. "The federal budget moves at glacial speed," McNamara complains. "That is going to need to be addressed."

The continued bird work by McLean and others has kept the East Coast on alert for the potential of another West Nile outbreak this summer. Last fall McLean and his colleagues found West Nile in a crow in Baltimore and in a migratory bird, the eastern phoebe. "They go to the southern U.S.," he notes. "That just convinces us that a lot of migratory birds were infected and flew south with the virus." Despite the fact that "wildlife is a good warning system for what could eventually cause problems in humans," McLean is not optimistic about a true and equal collaboration between his and McNamara's world and the CDC's: "We are on the outside looking in. We are not partners yet, and I am not sure we will ever get to be partners." The cost could be high. As McNamara points out, "Don't you want a diagnosis in birds before it gets to humans?" *—Marguerite Holloway*

FOWL SURVEILLANCE with so-called sentinel chickens, used in such states as Florida and California, can be a cost-effective way to spot mosquito-borne illness.

DAVID SCHARF *Peter Arnold, Inc. (top)*; JONATHAN F. DAY *University of Florida (bottom)*

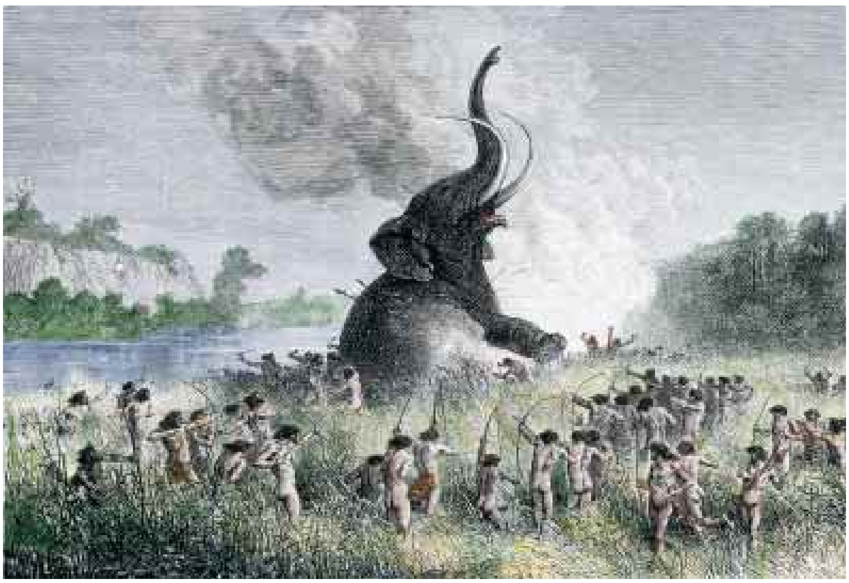
PALEOANTHROPOLOGY_DIET

A Taste for Science

One researcher's quest to understand how early Americans ate—and their mammoth refrigeration problem

There's just no delicate way to tell this story, so here goes: to test his hypothesis that early Americans used frozen lakes as refrigerators for their mastodon meals, University of Michigan paleontologist Daniel C. Fisher ate horse meat that had been floating raw in a local pond for several months.

Fisher is an expert on the natural history of mastodons and mammoths, two closely related species of elephantine mammals that inhabited much of North America until some 10,000 years ago; both were regularly hunted by humans. While excavating a pile of mastodon bones found in southern Michigan a decade ago, Fisher began to wonder whether the early Americans might have stored excess meat from a kill, instead of just abandoning it to scavengers. After all, a mastodon can weigh upward of 8,000 pounds—more than enough food for hundreds of your closest friends and relatives. Clusters of mastodon bones located near the remnants of two wooden columns offered the first clues.



MAMMOTH HUNT: Easily serves 100, but what to do with the leftovers?

The columns actually attracted Fisher's attention first. He thought that perhaps the remarkably positioned poles—young spruce trees stripped, flipped upside down and embedded in what had been the bottom of a pond—had reached above the surface of the water. The bones around the poles turned out to be selected cuts from one animal: ribs, vertebrae, part of a shoulder. All the bones would originally have had a fair amount of meat on them. And mixed in with the skeletal remains were the remnants of mastodon intestines with some rather strange contents. In addition to carrying the expected plant material, the organs held sand and stones—hardly standard fare for a mastodon.

"What we seem to be dealing with is virtually impossible to configure without human intervention," Fisher notes. His explanation: the hunters used the gravel-packed intestines as anchors to weigh down parts of a butchered animal, either to hold meat at the bottom of the pond or to prevent meat stored on the water's surface from drifting ashore. The wooden columns would have served as handy reminders of where the food had been stored.

But this discussion was mere speculation—would the meat even be edible after months in the water? Fisher decided one winter to test his idea. Starting with a few deer heads and legs of lamb, he put raw meat below the ice that covered ponds and peat bogs near the Ann Arbor campus. After a few months, he pulled the meat out to see if it was still fresh (it was). He also sent one leg of lamb to a biological laboratory to screen for dangerous pathogens (there were none).

When a friend's horse died of old age and the owner donated the body to Fisher for research, he scaled up the experiment. Fisher dropped chunks of horse meat weighing up to 170 pounds below the ice at a nearby pond, anchoring some segments to the bottom with short sections of intestines. Every week or two Fisher checked the meat. At first, he would cook and just chew the meat; eventually he graduated to swallowing each bite. "Altogether I ate the equivalent of a steak," Fisher estimates.

This unusual scientific method—which Fisher completed a few years ago but described at a meeting of archaeologists in Santa Fe, N.M., last fall—revealed two important characteristics of this potential prehistoric fridge: first, as the water warmed in the spring, lactobacilli, the common bacteria found in yogurt and cheese, colonized the meat. Fisher believes that these bacteria, which are abundant in soil and runoff and are not harmful to humans, rendered the meat inhospitable to other pathogens. So despite the unusual smell and taste that developed after a few months (Fisher compared it to Limburger cheese), the meat was safe to eat well into the summer. Second, as the bacterial colony grew, carbon dioxide gas built up in the meat, and eventually the meat became so buoyant that it rose naturally to the surface—making it hard to lose underwater.

With so much recent interest in trying to clone the frozen mammoth that was recovered from the Siberian permafrost last October, Fisher may one day have the chance to put his storage theory to the ultimate test. And he says he might even be willing to eat some of the mammoth meat that had been stored for centuries in the frozen tundra: "I guess if it smelled okay, I might try some." *—Sasha Nemecek*

NORTH WIND PICTURES

MATERIALS SCIENCE_RENEWABLES

Car Parts from Chickens

Researchers hatch a plan to make plastic from feathers

Nearly a decade ago poultry-processing plants around the nation asked researchers at the Department of Agriculture to solve a big environmental problem: find a more efficient way to dispose of the four billion pounds of chicken feathers produced annually in the U.S. What they were expecting was a method by which the feathers could be made more biodegradable after burial. But Walter Schmidt, a chemist at the Agricultural Research Service (ARS) in Beltsville, Md., went a step further to develop a recycling technology that will soon bring feathers into everyday life disguised as plastic and paper products.

Currently poultry farmers mix water with leftover feathers in large pressure cookers to make low-grade feedstuff for chickens and cattle—a venture that is generally not profitable. But converting feathers into value-added products required more than just a little steam. Schmidt and his colleagues developed an efficient mechanical method to separate the more valuable barb fibers (plumage) from the less useful central chaff, or quill. Though softer, the keratin fibers in the barbs are stronger and less brittle than those in the quill and therefore have a much broader range of applications.

The key to easy separation lay in the fact that the quills are bulkier and heavier. The feathers, dried and sterilized, are shredded and fed into a cylindrical device consisting of an outer and inner tube. The feathers are sucked through the central channel, and the quills are drawn off at the bottom, but thanks to air turbulence, the barbs float back up between the sides of the tubes.

Once separated, barb fibers can be used in many ways. Schmidt and his collaborators have made diaper filler, paper towels and water filters out of them. The ground fibers have been used in plastics, in pulp to make paper, and in combination with synthetic and natural fibers to make textiles. And the fibers are good for more chemically complex applications as well. For instance, by mixing the fiber powder with a reducing agent and placing the slurry in a hydraulic press, Attila Pavlath, a scientist for the ARS in California, has created polymer films. "The reducing agent acts like a hairdresser's perm solution to relax the protein bonds of the keratin, allowing us to mold the fiber into thin sheets of plastic," Pavlath explains. This polymer may first show up as biodegradable candy wrappers (similar to cellophane) and six-pack can-holders.

The powder can also replace additives, such as nonrecyclable fiberglass, that are used to strengthen plastic. Combined with polyethylene, the barbs can produce a more rigid plastic suitable for dog-food bowls and automobile interior parts, including the dashboard.

The quill portion doesn't have to go to waste, either. David Emery of Featherfiber Corporation in Nixa, Mo., has developed a process to make high-grade quill protein that is 90 percent digestible (typical quill meal is only 50 percent digestible), Emery says. The company has licensed Schmidt's patents and has just completed a pilot plant to produce feather fiber.

Farm animals may not be the only ones to benefit from a quill meal. Carlo Licata of MaXim LLC in Pasadena, Calif., believes that the quill portion is an excellent dietary supplement for humans. "That's because the keratin protein is very absorbent," Licata indicates, "and can retain nutrients for a longer period"—something like Metamucil, only better.

All this and more from chicken feathers without breaking the farm. "A typical farm produces 10,000 pounds of feathers per hour, which is enough to meet the needs of one plastic-producing plant," Schmidt remarks. If all the feathers in the U.S. were processed, more than five billion pounds of plastic products could be made.

Feather-derived plastics are just one of several nonpetroleum-based "green plastics" that have surfaced in the past year. Cargill-Dow Polymers in Minnetonka, Minn., recently announced production of a new kind of natural plastic made from polylactic acid, a compound derived from corn. Monsanto, maker of genetically modified plants, reported last October that it had fabricated a plant capable of producing biodegradable plastic of a type known as polyhydroxyalkanoate.

But the consequences of producing greener plastics are often overlooked, according to Tillman Gerngross, a biochemical engineer at Dartmouth College. "People too readily accept the premise that renewable equals environmentally good. It does not necessarily add up." If you have to use huge amounts of coal to make the plastics, then you are harming the environment just the same, he points out. And feather plastics are often only partially biodegradable. Still, Gerngross agrees that a move toward sustainable resources is desirable. That should prevent researchers like Walter Schmidt from chickening out too soon. *—Diane Martindale*

A NEW USE FOR OLD FEATHERS: Greener plastics from our favorite bird.

J. PAT CARTER *AP Photo*

Power to the PC

Distributed computing over the Internet goes commercial

To date, more than 1.7 million people have participated in the largest computation in history. These scientists, students and PC hot-rodders aren't shooting for a Guinness world record, either. The aim of the SETI@home project is to discover life on other planets. Individuals volunteer to put idle Web-connected computers to work analyzing the gigabytes of raw data collected by the Arecibo Observatory in Puerto Rico. The reward for joining this massive experiment? Prestige, mostly. And the possibility of being part of first contact. But can the same distributed-computing paradigm be used to turn a profit?

Absolutely, says Adam L. Beberg, a 26-year-old computer scientist. Beberg and a handful of colleagues are cranking away on Cosm, a set of software applications, programming tools and protocols to commercialize distributed computing. "I'm trying to build an infrastructure where a company could run our software and utilize 100 percent of their resources," Beberg explains.

Beberg had helped bring this notion of distributed computing to the masses with distributed.net, which he founded in 1997. It enlisted computer users on the Net to crack encryption keys for a contest sponsored by RSA Labs. Distributed.net now boasts the processing power of 160,000 Pentium II 266 megahertz computers working all day, every day, on similar code-cracking endeavors. Other academic and research outfits are also employing on-line distributed-computing techniques, which chop data into manageable chunks of "work units" in other processing-intensive applications: to find huge Mersenne primes (those numbers following the formula $2^p - 1$, where p is prime), calculate the quadrillionth bit of π (and beyond) and, potentially, conduct a 21st-century climate simulation.

Beberg sees plenty of opportunity for the commercialization of distributed computing. For instance, a pharmaceutical company may want to search for a new drug via computer models of viral agents. Or a digital-animation studio might need to render 100,000 high-resolution images for a feature film. Both tasks require tremendous computational power, yet most computer laboratories are limited by the number of PCs they have direct access to. "With Cosm, you could effectively take the computers used by, for example, customer-service representatives who hit a key every few minutes, probably playing solitaire, and give that computing power to the research department," says Beberg, who is simultaneously searching for venture capital while putting the finishing touches on Cosm.

Whereas the term "distributed computing" is commonly used when referring to projects like SETI@home, Beberg points out that his more robust Cosm system is more in line with the field's 30-year history than are the examples of "collaborative computing" currently on-line. Cosm's platform-independent software will run on any computer, is outfitted with strong security features and, perhaps most important, enables the client computers to talk with one another as well as with the server. "With problems like a weather simulation, where each piece of data depends on other pieces, you need to have communication," Beberg remarks.

The next step, of course, is to let Cosm loose on the Internet. Corporations, Beberg believes, will "hire" on-line users to yield their spare processing power, compensating them with cash or gifts. And that's when the market potential for "public" distributed computing will test its legs.

Several university projects are traversing a path similar to Beberg's—notably Globus, a project of the University of Southern California's Information Sciences Institute and Argonne National Laboratory, and the University of Virginia's Legion "worldwide virtual computer," whose offshoot, Applied Meta, counts numerous research, military and academic institutions as clients. But Cosm's latest private-sector competitor is Porivo Technologies, which has just scored nearly $1 million in venture capital. More a marketing team than a cabal of young computer scientists like Cosm, Porivo hopes to purchase the core of its operating software and launch what it calls the first "computer-processing service bureau." The Porivo Web site, basically a distributed-computing portal, would contain distributed-computing projects from which users could pick and choose. "If we can identify a clinical project, say, a cure for asthma, then we can potentially build a community of people who want to help," says Porivo CEO William Holmes, who notes that corporate clients will also be targeted.

If altruism isn't enough to lure participants, Holmes believes that subsidizing users' Internet service or giving them frequent-flier miles could do the trick. Ultimately, the commercialization of Internet-based distributed computing will most likely prove the old adage that you get what you pay for. *—David Pescovitz*

DAVID PESCOVITZ is a frequent contributor based in Oakland, Calif.

AVIATION_SIMULATION

Throwing in the Tower

A virtual-reality control tower helps to test new runway designs and traffic patterns

Heaven can wait, especially if you've got a layover at San Francisco International Airport. The Bay's famous fog, a set of parallel runways designed for pre–World War II airliners and all the problems associated with 21st-century air-traffic congestion have made the airport the nation's premier site for delayed flights: last year one in three were delayed 15 minutes or more.

"We need expansion and reconfiguration," explains Ron Wilson, director of public affairs for the city's Airport Commission. Federal rules mandate that, for instrument-only flights, parallel approaches be separated by 4,300 feet, but "the only way to get that separation is to put one runway in San Francisco Bay," Wilson notes. Local groups, however, are concerned that such changes could be environmentally harmful. Thanks to landfilling, "the Bay is a third smaller than when California became a state" in 1850, explains Will Travis, executive director of the San Francisco Bay Conservation and Development Commission. "We want to see if it's possible to address the problems without putting new tarmac down."

VIRTUAL CONTROL TOWER can emulate the busiest airports.

NASA

Bitter public debate has become a standard feature of proposed airport expansions and changes. Now, though, the National Aeronautics and Space Administration Ames Research Center and the Federal Aviation Administration have a new tool that will help planners hammer out solutions to such controversies. Called FutureFlight Central, it's a 360-degree virtual-reality air-traffic control tower that can be programmed to run simulations of surface movements—the primary source of delays—as well as takeoff and landing operations at any airport, real or imaginary. Its designers say this one-of-a-kind, $10-million simulator will allow engineers to hone their airport designs and let controllers test new traffic flows before anyone pours a single yard of concrete—or fills in one square foot of an already shrinking bay.

"You just can't change ground flow willy-nilly at an airport," says Nancy Dorighi, FutureFlight Central's operations manager. "When you want to construct new structures or build new runways, you can now try it in simulation first to figure out how to incorporate its ground-flow patterns."

And that's just a start. FutureFlight Central will also allow airlines, aircraft designers and others to see how well an all-new airliner will fit in with existing airport infrastructures. Or the simulator can let controllers test new software and hardware. And, Dorighi adds, "something we plan to do is integrate a noise model that will allow us to predict a footprint of noise." Looking even further ahead, NASA plans to use the room to develop 360-degree immersive mission-control rooms for robotic explorations of other planets.

The virtual-tower concept evolved from a prior project called the Surface Movement Advisor, a software tool that Ames began developing in 1994 to reduce the time airliners spend on the ground. At Atlanta's Hartsfield International Airport in 1997, the Advisor chopped one minute off the average taxi time per airliner, saving an estimated $20 million in fuel. FutureFlight Central was developed as an operational test bed for the Advisor. Dedicated last December, the virtual-reality control tower has recently signed its first two customers. Clients will be charged at cost, Dorighi indicates, which could range from $50,000 on up.

Still, she insists, the facility will take pains to keep out of local free-for-alls like the one brewing in San Francisco. "Basically we're a neutral party providing the science," she observes. "We'll give them the measurements. But NASA is not taking sides." *—Phil Scott*

PHIL SCOTT, based in New York City, specializes in aviation issues.

By the Numbers

EMPLOYMENT_GENDER DISPARITY

Women and the Professions

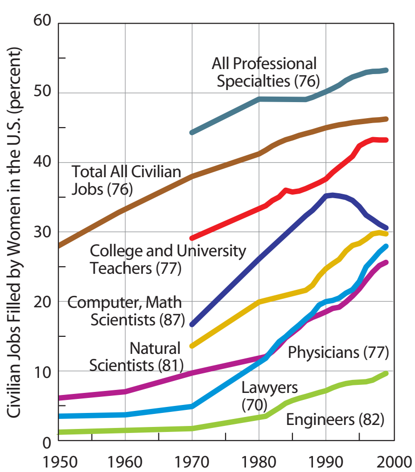
Of the 21 million professional jobs in the U.S., women hold 53 percent, but most of these are in fields that generally pay only moderately well, such as public school teaching and nursing. Of the eight million or so jobs in the better-paying professions—those with an average compensation of more than $40,000 in 1998—women hold only 28 percent. Almost all these better-paying jobs are in the six professions shown in the chart.

Overall, women's share of professional jobs appears to have stabilized, but their share of jobs in law and medicine is likely to continue rising as an increasing proportion of degrees in these fields go to women. In math and computer science, the proportion of women practitioners declined in the 1990s, although the number of women in this rapidly expanding field actually rose. According to Ruzena Bajcsy of the National Science Foundation, women's declining share of computer-science jobs reflects, in part, a huge surge of men into the profession in recent years as salaries rose markedly. She suggests that the increasing emphasis in the computer business on long hours, which conflict with family responsibilities, may have caused many women to go into other work. Another contributor to low female presence in computer jobs is the declining number of women receiving degrees in computer science beginning in the 1980s, a trend that was only reversed in 1997, when the number of female graduates rose moderately.

Women's share of jobs in the natural sciences and on college and university faculties leveled off in the late 1990s, despite an increase in the proportion of women receiving academic degrees in these fields in recent years. The U.S. Bureau of Labor Statistics predicts that total employment—male and female—in the professions will rise 27 percent between 1998 and 2008, with each of the six professions on the chart enjoying double-digit growth.

Women in the six professions average lower pay than men because they tend to work fewer hours and are in less financially rewarding positions. They are, for example, underrepresented in some high-paying medical specialties, such as cardiology and orthopedic surgery, and they are less apt to be partners in the biggest and most prestigious law firms.

But there appears to be a more fundamental reason why women make less: the widespread perception that men are better suited for important work. In the formulation of Virginia Valian, a psychologist at Hunter College, both males and females, from early childhood, develop what she terms "gender schemas," or sets of typically subconscious expectations about the proper role of the sexes, including the professional competence of men and women. "We expect men to do well," she says, "and see their behavior in the rosy light of our positive expectations. Conversely, we expect women to do less and judge their actual performance in the darker light of our negative expectations." Once people hold a gender schema, they tend to keep it in the face of discrepant evidence.



SOURCE: U.S. Bureau of the Census and Bureau of Labor Statistics. Figures in parentheses indicate women's earnings as a percent of men's earnings in 1998. The trend lines show decennial census data for 1950–1980 and five-year moving averages thereafter.

According to Valian's theory, negative judgments induced by a gender schema may be small, but their cumulative effect over the years results in substantially less progress by women, even when their credentials and performance are equal to those of men. Thus, women lawyers start out at the same salary as male colleagues, but after several years they are making less and are less likely to become partners. Because of gender schemas regarding the role of the sexes in the home, household tasks fall mostly to women, who may then be penalized if they work fewer hours than men in order to do housework. But in situations where it is possible to juggle work and family obligations successfully, as in academia, women still make less. That's because, Valian believes, they are judged in the light of biased gender schemas. This bias occurs despite evidence that, she argues, women's output is superior to that of male colleagues: on a per-article basis, articles by women are cited more frequently, although overall, men average more citations, because they publish more frequently. *—Rodger Doyle (rdoyle2@aol.com)*

RODGER DOYLE

SPACE PHYSIOLOGY

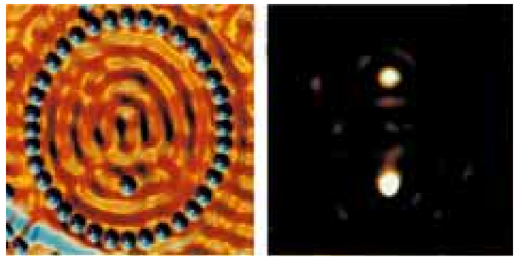
Whirl-a-Gig

To keep astronauts healthy on long spaceflights, engineers have long talked about elaborate systems of artificial gravity, such as giant space wheels. But according to Bernard Cohen and Steven T. Moore of the Mount Sinai School of Medicine in New York City, a simple centrifuge chair may be enough. During the 1998 Neurolab mission of the space shuttle, astronauts strapped themselves into a chair that spun at 45 rpm (*below*), subjecting their heads to simulated Earth gravity. A 20-minute ride every couple of days was enough to lessen disorientation during and after the flight. The findings were presented at the Space Technology and Applications International Forum in February. *—George Musser*

NASA

PHYSICS

Two Places at Once



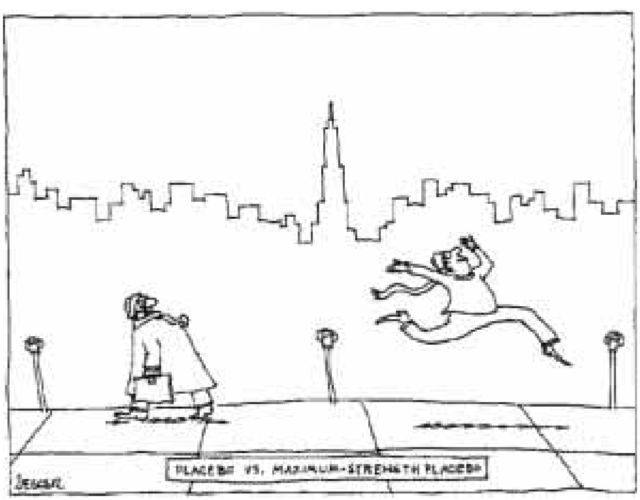
NATURE

Schrödinger's famous cat was both alive and dead at the same time, at least in the realm of atoms. Such superposed felines don't exist in everyday life, because environmental effects disrupt the delicate superposition. Now researchers at the National Institute of Standards and Technology, reporting in the January 20 *Nature,* have quantified this disruption, called decoherence. They held a beryllium ion in a magnetic trap and forced the ion's outermost electron to exist simultaneously in two different spin states. With lasers, they could control the physical separation of these two states—up to about 10 atoms' distance—and watched how the decoherence rate scaled exponentially with the separation. Physicists at the IBM Almaden Research Center melded the classical and quantum worlds in a different way: using a scanning tunneling microscope, they arranged atoms on a copper surface into an elliptically shaped corral (*left photograph*). A cobalt atom was placed at a focus of the ellipse; thanks to the wave nature of quantum particles, the corral reflected the electron waves from the cobalt atom, producing a mirage at the ellipse's second focus. The researchers found the phantom atom with measurements based on an electrical effect called Kondo resonance (*right photograph*). The work appears in the February 3 *Nature.* *—Philip Yam*

MEDICINE

Morticians Beware

Even when its human host is dead, the bacteria responsible for tuberculosis can sometimes keep right on living. In the January 27 *New England Journal of Medicine,* Johns Hopkins University researchers reported the first known case of TB transmission from a cadaver to a mortician. Lead author Timothy R. Sterling uncovered the unusual transfer route after comparing the DNA fingerprints of bacteria from both patients—they matched. The only time the two had met was during embalming, when blood was removed and fluids were injected to preserve the body. The embalmer inhaled infectious aerosols, probably created by the frothing of fluids through the deceased's mouth and nose. The discovery helps to explain why funeral home workers have had higher rates of TB infection and disease. *—Diane Martindale*



POLICY

Budget Boost

In February the Clinton administration unveiled the year 2001 research and development budget proposal, giving science its biggest financial boost ever. Under the budget umbrella, which included civilian and military research, civilian basic science got the best deal with an overall 7 percent boost, a hike totaling $2.8 billion, to bring its budget to $43 billion. The National Science Foundation, with a budget of $3.9 billion this year, led the pack, receiving a 17 percent increase. Much of the NSF money is directed at core disciplines but also includes specialties like nanotechnology, information technology and environmental biocomplexity. Second was the National Institutes of Health, which finished with a near 6 percent raise, adding $1 billion to its annual budget of $17.8 billion. Last but not least, NASA scraped up a respectable 3 percent, the first increase in years, to give it $14 billion in spending money. Whether words translate into cold, hard cash will be decided in the upcoming months during congressional deliberations. *—D.M.*

SENSES

The Fifth Taste

Almost a century ago Japanese researcher Kikunae Ikeda noted that the compound L-glutamate, abundant in animal protein, was responsible for a unique taste. He dubbed the taste "umami." Nevertheless, accepted wisdom had it that all tastes were combinations of the four standards: sweet, salty, sour and bitter. New research has vindicated Ikeda. Writing in the February *Nature Neuroscience,* Nirupa Chaudhari and colleagues at the University of Miami School of Medicine revealed that, based on rat studies, a specific molecule exists that acts as a receptor for L-glutamate, activating the umami taste. In hindsight, the presence of an umami-taste system is no surprise: many animals most likely seek out glutamate as a marker for high-protein foods. And the ubiquitous flavor additive monosodium glutamate probably owes its popularity to triggering the umami taste. Knowledge of the structure of the glutamate receptor could assist food scientists' efforts to modify the tastes of various foods.

—Steve Mirsky

A taste bud

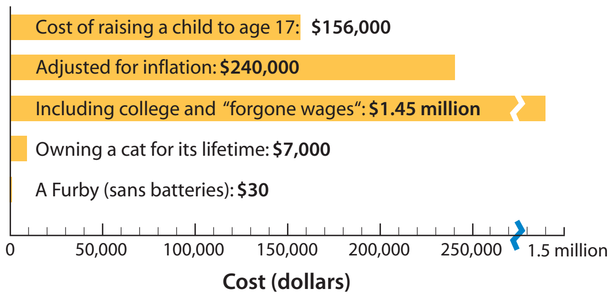
OMIKRON Photo Researchers, Inc.

DATA POINTS

So you want to start a family...

SUPERSTOCK

- Cost of a 40-pack of diapers for newborns: $9.49
- Number of diapers used before a child is toilet-trained: 10,000
- Annual tuition and fees at private, four-year college: $15,380
- Including room, board and other expenses: $21,339



SOURCES: Drugstore.com; Journal of Pediatrics*; College Board; USDA;* U.S. News & World Report *("forgone wages" analysis—wages not earned because of child-rearing);* New York Times*; eToys.com*

ART & SCIENCE

Insides Out

Medical Venus

ROSAMOND PURCELL/EXPLORATORIUM

Call it the "Oh, gross!" reaction. It's the feeling you get when watching a surgery on television or passing fresh roadkill—the sight of a body's inner mechanics is grotesque but mesmerizing. You cover your eyes, but you find yourself peeking.

The Revealing Bodies exhibit on view March 18 to September 4 at San Francisco's Exploratorium museum of science, art and human perception is a hot-spot for morbid fascination. Take the centerpiece of the exhibition: an 18th-century wax anatomical model known as the Medical Venus, on loan from the Museo Zoologica "La Specola" in Florence. The model depicts a supine female, her abdomen opened to reveal exquisitely lifelike internal organs. Or the dried human hands, belonging to anonymous 19th-century donors, skinned to reveal nerves and arteries. Or a 3-D sculptural version of the National Institutes of Health digital man and woman, based on photographs of corpses sliced into paper-thin segments.

"The exhibition offers a snapshot of the way representation technologies have influenced our cultural perception of our bodies," says Melissa Alexander, who developed the show in collaboration with a stable of artists and scientists. "It examines different tools for revealing bodies and asks how they end up in the mix of society and how cultural views drive scientific exploration."

Indeed, Revealing Bodies is a timeline of how medical science and art have intersected throughout the ages to enlighten and educate us about ourselves—from Aztec paper dolls used by ancient healers to represent diseases to the children's game Operation to demonstrations of near-infrared visible light imaging to an ultrasonic Doppler device that enables visitors to hear the blood rushing through their veins. With these exhibits, Revealing Bodies traces not only advances in scientific imaging but also mainstream society's psychological obsession with the human body as the ultimate cabinet of curiosity.

"Just looking carefully at what's right in front of you can be quite startling," says Rosamond Purcell, a renowned photographer of natural-history specimens who was commissioned to shoot several images for the exhibition. "And these collections are crying out to be looked at."

—David Pescovitz

PHYSICIST_BRIAN GREENE

A Greene Universe

The Columbia University theoretical physicist has a simple goal—explaining the universe with strings

Brian Greene's quest began early. Born in New York City, Greene grew up near the American Museum of Natural History. On rainy days the vast museum became his playground, but Greene was not like most boys his age. "Somehow the dinosaur exhibits, though impressive, never really excited me," he recalls. Instead what ignited his passion was the museum's Hayden Planetarium. "Ever since I can remember, I was always questioning what the universe was made of and how it got to be the way it got to be," Greene says.

Today, three decades later, Greene is still trying to answer those questions. A professor in physics and mathematics at Columbia University, he is one of the world's leading experts in string theory, which promises to explain the entire universe, including its origin and evolution. The theory asserts that all matter and forces are composed of incredibly tiny loops that look like strings. Loops vibrating in different ways become the fundamental particles, such as electrons, gluons and photons. Because of its sweeping potential to describe how everything works, string theory has become the most exciting concept in theoretical physics, and Greene has gotten the buzz as its hottest practitioner, his fame eclipsing even that of Edward Witten of the Institute for Advanced Study in Princeton, N.J.

By all accounts, Greene was destined to leave his mark in academia. At age five, fascinated with the power of the simple rules of arithmetic, he would pass the time by multiplying 30-digit numbers that his father had written down for him. To accommodate the calculations, they taped together sheets of construction paper. In the sixth grade he had exhausted the math resources at his school, prompting one of his teachers to write a note requesting help. Greene and his older sister took the note to Columbia University. "We literally went knocking from door to door," he recounts. After striking out at the computer science department, he found mathematics graduate student Neil Bellinson, who was willing to tutor him for free.

AT PLAY IN THE FIELDS OF BOHR AND EINSTEIN: **Brian Greene's research in string theory aims to unify quantum mechanics with general relativity.**

From such auspicious beginnings, Greene entered Harvard University in 1980, majoring in physics. There he first became aware that the two pillars of modern physics—quantum mechanics, which describes atoms and subatomic particles, and general relativity, which explains astronomical phenomena, such as black holes—are mutually incompatible. "It's as if the laws of the small and the laws of the large are in conflict with each other," Greene says. It has been modern physics' embarrassing secret. "The fact that the two theories don't fit together isn't really taught to you," he adds.

But it was not until Greene was at the University of Oxford as a Rhodes Scholar that he learned of a possible fix. It was the mid-1980s, physicists had just tamed several unruly infelicities with string theory, and the concept was experiencing a glorious rebirth as a way to unify quantum mechanics with general relativity. After attending a lecture on the topic, Greene was hooked. His thesis explored a possible way to coax experimentally testable predictions from string theory, and he continued this work at Harvard and later at Cornell University. In 1996 he moved back to New York City to set up a string-theory program at Columbia, coming full circle to the university where he was tutored as a youngster.

Manhattan seems the perfect place for Greene. Partial to chic black clothes, he bears a slight resemblance to the actor David Schwimmer of the TV series *Friends,* with the same boyish charm and comic timing. Only a touch of gray in his wavy hair hints that he is 38. But although Greene hardly looks the part of the fumbling, disheveled genius, he is no less the academic giant, intimately fluent in the arcane intricacies of string theory.

Ironically, the metaphorical beauty of the theory—the image of an untold number of strings vibrating in a cosmic symphony, all orchestrated by a single, omnipotent law of physics—belies the heinous mathematics involved. String theory requires extra dimensions of space (perhaps seven), in addition to the three that are commonly known. Proponents argue that the additional dimensions are

PETER MURPHY

Profile

curled up too tightly to see, just as a three-dimensional garden hose would look like a one-dimensional line when viewed from afar. To complicate matters, researchers have uncovered the possibility that one-dimensional strings can stretch themselves into two-dimensional membranes, which themselves can transform into higher-dimensional entities. Physicists such as Greene are having to invent unspeakably complex mathematics to describe this surreal landscape, just as Isaac Newton had to develop calculus to elucidate how forces act on objects.

One of Greene's major contributions to string theory occurred in 1992 while he was on sabbatical at the Institute for Advanced Study. Along with Paul S. Aspinwall and David R. Morrison, both at Duke University, Greene showed how the fabric of space could tear and repair itself—at least according to string theory. Though purely theoretical, the work was intriguing—general relatively prohibits ruptures in space-time—and Witten, the doyen of string theory, had independently arrived at the same result by using a different approach.

Unfortunately, space-time tears are well beyond what physicists can confirm or prove experimentally. In fact, researchers have yet to demonstrate any of the theory's extra dimensions—let alone the very existence of strings themselves. But Greene and other physicists are eagerly awaiting the Large Hadron Collider, a massive particle accelerator currently being built at CERN outside Geneva. If all goes according to plan, the LHC will smash together protons with such tremendous power that the collisions will create some of the hypothetical "superpartners"—selectrons, sneutrinos, squarks and the like—that string theory predicts.

Such proof could have come from the Superconducting Super Collider, had Congress not pulled the financial plug on that gargantuan accelerator in Texas. "If we had built that machine, our understanding of things could have taken a giant step forward," says Greene, who nonetheless can sympathize with the public's lack of support for the multibillion-dollar facility. "I think there's this sense that what we're trying to figure out now are esoteric details only of interest to physicists," he laments. That misconception is one reason why Greene wrote *The Elegant Universe,* the best-seller that explains the cosmic significance of strings and how they could answer some of humanity's deepest questions.

Exquisitely crafted in lucid prose, the book went into three printings in its first month, and Greene was soon whisked into a new role. His uncanny knack for distilling esoteric concepts into simple terms—along with his youthful good looks—has quickly made him the poster boy for theoretical physics. The trappings have been numerous: packed audiences for his speaking engagements; television appearances, most notably on an hour-long *Nightline in Primetime* special on ABC; and a bit part in the upcoming movie *Frequency,* starring Dennis Quaid. Political analyst George Stephanopoulos, who was Greene's running buddy at Oxford, has even joked that Greene, who is single, might be the first physicist to have groupies.

But Greene, who answered all his e-mails until the volume recently became unmanageable, doesn't see himself becoming a full-time popularizer. At this point, he has no plans for a second book. "Writing a book takes its toll on your research," says Greene, who adds that he always wants to remain on the front lines of physics. "I need to be fully engaged in the research to really know what's going on. I need to know all the details, all the subtleties."

The rush of adrenaline is another lure. "What has drawn me to science is the thrill of discovery," Greene says. "There's nothing like that moment of realizing that you've discovered something that has not yet been previously known." His current research investigates quantum geometry, the properties of space at extremely short distances, around the purported size of a typical string, or 10^{-33} centimeter (a hydrogen atom is about 10^{-8} centimeter wide). In this realm, space-time is no longer smooth and curved but stormy and frothy.

Such work could help determine the very essence of space and time. "How did space come into being and how did time come into being, and is there something more basic than space and time?" asks Greene, referring to string theory's postulate that space and time might merely be manifestations of something more fundamental. The answers to those questions might help explain why time, unlike space, seems to run in only one direction—forward.

That and other basic conundrums might be more easily solved if researchers knew the overarching idea behind string theory. With general relativity, that key principle was space-time curvature. Interestingly, whereas most theories develop from the top down, starting with a grand concept from which equations then flow, string theory arose from the bottom up. For Greene, this crucial gap in knowledge—what is the fundamental principle that would make string theory *have* to be right?—has been as frustrating as it has been tantalizing. "It's as if you had a painting from one of the great masters, but someone had come along and snipped out chunks of it," he says. "From what remains, you can tell that there was a beautiful painting there, but now you want to see the whole thing. And that's what we've been working on."

—Alden M. Hayashi in New York City

Greene has an uncanny **knack** for distilling **esoteric** concepts into simple terms.

PETER MURPHY

BRIAN GREENE: EXTRACURRICULAR

- **Born New York City, 1962**
- **Vegetarian**
- **Father was voice coach to Harry Belafonte**
- **Running buddies with George Stephanopoulos at Oxford**
- **Member of Oxford varsity judo team**
- **Has supplied snippets of dialogue for John Lithgow's character in *3rd Rock from the Sun***
- **Favorite *Star Trek* episode: "The City on the Edge of Forever"**

Rules of the Game

Friends and foes of genetically modified crops warily sign a deal

In Montreal this past January more than 130 countries agreed on a protocol for commerce in genetically modified organisms (GMOs). The agreement forestalled an all-out trade war between U.S.-allied food-exporting nations on one side and the European Union, together with some developing nations, on the other, but skirmishes are likely to continue. The Cartagena Protocol on Biosafety, named after the Colombian city where negotiations began, leaves unresolved key questions about when a country can ban the import of GMOs that it suspects could adversely affect health or the environment. The biotechnology industry is steeling itself for the more intrusive controls and tests of its products that are likely to be the price for expanded markets.

Although no harm from a GMO crop has ever been demonstrated, consumer anxieties are running at fever pitch in European countries, where environmental groups and newspapers denounce agricultural products of genetic engineering as "Frankenfoods." Activists charge that altered crops could wreak ecological havoc and cause new allergies.

The U.S. has seen much less opposition—perhaps because most consumers are unaware that a third of U.S. corn, soybean and cotton crops have been genetically engineered to tolerate an herbicide or to resist pests. But some signs of dissent have emerged. A bill introduced into the House of Representatives by Congressman Dennis J. Kucinich of Ohio would require labeling not only of GMO-containing foods but also of products derived from them, such as oils. Labeling rules have also been proposed in California.

The Cartagena protocol represents a compromise between the strict controls advocated by environmental groups, notably Greenpeace, and exporters who wanted to prevent countries from erecting spurious trade barriers. On the control side, it allows countries to block imports even if the evidence of danger falls short of certainty. It provides modest controls over GMOs destined for use as food or feed and thus not intended for deliberate release into the environment: shipments will have to be identified as "maybe" containing GMOs, and further requirements may be added over the next two years. A "biosafety clearinghouse" will allow countries to publish exactly what information they need. A stricter control regime requiring "advance informed agreement" will govern GMOs that are to be released.

"The U.S. government and biotech companies have been bullies around the world" by resisting demands for labeling, says Jane Rissler of the Union of Concerned Scientists. "This is a message that bullying is not going to work." As the world's largest food exporter, the U.S. played a critical part in the negotiations, even though it is not formally a party to them.

EFFIGY IN CORN: a Greenpeace protester preparing a banner scales past the fangs of a corncob during January's Montreal conference on genetically modified foods.

PAUL CHIASSON *AP Photo*

At the same time, the protocol does not affect countries' obligations under other agreements, particularly the World Trade Organization (WTO). That body requires trade decisions to be based on "sufficient scientific evidence." So if countries cannot agree on how the Cartagena protocol should apply in a specific instance, a would-be exporter could ask for adjudication by the WTO. U.S. exporters wanted to preserve WTO obligations in part because they require that any limits on trade be proportionate to the threat. "The protocol does a pretty good job of keeping the baby and pitching the bathwater," says Val Giddings of the Biotechnology Industry Organization—the bathwater being, in his view, proposed language that would have allowed countries to ban imports arbitrarily.

The requirement that shipments containing GMOs be identified may, however, put economic pressure on U.S. exporters to segregate shipments of GMOs from unmodified commodities—buyers could decide they are willing to pay more for crops that are certified to be unmodified. New tests becoming available enable GMOs to be detected at low concentrations, so strict segregation laws could be enforceable. Some European countries and Japan have already passed laws requiring that food products containing GMOs be labeled for the benefit of consumers.

But if the Cartagena protocol might slow consumer acceptance of GMOs in some countries, it could also pave the way for transgenic crops to become more widely used in others. Many experts, including Gordon Conway, president of the Rockefeller Foundation, believe that crops improved through biotechnology will be essential to feeding rapidly growing populations in developing countries. Scientists from such countries feared before the Montreal agreement that exaggerated European safety concerns could make it hard for them to gain access to improved crops. "It is completely unacceptable" for European countries to tell developing countries that agricultural biotechnology is not suitable for them, complains Calestous Juma of the Center for International Development at Harvard University, founder of the African Center for Technology Studies in Nairobi.

The GMO crops developed thus far by Monsanto and other companies, though economically advantageous to U.S. farmers, have brought no obvious benefits to consumers, notes bioethicist Gary Comstock of Iowa State University. That fact has limited public support for them, he says, but circumstances may soon change. Ingo Potrykus of the Swiss Federal Institute of Technology in Zurich and his colleagues published in *Science* earlier this year details of how they have been able to engineer beta carotene, a precursor of vitamin A, into rice. More than one million children are believed to die every year as a result of vitamin A deficiency, a toll that engineered rice could reduce dramatically. Potrykus, whose efforts to field-test pest-resistant transgenic rice in the Philippines have been stalled by a Greenpeace campaign there, says researchers in Africa, Asia and Latin America are keen to transfer the vitamin A–producing genes in his rice into locally adapted varieties, a task that may take two or three years. But, he reports, French rice importers have warned Thai growers that they risk losing their European export market if they cultivate the engineered grain. Potrykus calls that threat "a very unfair neocolonialism."

LABELING OF GM FOODS, such as this one for mayonnaise, is practiced in Europe and slowly gaining in the U.S.

JONATHAN PAYER *NYT Pictures*

The image problems of agricultural biotechnology have prompted major corporations to end their attempts to integrate it with pharmaceutical development. In the U.S., Monsanto, which has spent billions to cultivate the agricultural biotech market, is merging its pharmaceutical arm with Pharmacia & Upjohn and spinning off its agricultural division. In Europe, Novartis has combined its seeds business with AstraZeneca's agrochemicals division to create an agribusiness company to be known as Syngenta. Industry watcher John T. McCamant, a contributing editor of *Medical Technology Stock Letter,* says shareholders were objecting that pharmaceutical profits were being dragged down by agriculture's lackluster performance and wanted the two types of operation separated.

Still, experts predict that the setbacks will not be permanent. "It's purely financial. DNA and molecules are not going to go out of fashion," remarks Mark Cantley, an adviser to the European Commission, the executive arm of the European Union. Agricultural biotechnology "is here to stay because the advantages are so compelling," agrees Peter Day, director of Rutgers University's Biotechnology Center for Agriculture and the Environment. And people within the besieged industry say they intend to stay the course. "We are not shying away from the technology," declares Ted McKinney, a spokesman for Dow AgroSciences, which has made modest investments in the field. A new regime for GMOs may take some years to put in place, but the agreement in Montreal means there is at least a basis for making the best of biotechnology's potential.

—*Tim Beardsley in Washington, D.C.*

Cyber View

Who Wants Privacy?

For the past 20 years, the U.S. government restricted the export of encryption software except under strict conditions that dissuaded manufacturers from including it even in domestic products. U.S. programmers whose code appeared overseas found themselves under criminal investigation. With global electronic networks, simply posting a program on a local university Web server could be considered export, so researchers could not publish the simplest demonstration programs without confronting a complex bureaucracy.

The administration fought seemingly endless rearguard actions to prevent cryptographic exports, despite the widespread availability of equivalent software in other countries. Then, last fall the White House announced it was giving up the fight. In January the administration released new regulations they said would make crypto from U.S. sources widely available outside (and hence inside) the country.

Global availability would promote the use of encoding programs to keep e-mail and other communications safe from prying eyes, carry out hassle-free digital transactions, even furnish unforgeable credentials. The regulations allow trade in retail software containing encryption after a single technical review, and they allow people to "export" most cryptographic source code by telling the government the Web address where it will be posted. If the Bureau of Export Administration doesn't object within 30 days, the coders have nothing to worry about.

So where is the flood of secure products? Thus far the only readily visible sign of the changes is that secure Web browsers (required for on-line transactions) can now be downloaded easily by people outside the U.S. and Canada. David Sobel of the Electronic Privacy Information Center believes major e-mail vendors will start incorporating encryption in their programs soon and that the technology should start becoming pervasive within a couple years.

There is a lot of infrastructure to be built before the cryptographic millennium comes: everyone who wants to send or receive secure e-mail, for example, must have a personal set of encryption keys and a trustworthy way to find out the keys of their correspondents. Scott Schell of RSA Security (which owns crucial patents for public-key cryptography) says the company is hoping for legislation that would make digital signatures as binding as their ink-and-paper counterparts. In the meantime he expects many people and companies to make private agreements to use them. Everyone from nervous teenagers to corporate executives will be glad to be communicating out of easy view, he states. Verisign, a check and credit-card verification company, has is-

DAVID SUTER

sued about five million "digital certificates" that match a name and key to an e-mail address (at $14.95 a year for your own personal cryptographic verification).

Others are less sanguine. Cindy Cohn, a lawyer involved in one of the longest-running suits over export control (*Bernstein* v. *U.S.*) argues that the new regulations may be good for some businesses but are bad for free-software programmers and researchers. International teams of collaborators who exchange pieces of programs on a daily basis could be hamstrung by rules that can be read to require government notification for every Usenet posting, chat session or e-mail message. Furthermore, the regulations appear to restrict the electronic publication of any cryptographic software that can easily be called on by other programs—which could be almost any encoding software at all. Cohn has sent 11 pages of questions about the regulations to the Bureau of Export Administration, with no answer as of press time.

Cohn and others suggest that the government may be shifting its antiencryption focus from the desktop (where the war is essentially lost) to other areas of cyberspace. The regulations, Cohn remarks, make it harder to provide automatic encryption of information as it passes through the dozens of links in a typical Internet connection, so users who fail to encode their data before sending their data out may remain at risk. Indeed, Alan Davidson of the Center for Democracy and Technology also points out that law-enforcement agencies have been pushing legislation that would give them the right to recover the plaintext of files from either desktop computers or networked file servers to aid investigations—a step that would render many over-the-counter encryption programs moot.

Meanwhile the marketplace will have to decide whether it wants the secure, private, verifiable digital future that cryptography advocates had been predicting would follow export liberalization. Electronic cash, one long-hyped application, may never become ubiquitious. Instead "the e-cash niche in digital commerce is now occupied by credit cards, at least in the U.S.," says David Sorabella of RSA. Five years ago transaction costs made it uneconomical to sell goods worth less than about $20 by credit card, but today $5 and even $1 purchases are common.

Benefits of cryptography, such as secure e-mail and digital pseudonyms, have yet to be tested. Have the tens of millions of people who exchange information unguarded over the Internet every day become used to the notion that, as Scott McNealy of Sun Microsystems has said, "you have no privacy"? Schell predicts, on the contrary, that demand for some privacy, such as through untraceable pseudonyms, will increase as more and more people realize how much of their personal information is at risk. As an example, he cites this winter's admission by Web-advertising giant Doubleclick that it was matching its years-long database of Web-browsing habits with the names and addresses of several million potential targets for direct mail and telephone solicitations. Although Internet consumers may be willing to trade this kind of information for better-targeted Web ads, cryptographic tools may at least give them a chance to decide. *—Paul Wallich*

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COURTESY OF U.S. DEPARTMENT OF COMMERCE

The 1999 National Medal of Technology

The latest winners of the nation's highest honors for innovation are celebrated for outstanding contributions to the growth and commercialization of the Internet, biotechnology, pattern recognition and more

On March 14, 2000, in Washington, D.C., President Bill Clinton bestowed the 1999 National Medal of Technology on five distinguished recipients. Since 1985, when the first Medal was awarded, these ceremonies have recognized individuals, teams and corporations who as technological innovators have made lasting contributions to the enhancement of America's economic competitiveness and standard of living.

The Medalist selection program is administered by the Department of Commerce's Office of Technology Policy. An independent committee of experts from the scientific and technological community evaluates the candidates, who are nominated through an open, national, competitive solicitation.

Additional information about the winners and the awards appears on the Scientific American Web site (www.sciam.com) and on the National Medal home page (www.ta.doc.gov/Medal). The Tech Museum of Innovation in San Jose, Calif., has also established a permanent exhibit honoring all the Medal laureates.

A PATTERN OF SUCCESS

Raymond Kurzweil
Chairman
Kurzweil Technologies, Inc.
Wellesley Hills, Mass.

Ray Kurzweil has predicted that within the next few decades the intelligence of machines will exceed that of humans. If they do, two points should be remembered. First, the machines will have been given a huge boost by Kurzweil's work on pattern recognition, the skill of finding abstract meaning in complex data, which comes naturally to humans but is difficult for computers. Second, exceeding Kurzweil's own intelligence will not have been easy, as witnessed by his long list of accomplishments.

As a high school student, he programmed a computer to analyze the works of famous musical composers and then to compose new melodies in their style. That work led to first prize in the International Science Fair, an appearance on the television quiz show *I've Got A Secret* and, as one of the finalists in the Westinghouse Science Talent Search, a meeting with President Lyndon B. Johnson.

His first major venture was Kurzweil Computer Products, founded in 1974. Kurzweil and his colleagues invented the first optical character-recognition program capable of reading any typographic style, the first charge-coupled device (CCD) flat-bed scanner and the first text-to-voice synthesizer. Together these technologies became the Kurzweil Reading Machine of 1976, hailed as the most significant advance for the blind since the invention of Braille. Each of these inventions also became the foundation of a key Information Age industry on its own.

MICHAEL FEIN

RAY KURZWEIL seeks to simulate humans' gift for recognizing patterns.

Working with musician Stevie Wonder as a musical adviser, Kurzweil developed computer-based instruments that could reproduce realistically the musical responses of grand pianos and other acoustic instruments. This advance in electronic music revolutionized the recording industry and became the preferred medium for creating nearly all music on today's commercial albums, films and TV. Kurzweil's work also led to the first commercially marketed large-vocabulary speech-recognition system, forms of which are used in Voice Xpress Professional and other products for personal-computer users.

During his career, Kurzweil has founded seven companies, including Kurzweil Technologies and FAT KAT, Inc., which develops genetic algorithm- and neural net-based systems for making stock-market decisions. He is the author of three books, the most recent being *The Age of Spiritual Machines* (Viking, 1999).

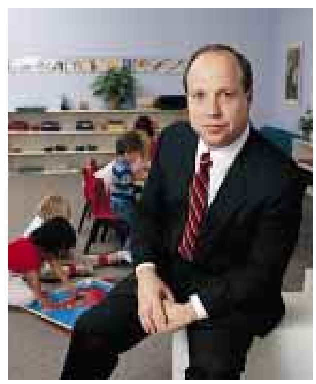
(A more detailed biography of Kurzweil is available at www.kurzweiltech.com. Kurzweil's article "The Coming Merging of Mind and Machine," written for the Fall 1999 issue of SCIENTIFIC AMERICAN PRESENTS: "Your Bionic Future," is available on-line at www.sciam.com/specialissues)

TURNING DNA INTO DOLLARS

The late **Robert A. Swanson**
Chairman
K&E Management, Ltd.
San Mateo, Calif.

When 29-year-old venture capitalist Robert Swanson first contacted Herbert W. Boyer of the University of California at San Francisco in 1976, he begged the co-inventor of recombinant DNA technology for just 10 minutes of his time. Recombinant DNA technology, more commonly known as gene splicing, was then thought of as an exciting research technique but little more. Swanson, however, saw its commercial potential and persuaded Boyer of it, too. With initial investments of $500 each, they founded Genentech, which is widely regarded as the first biotechnology company organized around the power of gene splicing.

Perhaps that initial foresight by itself would have been enough to earn Swanson his reputation as the father of modern biotechnology, but it was his leadership of Genentech through 1996 and his extensive influence throughout the burgeoning industry that cinched his claim to the title. Today the biotech sector, with revenues estimated at $150 billion, includes almost 1,300 companies in the U.S. alone. For many of these, Genentech served as a role model.



COURTESY OF GENENTECH, INC.

ROBERT A. SWANSON, the father of the biotech industry.

Genentech's first drug, and the first commercial product made by recombinant DNA, was a form of human insulin, which was marketed for diabetes by Eli Lilly and Company. Later products included human growth hormone, for treating children of unusually small stature; tissue plasminogen activator, a "clot-busting" compound that became a drug of choice for patients who have had a stroke or heart attack; and others against cancer, cystic fibrosis and immunological disorders. In 1980 Genentech became the first biotech company to offer stock to the public.

Swanson aggressively recruited scientific support within the academic community. University researchers were often reluctant to form industrial ties because pharmaceutical makers generally barred them from publishing their findings. Swanson instead encouraged open publication. Some of his longest-lived influences may therefore be in how he made researchers and universities more aware of the commercial value of their patents. (Ironically, that realization may have helped encourage two patent-infringement lawsuits filed by U.C.S.F. against Genentech, in 1990 and 1997.) After his retirement from Genentech, Swanson started his own venture-capital firm, K&E Management, and became chairman of the biotech start-up Tularik. Last December, regrettably, after a year's struggle, he died of brain cancer at age 52.

INVENTOR OF THE INTERNET

Robert W. Taylor
Founder, Systems Research Center
Digital Equipment Corporation

The Internet was Robert Taylor's idea. During the mid-1960s, while working as the director of the Information Processing Techniques Office at the Department of Defense's Advanced Research Projects Agency (ARPA), Taylor made a sociological observation about the three separate computer projects he was overseeing: lively communities of users seemed to spring up around each system of interactive terminals. He also made a technical observation: his (and others') work would be much easier if the three isolated systems could merge. He therefore proposed to his bosses the creation of Arpanet, the supernetwork of defense research networks, which eventually evolved into the Internet.

PETER DASILVA

ROBERT W. TAYLOR proposed the original Internet.

Throughout the three major chapters of his career, Taylor nurtured crucial aspects of modern computing. While at ARPA, he proselytized for interactive distributed computing and fought for the nascent network. With J.C.R. Licklider, he coauthored the seminal 1968 paper "The Computer as a Communications Device," which was one of the first to convey to the public the value of networks. He lent key funding support to work on fundamental computing technologies, such as time-sharing, artificial intelligence, graphics, the mouse and teleconferencing.

In 1970 Taylor founded the Computer Science Laboratory (CSL) at Xerox's Palo Alto Research Center. CSL was the spawning ground for the Ethernet (the first local-area network, or LAN) and for Pup, the first "internetwork" technology (which was needed to convert Arpanet into the more open Internet). Graphical-user interfaces developed there inspired those of the Macintosh and Windows operating systems; other inventions were laser printing and WYSIWYG word processing.

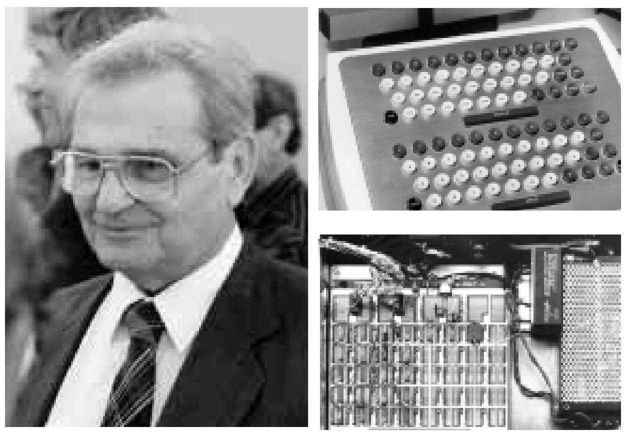
In 1984 Taylor moved to the Digital Equipment Corporation and started its famous Systems Research Center, which he managed until his retirement in 1996. Among SRC's long list of accomplishments are the first multiprocessor workstation, the first fault-tolerant switched LAN and the first electronic book.

Had it not been for Taylor's genius at assembling teams of gifted researchers and motivating them to tackle ambitious technological feats, the evolution of e-commerce and the information economy would have followed a different, perhaps far slower road. Few innovators can claim to have left so great a mark on the fortunes of the world.

CONVENIENT COMPUTING

Glen Jacob Culler
University of California, Santa Barbara

Give a thought to Glen Culler the next time you touch a computer keyboard. In the early 1960s, when the standards were being set for the ASCII code (which specifies the digital equivalents of alphanumeric characters), much of the computing establishment favored defining only uppercase characters, because that was how programs were traditionally written. Culler adamantly insisted, however, that lowercase characters, too, would in the long run prove essential. Luckily, he won the day.



U.C.S.B. COLLEGE OF ENGINEERING

GLEN JACOB CULLER believes computers should be intuitively simple to use.

That anecdote is merely a footnote in Culler's distinguished career. Three recurring themes run through his work, both in academia and in the private sector. First, Culler believed that computers should be true problem-solving tools—ones that helped users understand how to solve problems rather than just flexing mathematical muscle. Second, he strove to make the interactions of people with computers as simple and intuitive as possible. Third, he pioneered applications of "parallel architectures," in which multiple computers worked on aspects of a problem simultaneously.

Culler developed the first on-line systems for mathematical computing that allowed users to interact with the system through a graphical interface. Today graphic calculators make such an approach commonplace, but it was highly novel in the 1960s. The system at U.C. Santa Barbara also included the innovation of programmable function keys, capable of calling up long series of keystrokes or mathematical operations—a ubiquitous feature of modern devices. In the classroom at the university, the systems helped students nurture their intuition about mathematical functions.

The expertise of Culler's group at networking computers was why U.C. Santa Barbara was selected as one of the original sites of the Internet's predecessor, the Arpanet. Culler also pioneered applications of digital signal processing for music and speech, which have been instrumental in the modern telecommunications industry. Some of this work was conducted at the company he founded in 1971, Culler-Harrison, which later became Culler Scientific Systems.

Culler and his students have founded more than 30 companies within the Santa Barbara area alone, and the influence of their work is felt throughout the high-tech world. Thanks to his direct and indirect contributions, U.C. Santa Barbara is recognized as one of the leading public research universities in the U.S. In 1995 the university sponsored a symposium to honor Culler's contributions; many tributes to him arising from this event can be found on-line at kk.ucsb.edu/culler.html

SCANNING THE GLOBE

Symbol Technologies, Inc.
Holtsville, N.Y.

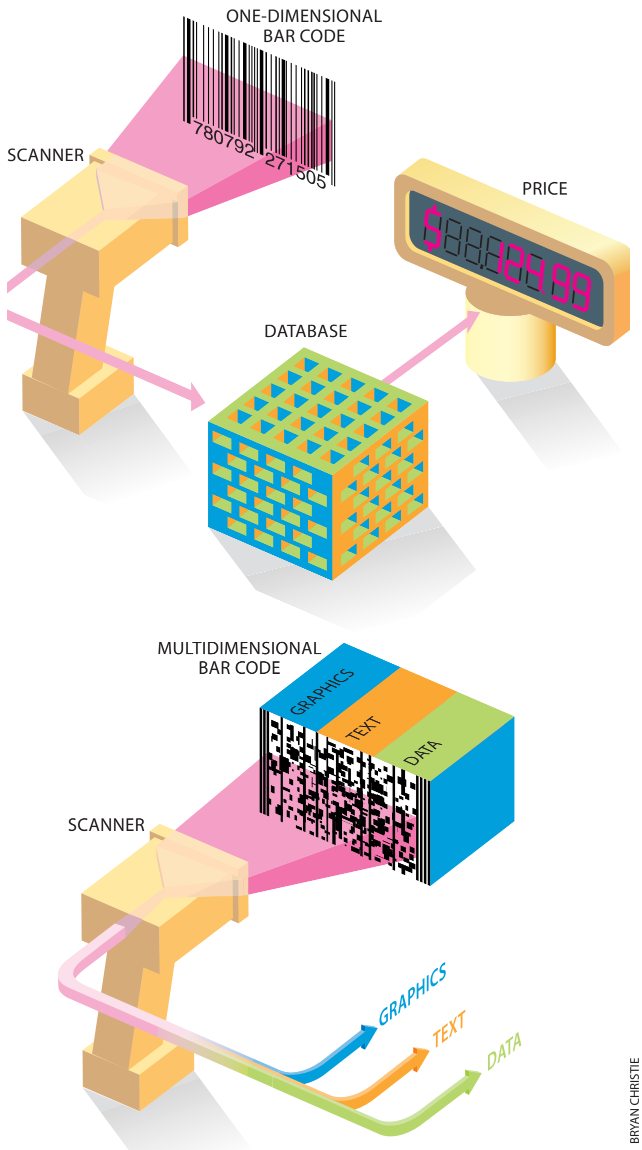
No matter how much the information-based economy grows, there are still points where it must connect to people, things and events in the physical universe. Businesses need to capture data on the fly, tracking the routing and performance of goods and materials. There, where the virtual rubber meets the real-world road, is where Symbol Technologies has established itself as a leader.

Symbol is perhaps most closely identified with laser bar-code scanning. It has helped to establish a global market for portable scanning systems, now found at retail checkout counters, on factory floors, in warehouses, in hospitals and on the belts of overnight package delivery agents. More broadly, Symbol provides solutions for mobile data-management systems and services. Beyond laser bar-code scanning, Symbol also develops technologies that are related to handheld computing and wireless networking, with a focus on making these instruments easier to use, more durable and more portable.

The company holds more than 400 patents related to image decoding, miniaturization, ergonomics, power optimization and design ruggedness. Innovations cited by the National Medal awards committee include the handheld laser bar-code scanner, the scanner-integrated computer, the wearable scanning computer, the spread spectrum–based wireless LAN and the portable self-checkout shopping system.

Symbol claims a base of more than eight million scanners and mobile computers, as well as 30,000 wireless LANs and more than 50,000 self-checkout shopping scanners. Its revenue is estimated at $1.5 billion in 2000, about half of which comes from overseas. More information about Symbol is available at the company's Web site, www.symbol.com

COURTESY OF SYMBOL TECHNOLOGIES, INC.



BRYAN CHRISTIE

BAR CODES have become fixtures on countless products (*above*). Scanners of traditional one-dimensional bar codes needed to consult external databases to obtain price or other information (*top right*). Symbol Technologies has pioneered the use of multidimensional bar codes in which diverse forms of information can be embedded (*bottom right*).

QUANTUM TELEPORTATION

The science-fiction dream of "beaming" objects from place to place is now a reality—at least for particles of light

by Anton Zeilinger

The scene is a familiar one from science-fiction movies and TV: an intrepid band of explorers enters a special chamber; lights pulse, sound effects warble, and our heroes shimmer out of existence to reappear on the surface of a faraway planet. This is the dream of teleportation—the ability to travel from place to place without having to pass through the tedious intervening miles accompanied by a physical vehicle and airline-food rations. Although the teleportation of large objects or humans still remains a fantasy, quantum teleportation has become a laboratory reality for photons, the individual particles of light.

Quantum teleportation exploits some of the most basic (and peculiar) features of quantum mechanics, a branch of physics invented in the first quarter of the 20th century to explain processes that occur at the level of individual atoms. From the beginning, theorists realized that quantum physics led to a plethora of new phenomena, some of which defy common sense. Technological progress in the final quarter of the 20th century has enabled researchers to conduct many experiments that not only demonstrate fundamental, sometimes bizarre aspects of quantum mechanics but, as in the case of quantum teleportation, apply them to achieve previously inconceivable feats.

In science-fiction stories, teleportation often permits travel that is instantaneous, violating the speed limit set down by Albert Einstein, who concluded from his theory of relativity that nothing can travel faster than light [see "Faster Than Light?" by Raymond Y. Chiao, Paul G. Kwiat and Aephraim M. Steinberg; Scientific American, August 1993]. Teleportation is also less cumbersome than the more ordinary means of space travel. It is said that Gene Roddenberry, the creator of *Star Trek*, conceived of the "transporter beam" as a way to save the expense of simulating landings and takeoffs on strange planets.

The procedure for teleportation in science fiction varies from story to story but generally goes as follows: A device scans the original object to extract all the information needed to describe it. A transmitter sends the information to the receiving station, where it is used to obtain an exact replica of the original. In some cases, the material that made up the original is also transported to the receiving station, perhaps as "energy" of some kind; in other cases, the replica is made of atoms and molecules that were already present at the receiving station.

Quantum mechanics seems to make such a teleportation scheme impossible in principle. Heisenberg's uncertainty principle rules that one cannot know both the precise position of an object and its momentum at the same time. Thus, one cannot perform a perfect scan of the object to be teleported; the location or velocity of every atom and electron would be subject to errors. Heisenberg's uncertainty principle also applies to other pairs of quantities, making it impossible to measure the exact, total quantum state of any object with certainty. Yet such measurements would be necessary to obtain all the information needed to describe the original exactly. (In *Star Trek* the "Heisenberg Compensator" somehow miraculously overcomes that difficulty.)

A team of physicists overturned this conventional wisdom in 1993, when they discovered a way to use quantum mechanics itself for teleportation. The team—Charles H. Bennett of IBM; Gilles Brassard, Claude Crépeau and Richard Josza of the University of Montreal; Asher Peres of Technion–Israel Institute of Technology; and William K. Wootters of Williams College—found that a peculiar but fundamental feature of quantum mechanics, entanglement, can be used to circumvent the limitations imposed by Heisenberg's uncertainty principle without violating it.

Entanglement

It is the year 2100. A friend who likes to dabble in physics and party tricks has brought you a collection of pairs of dice. He lets you roll them once, one pair at a time. You handle the first pair gingerly, remembering the fiasco with the micro–black hole last Christmas. Finally, you roll the two dice and get double 3. You roll the next pair. Double 6. The next: double 1. They always match.

The dice in this fable are behaving as if

TRAVELERS ARRIVE at Grand Central Station's teleport terminal. Although teleporting large objects, let alone living beings, will never be practical outside of fiction, teleportation of elementary quantum states *has* been demonstrated.

SPACE CHANNEL/PHILIP SAUNDERS


< Teleport Exit
< Baggage
< Hover Cabs
< Skyway
< Rentals
ENTROPIC DECAY
ELECTRON LOCK
DECOHERENCE
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QUANTUM
TRANSIT
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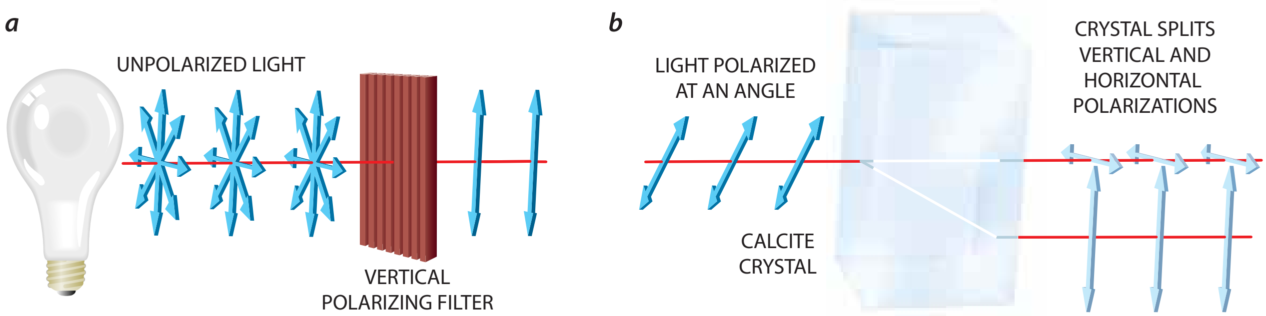


UNPOLARIZED LIGHT consists of photons that are polarized in all directions (*a*). In polarized light the photons' electric-field oscillations (*arrows*) are all aligned. A calcite crystal (*b*) splits a light beam in two, sending photons that are polarized parallel with its axis into one beam and those that are perpendicular into the other. Intermediate angles go into a quantum superposition of both beams. Each such photon can be detected in one beam or the other, with probability depending on the angle. Because probabilities are involved, we cannot measure the unknown polarization of a single photon with certainty.

LAURIE GRACE

they were quantum entangled particles. Each die on its own is random and fair, but its entangled partner somehow always gives the correct matching outcome. Such behavior has been demonstrated and intensively studied with real entangled particles. In typical experiments, pairs of atoms, ions or photons stand in for the dice, and properties such as polarization stand in for the different faces of a die.

Consider the case of two photons whose polarizations are entangled to be random but identical. Beams of light and even individual photons consist of oscillations of electromagnetic fields, and polarization refers to the alignment of the electric field oscillations [*see illustration above*]. Suppose that Alice has one of the entangled photons and Bob has its partner. When Alice measures her photon to see if it is horizontally or vertically polarized, each outcome has a 50 percent chance. Bob's photon has the same probabilities, but the entanglement ensures that he will get exactly the same result as Alice. As soon as Alice gets the result "horizontal," say, she knows that Bob's photon will also be horizontally polarized. Before Alice's measurement the two photons do not have individual polarizations; the entangled state specifies only that a measurement will find that the two polarizations are equal.

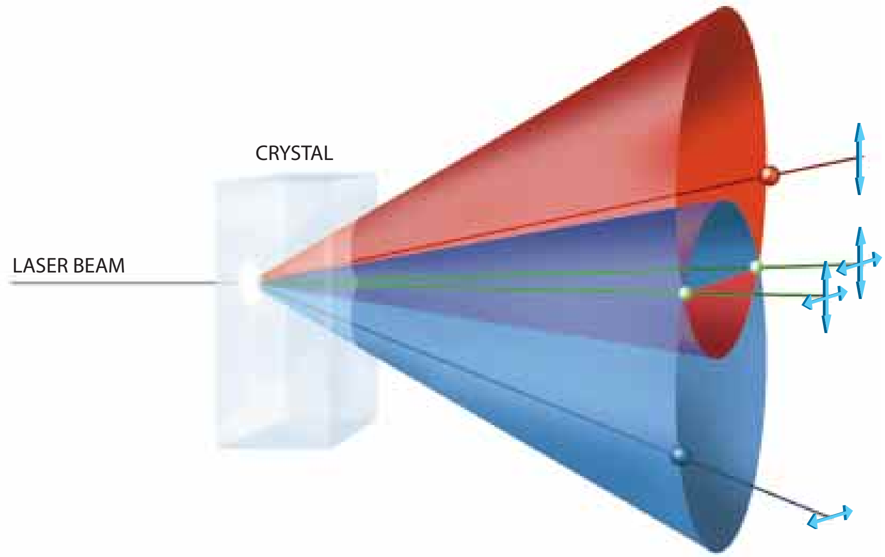
An amazing aspect of this process is that it doesn't matter if Alice and Bob are far away from each other; the process works so long as their photons' entanglement has been preserved. Even if Alice is on Alpha Centauri and Bob on Earth, their results will agree when they compare them. In every case, it is as if Bob's photon is magically influenced by Alice's distant measurement, and vice versa.

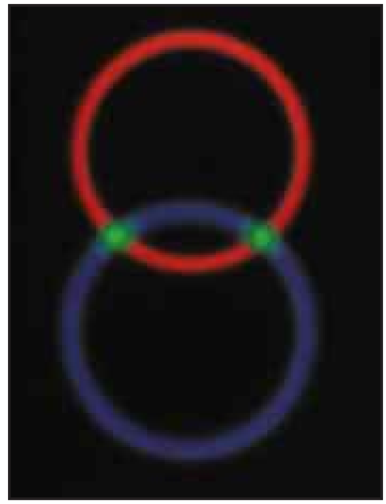
You might wonder if we can explain the entanglement by imagining that each particle carries within it some recorded instructions. Perhaps when we entangle the two particles, we synchronize some hidden mechanism within them that determines what results they will give when they are measured. This would explain away the mysterious effect of Alice's measurement on Bob's particle. In the 1960s, however, Irish physicist John Bell proved a theorem that in certain situations any such "hidden variables" explanation of quantum entanglement would have to produce results different from those predicted by standard quantum mechanics. Experiments have confirmed the predictions of quantum mechanics to a very high accuracy.

Austrian physicist Erwin Schrödinger, one of the co-inventors of quantum mechanics, called entanglement "the essential feature" of quantum physics. Entanglement is often called the EPR effect and the particles EPR pairs, after Einstein, Boris Podolsky and Nathan Rosen, who in 1935 analyzed the effects of entanglement acting across large distances. Ein-

PREPARING FOR QUANTUM TELEPORTATION ...

QUANTUM TELEPORTATION OF A PERSON (impossible in practice but a good example to aid the imagination) would begin with the person inside a measurement chamber (*left*) alongside an equal mass of auxiliary material (*green*). The auxiliary matter has previously been quantum-entangled with its counterpart, which is at the faraway receiving station (*right*).





LAURIE GRACE (*left*); P. G. KWIAT AND M. RECK *Institute for Experimental Physics, University of Vienna (right)*

ENTANGLED PHOTON PAIRS are created when a laser beam passes through a crystal such as beta barium borate. The crystal occasionally converts a single ultraviolet photon into two photons of lower energy, one polarized vertically (*on red cone*), one polarized horizontally (*on blue cone*). If the photons happen to travel along the cone intersections (*green*), neither photon has a definite polarization, but their relative polarizations are complementary; they are then entangled. Colorized image (*at right*) is a photograph of down-converted light. Colors do not represent the color of the light.

stein talked of it as "spooky action at a distance." If one tried to explain the results in terms of signals traveling between the photons, the signals would have to travel faster than the speed of light. Naturally, many people have wondered if this effect could be used to transmit information faster than the speed of light.

Unfortunately, the quantum rules make that impossible. Each local measurement on a photon, considered in isolation, produces a completely random result and so can carry no information from the distant location. It tells you nothing more than what the distant measurement result probabilities would be, depending on what was measured there. Nevertheless, we can put entanglement to work in an ingenious way to achieve quantum teleportation.

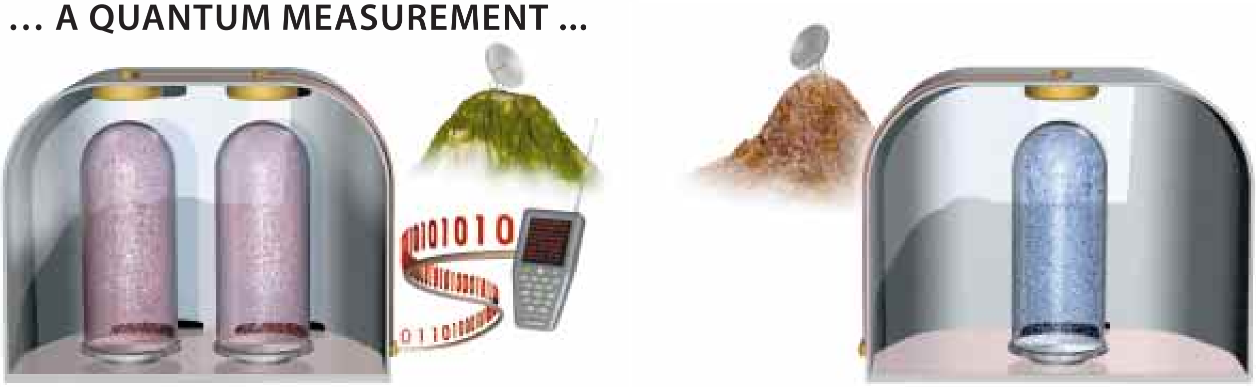
Putting Entangled Photons to Work

Alice and Bob anticipate that they will want to teleport a photon in the future. In preparation, they share an entangled auxiliary pair of photons, Alice taking photon A and Bob photon B. Instead of measuring them, they each store their photon without disturbing the delicate entangled state [*see upper illustration on next page*].

In due course, Alice has a third photon—call it photon X—that she wants to teleport to Bob. She does not know what photon X's state is, but she wants Bob to have a photon with that same polarization. She cannot simply measure the photon's polarization and send Bob the result. In general, her measurement result would not be identical to the photon's original state. This is Heisenberg's uncertainty principle at work.

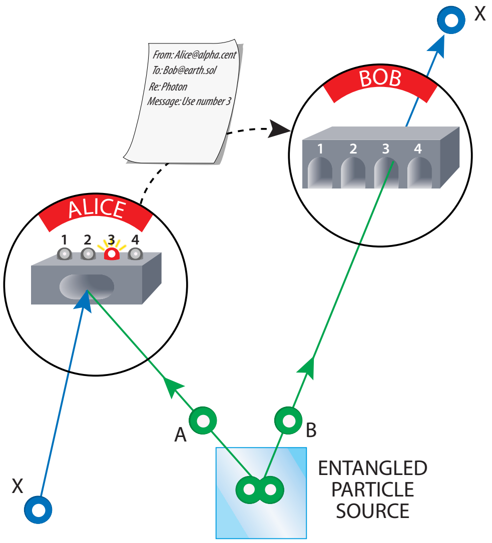
Instead, to teleport photon X, Alice measures it jointly with photon A, without determining their individual polarizations. She might find, for instance, that their polarizations are "perpendicular" to each other (she still does not know the absolute polarization of either one, however). Technically, the joint measurement

… A QUANTUM MEASUREMENT …



JOINT MEASUREMENT carried out on the auxiliary matter and the person (*left*) changes them to a random quantum state and produces a vast amount of random (but significant) data—two bits per elementary state. By "spooky action at a distance," the measurement also instantly alters the quantum state of the faraway counterpart matter (*right*). MORE>>>

DAVID FIERSTEIN



IDEAL QUANTUM TELEPORTATION relies on Alice, the sender, and Bob, the receiver, sharing a pair of entangled particles A and B (*green*). Alice has a particle that is in an unknown quantum state X (*blue*). Alice performs a Bell-state measurement on particles A and X, producing one of four possible outcomes. She tells Bob about the result by ordinary means. Depending on Alice's result, Bob leaves his particle unaltered (1) or rotates it (2, 3, 4). Either way it ends up a perfect replica of the original particle X.

LAURIE GRACE

of photon A and photon X is called a Bell-state measurement. Alice's measurement produces a subtle effect: it changes Bob's photon to correlate with a combination of her measurement result and the state that photon X originally had. In fact, Bob's photon now carries her photon X's state, either exactly or modified in a simple way.

To complete the teleportation, Alice must send a message to Bob—one that travels by conventional means, such as a telephone call or a note on a scrap of paper. After he receives this message, if necessary Bob can transform his photon B, with the end result that it becomes an exact replica of the original photon X. Which transformation Bob must apply depends on the outcome of Alice's measurement. There are four possibilities, corresponding to four quantum relations between her photons A and X. A typical transformation that Bob must apply to his photon is to alter its polarization by 90 degrees, which he can do by sending it through a crystal with the appropriate optical properties.

Which of the four possible results Alice obtains is completely random and independent of photon X's original state. Bob therefore does not know how to process his photon until he learns the result of Alice's measurement. One can say that Bob's photon instantaneously contains all the information from Alice's original, transported there by quantum mechanics. Yet to know how to read that information, Bob must wait for the classical information, consisting of two bits that can travel no faster than the speed of light.

Skeptics might complain that the only thing teleported is the photon's polarization state or, more generally, its quantum state, not the photon "itself." But because a photon's quantum state is its defining characteristic, teleporting its state is completely equivalent to teleporting the particle [*see box on page 57*].

Note that quantum teleportation does not result in two copies of photon X. Classical information can be copied any number of times, but perfect copying of quantum information is impossible, a result known as the no-cloning theorem, which was proved by Wootters and Wojciech H. Zurek of Los Alamos National Laboratory in 1982. (If we could clone a quantum state, we could use the clones to violate Heisenberg's principle.) Alice's measurement actually entangles her photon A with photon X, and photon X loses all memory, one might say, of its original state. As a member of an entangled pair, it has no individual polarization state. Thus, the original state of photon X disappears from Alice's domain.

Circumventing Heisenberg

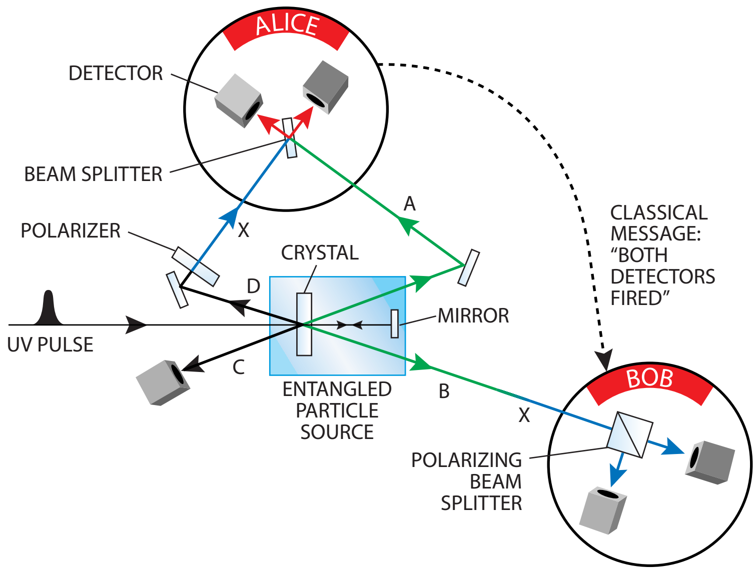
Furthermore, photon X's state has been transferred to Bob with neither Alice nor Bob learning anything about what the state is. Alice's measurement result, being entirely random, tells them nothing about the state. This is how the process circumvents Heisenberg's principle, which stops us from determining the complete quantum state of a particle but does not preclude teleporting the complete state so long as we do not try to see what the state is!

Also, the teleported quantum information does not travel materially from Alice to Bob. All that travels materially is the message about Alice's measurement result, which tells Bob how to process his photon but carries no information about photon X's state itself.

In one out of four cases, Alice is lucky with her measurement, and Bob's photon immediately becomes an identical

... TRANSMISSION OF RANDOM DATA ...

MEASUREMENT DATA must be sent to the distant receiving station by conventional means. This process is limited by the speed of light, making it impossible to teleport the person faster than the speed of light.



INNSBRUCK EXPERIMENT begins with a short pulse of ultraviolet laser light. Traveling left to right through a crystal, this pulse produces the entangled pair of photons A and B, which travel to Alice and Bob, respectively. Reflected back through the crystal, the pulse creates two more photons, C and D. A polarizer prepares photon D in a specific state, X. Photon C is detected, confirming that photon X has been sent to Alice. Alice combines photons A and X with a beam splitter [*see illustration on next page*]. If she detects one photon in each detector (as occurs at most 25 percent of the time), she notifies Bob, who uses a polarizing beam splitter to verify that his photon has acquired X’s polarization, thus demonstrating successful teleportation.

LAURIE GRACE

replica of Alice’s original. It might seem as if information has traveled instantly from Alice to Bob, beating Einstein’s speed limit. Yet this strange feature cannot be used to send information, because Bob has no way of knowing that his photon is already an identical replica. Only when he learns the result of Alice’s Bell-state measurement, transmitted to him via classical means, can he exploit the information in the teleported quantum state. Suppose he tries to guess in which cases teleportation was instantly successful. He will be wrong 75 percent of the time, and he will not know which guesses were correct. If he uses the photons based on such guesses, the results will be the same as if he had taken a beam of photons with random polarizations. In this way, Einstein’s relativity prevails; even the spooky instantaneous action at a distance of quantum mechanics fails to send usable information faster than the speed of light.

It would seem that the theoretical proposal described above laid out a clear blueprint for building a teleporter; on the contrary, it presented a great experimental challenge. Producing entangled pairs of photons has become routine in physics experiments in the past decade, but carrying out a Bell-state measurement on two independent photons had never been done before.

Building a Teleporter

A powerful way to produce entangled pairs of photons is spontaneous parametric down-conversion: a single photon passing through a special crystal sometimes generates two new photons that are entangled so that they will show opposite polarization when measured [*see top illustration on page 53*].

A much more difficult problem is to entangle two independent photons that already exist, as must occur during the operation of a Bell-state analyzer. This means that the two photons (A and X) somehow have to lose their private features. In 1997 my group (Dik Bouwmeester, Jian-Wei Pan, Klaus Mattle, Manfred Eibl and Harald Weinfurter), then at the University of Innsbruck, applied a solution to this problem in our teleportation experiment [*see illustration at left*].

In our experiment, a brief pulse of ultraviolet light from a laser passes through a crystal and creates the entangled photons A and B. One travels to Alice, and the other goes to Bob. A mirror reflects the ultraviolet pulse back through the crystal again, where it may create another pair of photons, C and D. (These will also be entangled, but we don’t use their entanglement.) Photon C goes to a detector, which alerts us that its partner D is available to be teleported. Photon D passes through a polarizer, which we can orient in any conceivable way. The

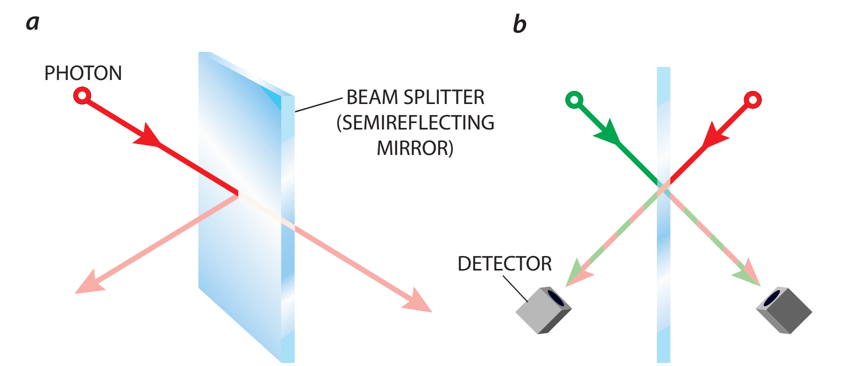
... RECONSTRUCTION OF THE TRAVELER

RECEIVER RE-CREATES THE TRAVELER, exact down to the quantum state of every atom and molecule, by adjusting the counterpart matter’s state according to the random measurement data sent from the scanning station.

DAVID FIERSTEIN

resulting polarized photon is our photon X, the one to be teleported, and travels on to Alice. Once it passes through the polarizer, X is an independent photon, no longer entangled. And although *we* know its polarization because of how we set the polarizer, Alice does not. We reuse the same ultraviolet pulse in this way to ensure that Alice has photons A and X at the same time.

Now we arrive at the problem of performing the Bell-state measurement. To do this, Alice combines her two photons (A and X) using a semireflecting mirror, a device that reflects half of the incident light. An individual photon has a 50–50 chance of passing through or being reflected. In quantum terms, the photon goes into a superposition of these two possibilities [*see illustration at right*].



BEAM SPLITTER, or semireflecting mirror (*a*), reflects half the light that hits it and transmits the other half. An individual photon has a 50–50 chance of reflection or transmission. If two identical photons strike the beam splitter at the same time, one from each side (*b*), the reflected and transmitted parts interfere, and the photons lose their individual identities. We will detect one photon in each detector 25 percent of the time, and it is then impossible to say if both photons were reflected or both were transmitted. Only the relative property—that they went to different detectors—is measured.

Now suppose that two photons strike the mirror from opposite sides, with their paths aligned so that the reflected path of one photon lies along the transmitted path of the other, and vice versa. A detector waits at the end of each path. Ordinarily the two photons would be reflected independently, and there would be a 50 percent chance of them arriving in separate detectors. If the photons are indistinguishable and arrive at the mirror at the same instant, however, quantum interference takes place: some possibilities cancel out and do not occur, whereas others reinforce and occur more often. When the photons interfere, they have only a 25 percent likelihood of ending up in separate detectors. Furthermore, when that occurs it corresponds to detecting one of the four possible Bell states of the two photons—the case that we called "lucky" earlier. The other 75 percent of the time the two photons both end up in one detector, which corresponds to the other three Bell states but does not discriminate among them.

When Alice simultaneously detects one photon in each detector, Bob's photon instantly becomes a replica of Alice's original photon X. We verified that this teleportation occurred by showing that Bob's photon had the polarization that we imposed on photon X. Our experiment was not perfect, but the correct polarization was detected 80 percent of the time (random photons would achieve 50 percent). We demonstrated the procedure with a variety of polarizations: vertical, horizontal, linear at 45 degrees and even a nonlinear kind of polarization called circular polarization.

The most difficult aspect of our Bell-state analyzer is making photons A and X indistinguishable. Even the timing of when the photons arrive could be used to identify which photon is which, so it is important to "erase" the time information carried by the particles. In our experiment, we used a clever trick first suggested by Marek Zukowski of the University of Gdansk: we send the photons through very narrow bandwidth wavelength filters. This process makes the wavelength of the photons very precise, and by Heisenberg's uncertainty relation it smears out the photons in time.

A mind-boggling case arises when the teleported photon was itself entangled with another and thus did not have its own individual polarization. In 1998 my Innsbruck group demonstrated this scenario by giving Alice photon D without polarizing it, so that it was still entangled with photon C. We showed that when the teleportation succeeded, Bob's photon B ended up entangled with C. Thus, the *entanglement* with C had been transmitted from A to B.

Piggyback States

Our experiment clearly demonstrated teleportation, but it had a low rate of success. Because we could identify just one Bell state, we could teleport Alice's photon only 25 percent of the time—the occasions when that state occurred. No complete Bell-state analyzer exists for independent photons or for any two independently created quantum particles, so at present there is no experimentally proven way to improve our scheme's efficiency to 100 percent.

In 1994 a way to circumvent this problem was proposed by Sandu Popescu, then at the University of Cambridge. He suggested that the state to be teleported could be a quantum state riding piggyback on Alice's auxiliary photon A. Francesco De Martini's group at the University of Rome I "La Sapienza" successfully demonstrated this scheme in 1997. The auxiliary pair of photons was entangled according to the photons' locations: photon A was split, as by a beam splitter, and sent to two different parts of Alice's apparatus, with the two alternatives linked by entanglement to a similar splitting of Bob's photon B. The state to be teleported was also carried by Alice's photon A—its polarization state. With both roles played by one photon, detecting all four possible Bell states becomes a standard single-particle measurement: detect Alice's photon in one of two possible locations with one of two possible polarizations. The drawback of the scheme is that if Alice were given a separate unknown state X to be teleported she would somehow have to transfer the state onto the polarization of her photon A, which no one knows how to do in practice.

Polarization of a photon, the feature employed by the Innsbruck and the Rome experiments, is a discrete quantity, in that any polarization state can be expressed as a superposition of just two discrete states, such as vertical and horizontal polarization. The electromagnetic field associated with light also has continuous features that amount to superpositions of an infinite number of basic states. For example, a light beam can be "squeezed," meaning that one of its properties is made extremely precise or noise-free, at the expense of greater randomness in another property (à la Heisenberg). In 1998 Jeffrey Kimble's group at the California Institute of Technology teleported such a squeezed state from one beam of light to another, thus demonstrating teleportation of a continuous feature.

Remarkable as all these experiments are, they are a far cry from quantum teleportation of large objects. There are two essential problems: First, one needs an entangled pair of the same kind of objects. Second, the object to be teleported and the entangled pairs must be sufficiently isolated from the environment. If any information leaks to or from the environment through stray interactions, the objects' quantum states degrade, a process called decoherence. It is hard to imagine how we could achieve such extreme isolation for a large piece of equipment, let alone a living creature that breathes air and radiates heat. But who knows how fast development might go in the future?

Certainly we could use existing technology to teleport elementary states, like those of the photons in our experiment, across distances of a few kilometers and maybe even up to satellites. The technology to teleport states of individual atoms is at hand today: the group led by Serge Haroche at the École Normale Supérieure in Paris has demonstrated entanglement of atoms. The entanglement of molecules and then their teleportation may reasonably be expected within the next decade. What happens beyond that is anybody's guess.

A more important application of teleportation might very well be in the field of quantum computation, where the ordinary notion of bits (0's and 1's) is generalized to quantum bits, or qubits, which can exist as superpositions and entanglements of 0's and 1's. Teleportation could be used to transfer quantum information between quantum processors. Quantum teleporters can also serve as basic components used to build a quantum computer [*see box on page 59*]. The cartoon on the next page illustrates an intriguing situation in which a combination of teleportation and quantum computation could occasionally yield an advantage, almost as if one had received the teleported information instantly instead of having to wait for it to arrive by normal means.

Quantum mechanics is probably one of the profoundest theories ever discovered. The problems that it poses for our everyday intuition about the world led

SKEPTICS CORNER

THE AUTHOR ANSWERS COMMON TELEPORTATION QUESTIONS

Isn't it an exaggeration to call this teleportation? After all, it is only a quantum state that is teleported, not an actual object. This question raises the deeper philosophical one of what we mean by identity. How do we know that an object—say, the car we find in our garage in the morning—is the same one we saw a while ago? When it has all the right features and properties. Quantum physics reinforces this point: particles of the same type in the same quantum state are indistinguishable even in principle. If one could carefully swap all the iron atoms in the car with those from a lump of ore and reproduce the atoms' states exactly, the end result would be identical, at the deepest level, to the original car. Identity cannot mean more than this: being the same in all properties.

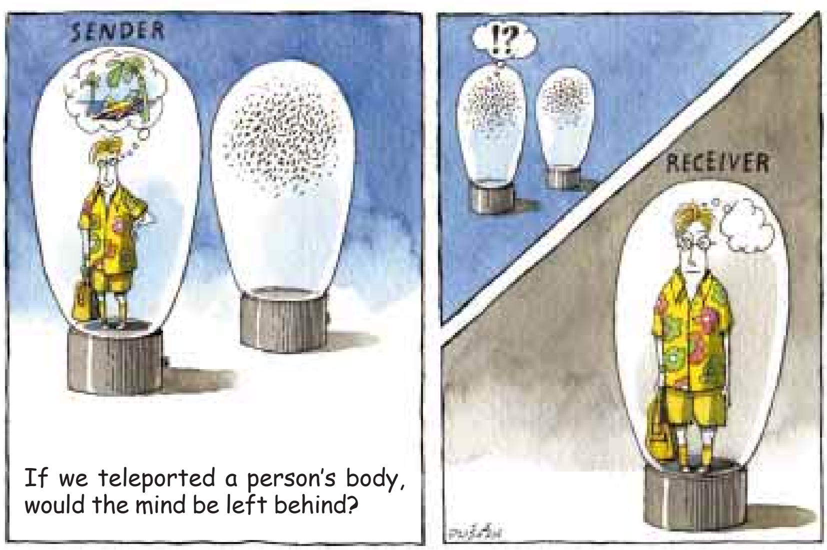
Isn't it more like "quantum faxing"? Faxing produces a copy that is easy to tell apart from the original, whereas a teleported object is indistinguishable even in principle. Moreover, in quantum teleportation the original must be destroyed.

Can we really hope to teleport a complicated object? There are many severe obstacles. First, the object has to be in a pure quantum state, and such states are very fragile. Photons don't interact with air much, so our experiments can be done in the open, but experiments with atoms and larger objects must be done in a vacuum to avoid collisions with gas molecules. Also, the larger an object becomes, the easier it is to disturb its quantum state. A tiny lump of matter would be disturbed even by thermal radiation from the walls of the apparatus. This is why we do not routinely see quantum effects in our everyday world.

Quantum interference, an easier effect to produce than entanglement or teleportation, has been demonstrated with buckyballs, spheres made of 60 carbon atoms. Such work will proceed to larger objects, perhaps even small viruses, but don't hold your breath for it to be repeated with full-size soccer balls!

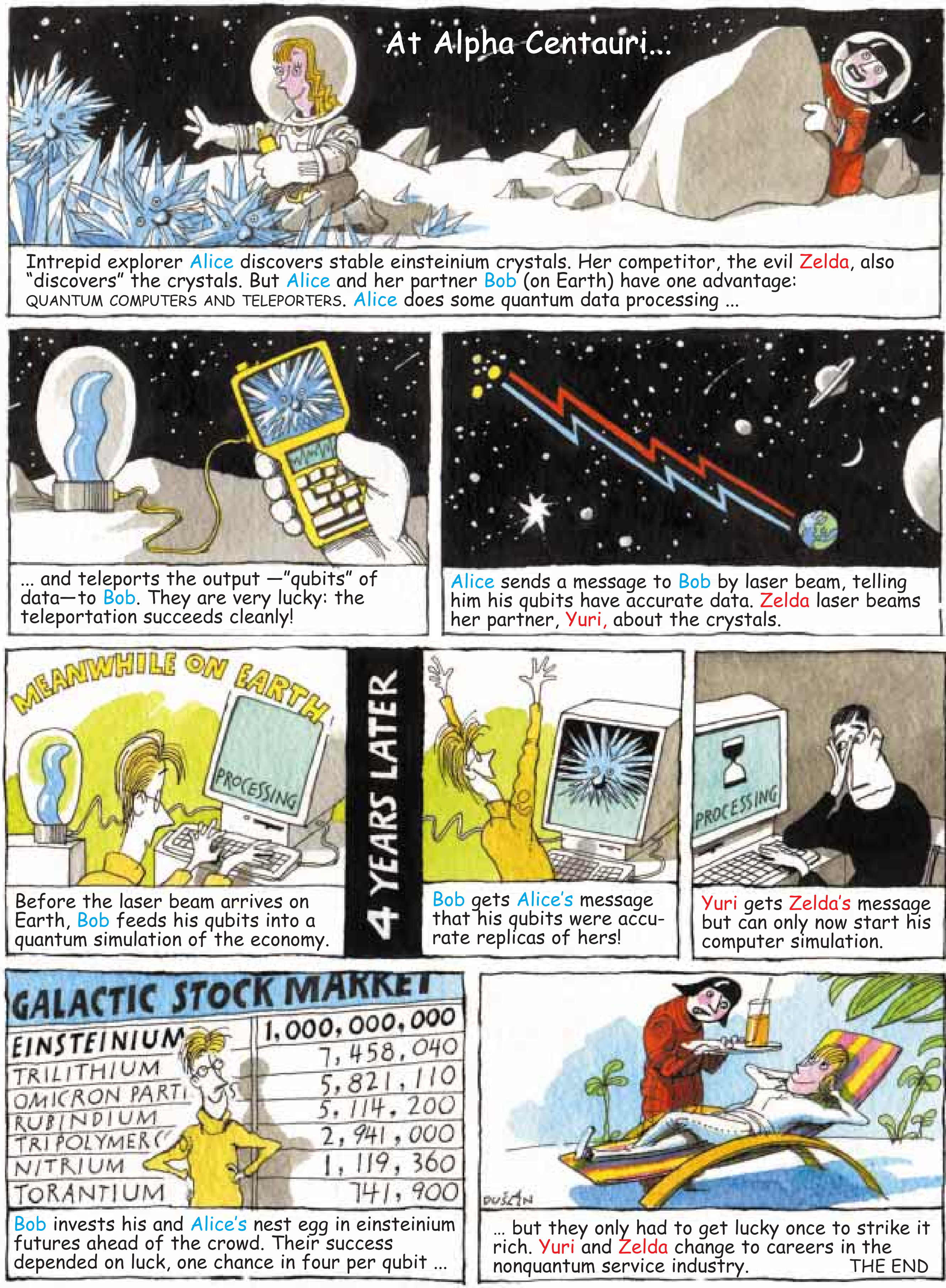
Another problem is the Bell-state measurement. What would it mean to do a Bell-state measurement of a virus consisting of, say, 10^7 atoms? How would we extract the 10^8 bits of information that such a measurement would generate? For an object of just a few grams the numbers become impossible: 10^{24} bits of data.

Would teleporting a person require quantum accuracy? Being in the same quantum state does not seem necessary for being the same person. We change our states all the time and remain the same people—at least as far as we can tell! Conversely, identical twins or biological clones are not "the same people," because they have different memories. Does Heisenberg uncertainty prevent us from replicating a person precisely enough for her to think she was the same as the original? Who knows. It is intriguing, however, that the quantum no-cloning theorem prohibits us from making a perfect replica of a person.



DUSAN PETRICIC

THE QUANTUM ADVENTURES OF ALICE & BOB



DUSAN PETRICIC

Einstein to criticize quantum mechanics very strongly. He insisted that physics should be an attempt to grasp a reality that exists independently of its observation. Yet he realized that we run into deep problems when we try to assign such an independent physical reality to the individual members of an entangled pair. His great counterpart, Danish physicist Niels Bohr, insisted that one has to take into account the whole system—in the case of an entangled pair, the arrangement of both particles together. Einstein's desideratum, the independent real state of each particle, is devoid of meaning for an entangled quantum system.

Quantum teleportation is a direct descendant of the scenarios debated by Einstein and Bohr. When we analyze the experiment, we would run into all kinds of problems if we asked ourselves what the properties of the individual particles *really* are when they are entangled. We have to analyze carefully what it means to "have" a polarization. We cannot escape the conclusion that all we can talk about are certain experimental results obtained by measurements. In our polarization measurement, a click of the detector lets us construct a picture in our mind in which the photon actually "had" a certain polarization at the time of measurement. Yet we must always remember that this is just a made-up story. It is valid only if we talk about that specific experiment, and we should be cautious in using it in other situations.

Indeed, following Bohr, I would argue that we can understand quantum mechanics if we realize that science is not describing how nature *is* but rather expresses what we can *say* about nature. This is where the current value of fundamental experiments such as teleportation lies: in helping us to reach a deeper understanding of our mysterious quantum world. SA

QUANTUM COMPUTERS

Perhaps the most realistic application of quantum teleportation outside of pure physics research is in the field of quantum computation. A conventional digital computer works with bits, which take definite values of 0 or 1, but a quantum computer uses quantum bits, or qubits [see "Quantum Computing with Molecules," by Neil Gershenfeld and Isaac L. Chuang; SCIENTIFIC AMERICAN, June 1998]. Qubits can be in quantum superpositions of 0 and 1 just as a photon can be in a superposition of horizontal and vertical polarization. Indeed, in sending a single photon, the basic quantum teleporter transmits a single qubit of quantum information.

Superpositions of numbers may seem strange, but as the late Rolf Landauer of IBM put it, "When we were little kids learning to count on our very sticky classical fingers, we didn't know about quantum mechanics and superposition. We gained the wrong intuition. We thought that information was classical. We thought that we could hold up three fingers, then four. We didn't realize that there could be a superposition of both."

A quantum computer can work on a superposition of many different inputs at once. For example, it could run an algorithm simultaneously on one million inputs, using only as many qubits as a conventional computer would need bits to run the algorithm once on a single input. Theorists have proved that algorithms running on quantum computers can solve certain problems faster (that is, in fewer computational steps) than any known algorithm running on a classical computer can. The problems include finding items in a database and factoring large numbers, which is of great interest for breaking secret codes.

So far only the most rudimentary elements of quantum computers have been built: logic gates that can process one or two qubits. The realization of even a small-scale quantum computer is still far away. A key problem is transferring quantum data reliably between different logic gates or processors, whether within a single quantum computer or across quantum networks. Quantum teleportation is one solution.

In addition, Daniel Gottesman of Microsoft and Isaac L. Chuang of IBM recently proved that a general-purpose quantum computer can be built out of three basic components: entangled particles, quantum teleporters and gates that operate on a single qubit at a time. This result provides a systematic way to construct two-qubit gates. The trick of building a two-qubit gate from a teleporter is to teleport two qubits from the gate's input to its output, using carefully modified entangled pairs. The entangled pairs are modified in just such a way that the gate's output receives the appropriately processed qubits. Performing quantum logic on two unknown qubits is thus reduced to the tasks of preparing specific predefined entangled states and teleporting. Admittedly, the complete Bell-state measurement needed to teleport with 100 percent success is itself a type of two-qubit processing. *—A.Z.*

LAURIE GRACE

The Author

ANTON ZEILINGER is at the Institute for Experimental Physics at the University of Vienna, having teleported there in 1999 after nine years at the University of Innsbruck. He considers himself very fortunate to have the privilege of working on exactly the mysteries and paradoxes of quantum mechanics that drew him into physics nearly 40 years ago. In his little free time, Zeilinger interacts with classical music and with jazz, loves to ski, and collects antique maps.

Further Information

QUANTUM INFORMATION AND COMPUTATION. Charles H. Bennett in *Physics Today,* Vol. 48, No. 10, pages 24–31; October 1995.

EXPERIMENTAL QUANTUM TELEPORTATION. D. Bouwmeester, J. W. Pan, K. Mattle, M. Eibl, H. Weinfurter and A. Zeilinger in *Nature,* Vol. 390, pages 575–579; December 11, 1997.

QUANTUM INFORMATION. Special issue of *Physics World,* Vol. 11, No. 3; March 1998.

QUANTUM THEORY: WEIRD AND WONDERFUL. A. J. Leggett in *Physics World,* Vol. 12, No. 12, pages 73–77; December 1999.

More about quantum teleportation and related physics experiments is available at www.quantum.at on the World Wide Web.

Building a Brainier Mouse

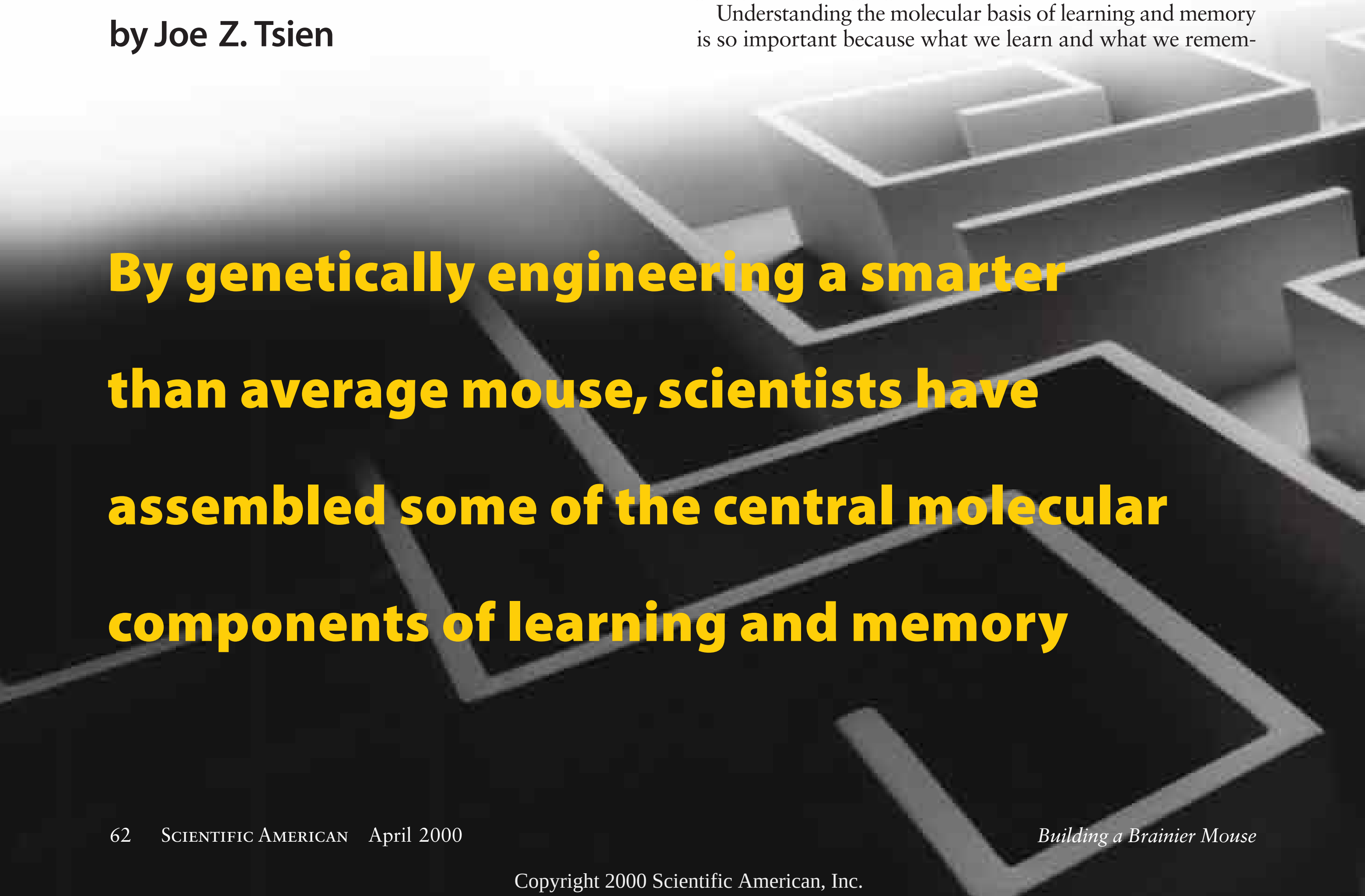
by Joe Z. Tsien

When I decided to become a scientist, never in my wildest dreams did I imagine that my work would provide fodder for CBS's *Late Show with David Letterman.* But last September, after my colleagues and I announced that we had doctored the genes of some mice to enhance their learning and memory skills, I turned on my television to find that my creations were the topic of one of Letterman's infamous Top Ten Lists. As I watched, the comedian counted down his roster of the Top Ten Term Paper Topics Written by Genius Mice. (My personal favorites are "Our Pearl Harbor: The Day Glue Traps Were Invented" and "Outsmarting the Mousetrap: Just Take the Cheese Off Really, Really Fast.")

My furry research subjects had become overnight celebrities. I received mail by the bagful and was forwarded dozens of jokes in which "smart" mice outwitted duller humans and their feeble traps. It seemed that the idea of a more intelligent mouse was something that everyone could identify with and find humorous.

But my co-workers and I did not set out merely to challenge the inventiveness of mousetrap manufacturers. Our research was part of a decades-long line of inquiry into exactly what happens in the brain during learning and what memories are made of. By generating the smart mice—a strain that we dubbed *Doogie* after the boy genius on the TV show *Doogie Howser, M.D.*—we validated a 50-year-old theory about the mechanisms of learning and memory and illustrated the central role of a particular molecule in the process of memory formation. That molecule could one day serve as a possible target for drugs to treat brain disorders such as Alzheimer's disease or even, perhaps, to boost learning and memory capacity in normal people.

Understanding the molecular basis of learning and memory is so important because what we learn and what we remem-



By genetically engineering a smarter than average mouse, scientists have assembled some of the central molecular components of learning and memory

ber determine largely who we are. Memory, not merely facial and physical appearance, defines an individual, as everyone who has known someone with Alzheimer's disease understands all too well. Furthermore, learning and memory extend beyond the individual and transmit our culture and civilization over generations. They are major forces in driving behavioral, cultural and social evolution.

The ABCs of Learning and Memory

The human brain has approximately 100 billion nerve cells, or neurons, that are linked in networks to give rise to a variety of mental and cognitive attributes, such as memory, intelligence, emotion and personality. The foundations for understanding the molecular and genetic mechanisms of learning and memory were laid in 1949, when Canadian psychologist Donald O. Hebb came up with a simple yet profound idea to explain how memory is represented and stored in the brain. In what is now known as Hebb's learning rule, he proposed that a memory is produced when two connected neurons are active simultaneously in a way that somehow strengthens the synapse, the site where the two nerve cells touch each other. At a synapse, information in the form of chemicals called neurotransmitters flows from the so-called presynaptic cell to one dubbed the postsynaptic cell.

In 1973 Timothy V. P. Bliss and Terje Lømo, working in Per Andersen's laboratory at the University of Oslo, discovered an experimental model with the hallmark features of Hebb's theory. They found that nerve cells in a sea horse–shaped region of the brain, appropriately called the hippocampus (from the Greek for "horse-headed sea monster"), become more tightly linked when stimulated by a series of high-frequency electrical pulses. The increase in synaptic strength—a phenomenon known as long-term potentiation (LTP)—can last for hours, days or even weeks. The fact that LTP is found in the hippocampus is particularly fascinating because the hippocampus is a crucial brain structure for memory formation in both humans and animals.

Later studies by Mark F. Bear of the Howard Hughes Medical Institute at Brown University and other scientists showed that applying a low-frequency stimulation to the same hippocampal pathway produces a long-lasting *decrease* in the strength of the connections there. The reduction is also long-lasting and is known as long-term depression (LTD), although it apparently has nothing to do with clinical depression.

The strengthening and weakening of synaptic connections through LTP- and LTD-like processes have become the leading candidate mechanisms for storing and erasing learned information in the brain. We now know that LTP and LTD come in many different forms. The phenomena also occur in many brain regions besides the hippocampus, including the neocortex—the "gray matter"—and the amygdala, a structure involved in emotion.

What is the molecular machinery controlling these forms of synaptic changes, or plasticity? Studies in the 1980s and 1990s by Graham L. Collingridge of the University of Bristol in England, Roger A. Nicoll of the University of California at San Francisco, Robert C. Malenka of Stanford University, Gary S. Lynch of the University of California at Irvine and other researchers have found that the changes depend on a single type of molecule. The researchers demonstrated that the induction of the major forms of LTP and LTD requires the activation of so-called NMDA receptors, which sit on the cell membranes of postsynaptic neurons.

NMDA receptors are really minuscule pores that most scientists think are made up of four protein subunits that control the entry of calcium ions into neurons. (The name of the receptors derives from *N*-methyl-D-aspartate, an artificial chemical

JANA BRENNING (*digital illustration*); PHOTODISC (*maze*); CORBIS (*lamp*); PETER MURPHY (*mouse*)

THE BASICS

A MOUSE NAMED *DOOGIE*

The author reviews the qualities of "smart" mice—and their implications for people

How are *Doogie* mice different from other mice? **They have been genetically engineered to make more than the usual amount of a key subunit of a protein called the *N*-methyl-D-aspartate (NMDA) receptor.**

What does the NMDA receptor do? **It helps to strengthen the connection between two neurons that happen to be active at the same time. Scientists theorize that such strengthening is the basis for learning and memory.**

How smart are *Doogie* mice? **They will never do differential equations or play the stock market, but they are better than normal mice at distinguishing between objects they have seen before and at recalling how to find a platform in a tank of murky water, for instance.**

How does their genetic alteration make them smarter? **The NMDA receptors of *Doogie* mice stay open nearly twice as long as those of normal mice. The extra time somehow helps them form a new memory more effectively.**

Could the same technique be used to enhance people's ability to learn and remember? **Theoretically, the possibility exists. But learning and memory in humans are much more complex than recognizing objects or remembering a water maze. Besides the scientific and technical barriers, the safety and ethical issues surrounding human genetic engineering would also need to be addressed. It is much more likely that pharmaceutical companies will first attempt to develop drugs that interact with the NMDA receptor to boost memory ability in people with memory deficits.**

that happens to bind to them.) They are perfect candidates for implementing the synaptic changes of Hebb's learning rule because they require two separate signals to open—the binding of the neurotransmitter glutamate and an electrical change called membrane depolarization. Accordingly, they are the ideal molecular switches to function as "coincidence detectors" to help the brain associate two events.

PETER MURPHY

Although LTP and LTD had been shown to depend on NMDA receptors, linking LTP- and LTD-like processes to learning and memory turned out to be much more difficult than scientists originally thought. Richard G. M. Morris of the University of Edinburgh and his colleagues have observed that rats whose brains have been infused with drugs that block the NMDA receptor cannot learn how to negotiate a test called a Morris water maze as well as other rats. The finding is largely consistent with the prediction for the role of LTP in learning and memory. The drugs often produce sensory-motor and behavioral disturbances, however, indicating the delicate line between drug efficacy and toxicity.

Four years ago, while I was working in Susumu Tonegawa's laboratory at the Massachusetts Institute of Technology, I went one step further and developed a new genetic technique to study the NMDA receptor in learning and memory. The technique was a refinement of the method for creating so-called knockout mice—mice in which one gene has been selectively inactivated, or "knocked out." Traditional knockout mice lack a particular gene in every cell and tissue. By studying the health and behavior of such animals, scientists can deduce the function of the gene.

But many types of knockout mice die at or before birth because the genes they lack are required for normal development. The genes encoding the various subunits of the NMDA receptors turned out to be similarly essential: regular NMDA-receptor knockout mice died as pups. So I devised a way to delete a subunit of the NMDA receptor in only a specific region of the brain.

The idea of a more intelligent mouse was something that everyone could identify with and find humorous.

Scoring a Knockout

Using the new technique, I engineered mice that lacked a critical part of the NMDA receptor termed the NR1 subunit in a part of their hippocampus known as the CA1 region. It was fortunate that we knocked out the gene in the CA1 region because that is where most LTP and LTD studies have been conducted and because people with brain damage to that area have memory deficits. In collaboration with Matthew A. Wilson, Patricio T. Huerta, Thomas J. McHugh and Kenneth I. Blum of M.I.T., I found that the knockout mice have lost the capacity to change the strength of the neuronal connections in the CA1 regions of their brains. These mice exhibit abnormal spatial representation and have poor spatial memory: they cannot remember their way around a water maze. More recent studies in my own laboratory at Princeton University have revealed that the mice also show impairments in several other, nonspatial memory tasks.

Although these experiments supported the hypothesis that the NMDA receptors are crucial for memory, they were not fully conclusive. The drugs used to block the receptors could have exerted their effects through other molecules in addition to NMDA receptors, for example. And the memory deficits of the knockout mice might have been caused by another, unexpected abnormality independent of the LTP/LTD deficits.

To address these concerns, a couple of years ago I decided to try to increase the function of NMDA receptors in

TESTING *DOOGIE*
Putting the Smart Mouse through Its Paces

In the initial tests of *Doogie* mice, we found that they were more likely than normal mice to recognize a familiar object over a novel one, such as the red toy in the photograph above. But that test, which is called an object-recognition task, assesses only one type of memory.

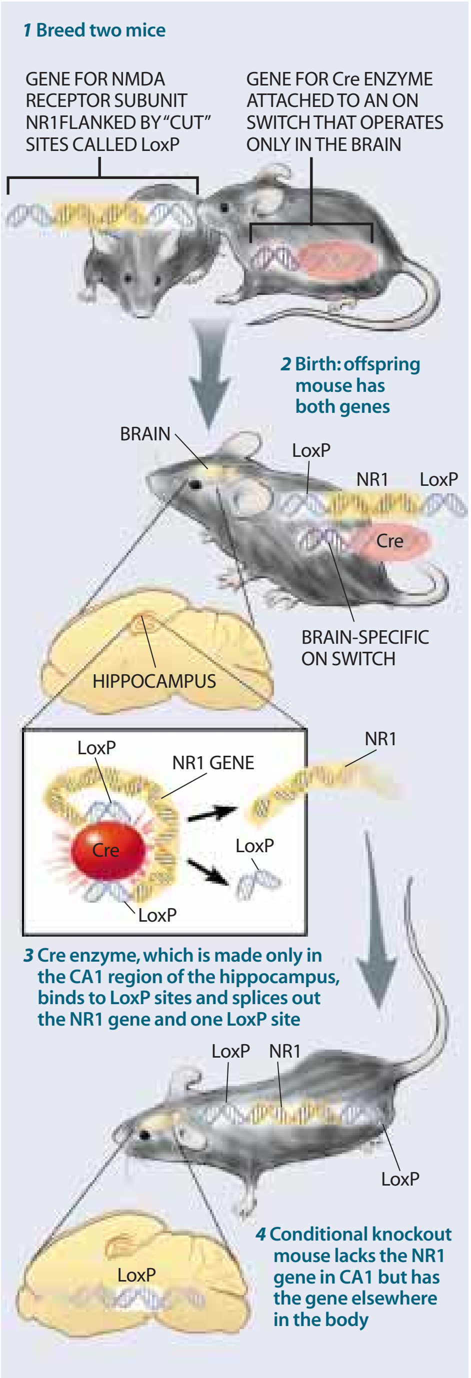
To further evaluate whether *Doogie* mice have enhanced learning and memory abilities, we used a more complex laboratory test called the Morris water maze. In this test we put a mouse into a circular pool that was 1.2 meters in diameter and filled with murky water. We placed into the pool a nearly invisible, clear Plexiglas platform that was almost—but not quite—as tall as the water was deep, so that it was just hidden beneath the surface. We surrounded the pool with a black shower curtain that had certain landmarks on it, such as the red dot in the top photograph at the left. Mice do not like to get wet, so in these tests they generally swim around until they find the platform, where they can pull themselves almost out of the water and rest.

We found that the *Doogie* mice located the submerged platform faster than normal mice, so we took the test a step further: we removed the platform to see if the animals would remember where the platform had been in relation to landmarks such as the red dot. When we put them back into the pool, *Doogie* mice spent more time than normal mice in the quarter of the pool where the platform had been, indicating that they remembered where it should be. What did they get as a reward? A toweling off and a stint under the heat lamp. *—J.Z.T.*

PETER MURPHY

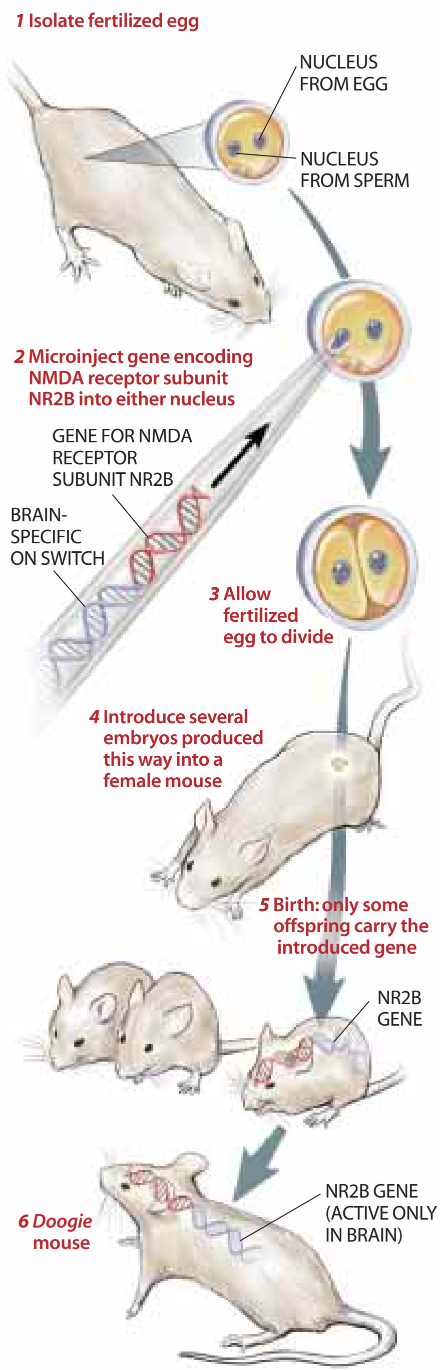
HOW TO MAKE A DUMB MOUSE

Remove part of a key receptor from its brain



HOW TO MAKE A SMART MOUSE

Add an extra copy of part of a key receptor to its brain



MAKING DUMB AND SMART MICE involves tampering with a protein called the NMDA receptor that is important for learning and memory. But the NMDA receptor plays crucial roles elsewhere in the body, so the author and his colleagues used snippets of DNA (on switches in the diagram) to manipulate the genes for various subunits of the receptor *only* in the brain. The smart, or *Doogie*, mice have extra subunits in their brains; the dumb, or conditional knockout, mice lack a different NMDA receptor subunit in their brains.

mice to see whether such an alteration improved the animals' learning and memory. If it did, that result—combined with the previous ones—would tell us that the NMDA receptor truly is a central player in memory processes.

This time I focused on different parts of the NMDA receptor, the NR2A and NR2B subunits. Scientists have known that the NMDA receptors of animals as diverse as birds, rodents and primates remain open longer in younger individuals than in adults. Some researchers, including my colleagues and me, have speculated that the difference might account for the fact that young animals are usually able to learn more readily—and remember what they have learned longer—than their older counterparts.

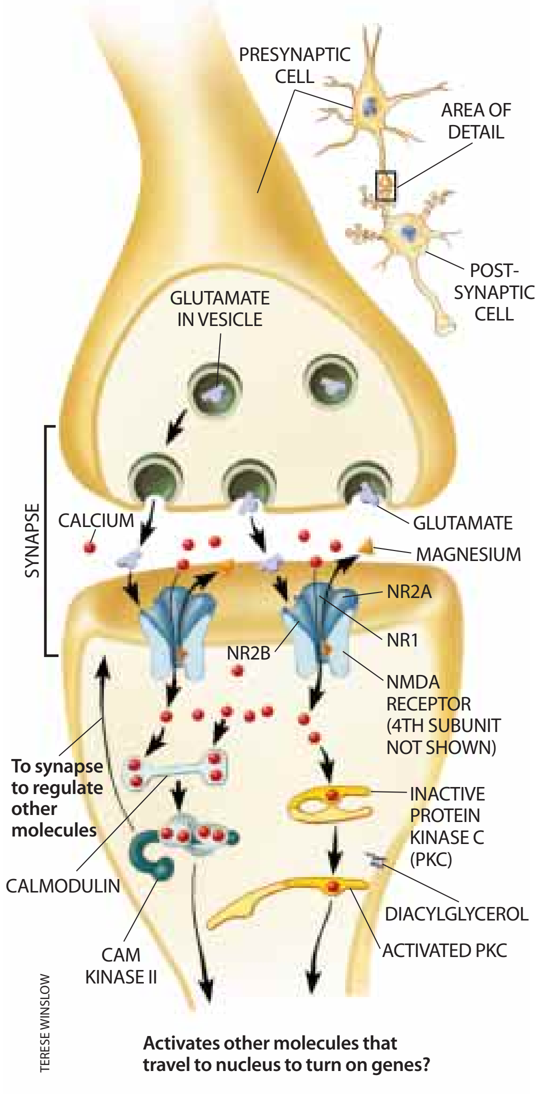
As individuals mature, they begin to switch from making NMDA receptors that contain NR2B subunits to those that include NR2A subunits. Laboratory studies have shown that receptors with NR2B subunits stay open longer than those with NR2A. I reasoned that the age-related switch could explain why adults can find it harder to learn new information.

So I took a copy of the gene that directs the production of NR2B and linked it to a special piece of DNA that served as an on switch to specifically increase the gene's ability to make the protein in the adult brain. I injected this gene into fertilized mouse eggs, where it was incorporated into the chromosomes and produced genetically modified mice carrying the extra copy of the NR2B gene.

Working in collaboration with Guosong Liu of M.I.T. and Min Zhuo of Washington University, my colleagues and I found that NMDA receptors from the genetically engineered mice could remain open for roughly 230 milliseconds, almost twice as long as those of normal mice. We also determined that neurons in the hippocampi of the adult mice were capable of making stronger synaptic connections than those of normal mice of the same age. Indeed, their connections resembled those in juvenile mice.

What Smart Mice Can Do

Next, Ya-Ping Tang and other members of my laboratory set about evaluating the learning and memory skills of the mice that we had named *Doogie*. First, we tested one of the most basic aspects of memory, the ability to recognize an object. We placed *Doogie* mice into an open box and allowed them to explore two objects for five minutes. Several days later we replaced one object with a new one and returned the mice to the box. The genetically modified mice remembered the old object and devoted their time to exploring the new one. Normal mice, however, spent an equal amount of time exploring both objects, indicating that the old object was no more familiar to them than the new. By



TERESE WINSLOW

TWO NEURONS MEET at a junction called a synapse. A leading hypothesis of how memories form involves proteins called NMDA receptors, which sit on the surfaces of postsynaptic cells. NMDA receptors, which are tiny pores through which calcium can pass, can link two events in time—a prerequisite for laying down a memory—because they open only when they receive two signals. The first signal is the binding of glutamate released by the presynaptic cell; the other is electrical stimulation by input from another neuron that expels magnesium from the channel of the receptor. The inrush of calcium activates biochemical cascades that eventually strengthen the synapse.

repeating the test at different intervals, we found that the genetically modified mice remembered objects four to five times longer than their normal counterparts did.

In the second round of tests, Tang and I examined the ability of the mice to learn to associate a mild shock to their paws with being in a particular type of chamber or hearing a certain tone. We found that the *Doogie* mice were more likely to "freeze"—an indication that they remembered fear—than were normal mice when we returned the animals to the chamber or played them the tone several days later. These tests suggested to us that the *Doogie* mice had better memory. But were they also faster learners?

Learning and memory represent different stages of the same gradual and continuous process whose steps are often not easy to distinguish. Without memory, one cannot measure learning; without learning, no memory exists to be assessed. To determine whether the genetic alteration of the *Doogie* mice helped them to learn, we employed a classic behavioral experimental paradigm known as fear-extinction learning.

In the fear-extinction test, we conditioned the mice as we did before in a shock chamber, then placed the animals back into the fear-causing environment—but without the paw shocks—again and again. Most animals take five repetitions or so to unlearn the link between being in the shock chamber and receiving a shock. The *Doogie* mice learned to be unafraid after only two repetitions. They also learned not to fear the tone faster than the normal mice.

The last behavioral test was the Morris water maze, in which the mice were required to use visual cues on a laboratory wall to find the location of a submerged platform hidden in a pool of milky water. This slightly more complicated task involves many cognitive factors, including analytical skills, learning and memory, and the ability to form strategies. Again, the genetically modified mice performed better than their normal counterparts.

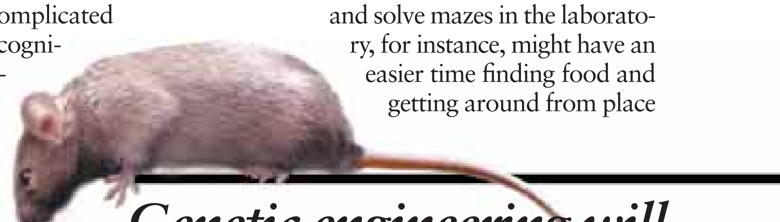
Our experiments with *Doogie* mice clearly bore out the predictions of Hebb's rule. They also suggested that the NMDA receptor is a molecular master switch for many forms of learning and memory.

Although our experiments showed the central role of NMDA receptors in a variety of learning and memory processes, it is probably not the only molecule involved. We can expect many molecules that play a role in learning and memory to be identified in the coming years.

Everyone I have encountered since the publication of our results has wanted to know whether the findings mean we will soon be able to genetically engineer smarter children or devise pills that will make everyone a genius. The short answer is no—and would we even want to?

Intelligence is traditionally defined in dictionaries and by many experimental biologists as "problem-solving ability." Although learning and memory are integral parts of intelligence, intelligence is a complex trait that also involves many other factors, such as reasoning, analytical skills and the ability to generalize previously learned information. Many animals have to learn, remember, generalize and solve various types of problems, such as negotiating their terrain, foreseeing the relation between cause and effect, escaping from dangers, and avoiding poisonous foods. Humans, too, have many different kinds of intelligence, such as the intelligence that makes someone a good mathematician, an effective CEO or a great basketball player.

Because learning and memory are two of the fundamental components of problem solving, it would not be totally surprising if enhancing learning and memory skills led to improved intelligence. But the various kinds of intelligence mean that the type and degree of enhancement must be highly dependent on the nature of the learning and memory skills involved in a particular task. Animals with an improved ability to recognize objects and solve mazes in the laboratory, for instance, might have an easier time finding food and getting around from place to place in the wild. They might also be more likely to escape from predators or even to learn to avoid traps. But genetic engineering will never turn the mice into geniuses capable of playing the piano.



Genetic engineering will never turn mice into geniuses capable of playing the piano.

Our finding that a minor genetic manipulation makes such a measurable difference in a whole set of learning and memory tasks points to the possibility that NR2B may be a new drug target for

PETER MURPHY

treating various age-related memory disorders. An immediate application could be to search for chemicals that would improve memory by boosting the activity or amount of NR2B molecules in patients who have healthy bodies but whose brains have begun to be ravaged by dementia during aging. Such drugs might improve memory in mildly and modestly impaired patients with Alzheimer's disease and in people with early forms of other dementias. The rationale would be to boost the memory function of the remaining healthy neurons by modulating and enhancing the cells' NR2B activity. Of course, designing such compounds will take at least a decade and will face many uncertainties. The possible side effects of such drugs in humans, for example, would need to be carefully evaluated, although the increased NR2B activity in the *Doogie* mice did not appear to cause toxicity, seizures or strokes.

But if more NR2B in the brain is good for learning and memory, why has nature arranged for the amount to taper off with age? Several schools of thought weigh in on this question. One posits that the switch from NR2B to NR2A prevents the brain's memory capacity from becoming overloaded. Another, which I favor, suggests that the decrease is evolutionarily adaptive for populations because it reduces the likelihood that older individuals—who presumably have already reproduced—will compete successfully against younger ones for resources such as food.

The idea that natural selection does not foster optimum learning and memory ability in adult organisms certainly has profound implications. It means that genetically modifying mental and cognitive attributes such as learning and memory can open an entirely new way for the targeted genetic evolution of biology, and perhaps civilization, with unprecedented speed. SA

THE SEARCH FOR A MEMORY-BOOSTING DRUG

Smarter Mice Are Only the First Step

How close are researchers to devising a pill to help you remember where you put your car keys? The short answer is "not very." But that doesn't mean they aren't working on it—and hard. Less than eight months after Joe Z. Tsien of Princeton University (the author of the preceding article) and his colleagues reported genetically engineering a smarter mouse, Tsien has teamed up with venture capitalist Charles Hsu to form a company based on the discovery.

The newly incorporated firm is called Eureka Pharmaceuticals, and its home for the time being is Hsu's office at the Walden Group in San Francisco. The company's first order of business is to use gene technology called genomics to identify molecules that are potential targets for drugs to treat central nervous system disorders such as memory loss and dementia. "We believe the tools that Joe and his colleagues have developed can be translated pretty quickly into a basis for discovering therapies for human disease," Hsu says. Hsu is the CEO of Eureka; Tsien is the company's scientific adviser but will remain at Princeton.

Eureka's first target is the so-called NMDA receptor—which Tsien and his co-workers manipulated genetically to make their smart *Doogie* mice—although the company will also look for other targets. The receptor is essentially a pore that allows calcium to enter nerve cells, a prerequisite for strengthening the connection between two nerve cells. Such strengthening is thought to be the basis for learning and memory.

Over the past decade, several pharmaceutical companies have tested as possible stroke drugs various compounds that decrease the activity of the NMDA receptor. When the brain is starved of blood, such as happens when the blood clot of a stroke blocks an artery, nerve cells can release too much glutamate, a chemical the cells use to communicate. In a phenomenon called excitotoxicity, the excess glutamate binds to NMDA receptors on other nerve cells, allowing a tsunami of calcium to flood into the other cells. Together with the lack of oxygen, this causes the cells to die.

So far, however, the search for NMDA-receptor blockers that could serve as stroke drugs has been "incredibly disappointing," comments neuroscientist Robert C. Malenka of Stanford University. The problem, he explains, is finding a chemical that binds to precisely the right spot on the NMDA receptor and in just the right way, without causing other neurological effects. (After all, the illicit hallucinogenic drug phencyclidine—also known as PCP or "angel dust"—also binds to the receptor.)

The lack of success with NMDA-receptor blockers against stroke—together with the possibility that agents that bind to the receptor might be toxic—has blunted some scientists' enthusiasm for developing drugs that might boost learning and memory by activating the receptor. "Nobody is seriously considering upregulating the activity of the NMDA receptor to boost memory, to my knowledge," Malenka says. "But maybe some clever person will come up with that magic drug that will tweak the receptor just so."

A more likely scenario—and one being pursued by Tsien—might be developing drugs that subtly modulate the activity of the NMDA receptor, without binding to it directly, according to Ira B. Black of the University of Medicine and Dentistry of New Jersey. Black studies a naturally occurring chemical called brain-derived neurotrophic factor (BDNF), which increases the likelihood that parts of the NMDA receptor will have a phosphate group tacked onto them. NMDA receptors with phosphate groups are more likely to be active than those without such groups.

Still, most neuroscientists concur that the search for a drug that enhances learning and memory without side effects will take time. ***—Carol Ezzell, staff writer***

The Author

PETER MURPHY

JOE Z. TSIEN has been an assistant professor in the department of molecular biology at Princeton University since 1997. He came to the U.S. in 1986 after graduating from East China Normal University in Shanghai and working for two years as an instructor at East China University of Science and Technology in Shanghai. He received his Ph.D. in biochemistry and molecular biology in 1990 from the University of Minnesota. He has consulted for several biotechnology companies seeking to develop therapies for age-related memory disorders. The *Doogie* mouse was a hit in his seven-year-old son's class during show-and-tell.

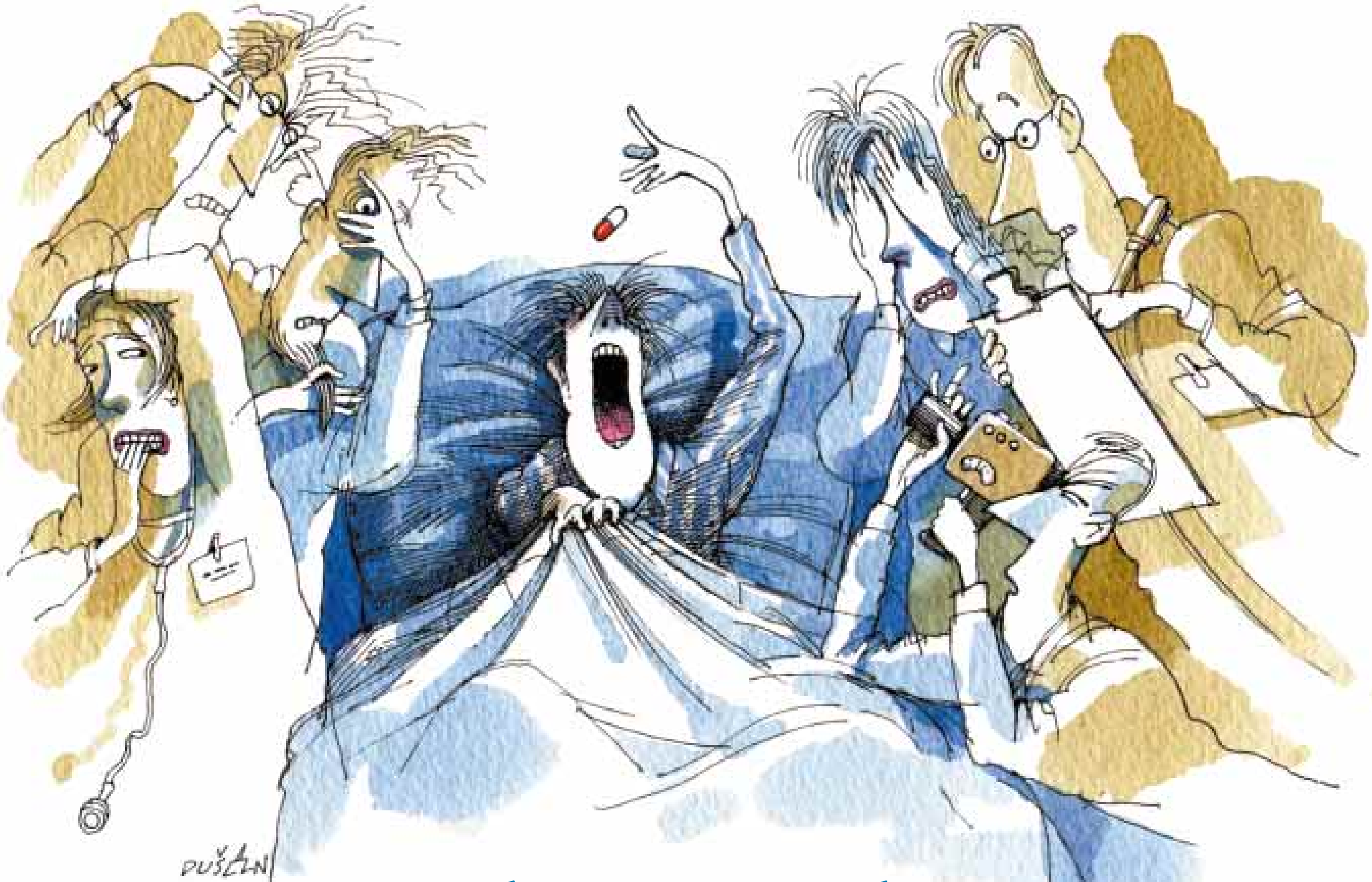
Further Information

THE ORGANIZATION OF BEHAVIOR: A NEUROPSYCHOLOGICAL THEORY. Donald O. Hebb. John Wiley, 1949.

MEMORY AND BRAIN. Larry R. Squire. Oxford University Press, 1987.

LONG-TERM POTENTIATION—A DECADE OF PROGRESS? Robert C. Malenka and Roger A. Nicoll in *Science*, Vol. 285, No. 5435, pages 1870–1874; September 17, 1999.

ENHANCING THE LINK BETWEEN HEBB'S COINCIDENCE DETECTION AND MEMORY FORMATION. Joe Z. Tsien in *Current Opinion in Neurobiology*, Vol. 10, No. 2; April 2000.



Understanding CLINICAL TRIALS

The journey from initial medical research to the bottle in your family's medicine cabinet is complex, time-consuming and expensive. Can the clinical trial process be refined?

by Justin A. Zivin

One of the biggest stories in medicine of the past five years is surely the furor over angiostatin and endostatin, compounds heralded by some media reports as the cure for cancer (a premature claim, to be sure). The two substances—which dramatically reduced tumor size in a group of laboratory mice—made headlines for a few weeks in the spring of 1998 but then faded from public view.

Scientists, however, continued their slow, methodical study of the potential drugs. A year and a half later, in September 1999, doctors were at last ready to begin testing endostatin in humans. At press time, phase I of a clinical trial was under way in Boston, Houston, and Madison, Wis.; barring unforeseen complications, testing should continue through most of this year. But even if all goes smoothly and endostatin proves to be a safe and effective treatment, it will not be available to patients for several more years.

Another story that often makes the evening news is the promise of gene therapy, but almost half a century after the revolution in molecular biology began, no such treatments are available. Testing of gene therapy is under way, however—and is currently the subject of intense scrutiny. The complaint this time is not about the slow progress of research but about whether the research is actually harming patients. In September of last year, a young man participating in a phase I trial of gene therapy for a rare metabolic disorder, ornithine transcarbamylase deficiency, died as a result of complications caused by the treatment. In the subsequent months, reports of additional deaths in gene therapy clinical trials have also been made public. Much of the discussion of these tragedies has focused on how the trials were run and whether misconduct on the part of the researchers could have led to the deaths.

The three-part clinical trial process required to judge the efficacy and safety of potential treatments is a major undertaking. The necessary trials may require more than a decade to complete and cost hundreds of millions of dollars. (For more detailed descriptions of the three phases of a clinical trial, see the boxes on pages 71, 73 and 75.) Trials that fail to show that a treatment works outnumber substantially those that prove that one *does* work, but both can cost the same. Although the precise numbers are not available because pharmaceutical companies do not like to report their failures, it is safe to say that thousands of drugs and medical devices have been evaluated in the past decade alone.

Most people know very little of how trials are conducted or what their scientific foundations are. Yet they may be asked to risk their health, and possibly their lives, to participate in a trial—often with little time to make weighty decisions. Furthermore, in recent years human trials have become more than just a way to screen new drugs. They have taken on an important role in the delivery of health care: many patients view participation in a trial as the only way to obtain experimental medications they consider potentially lifesaving.

Concerns about the way clinical trials are conducted have surfaced regarding the money, time and potential conflicts of interest involved. Do drug companies push researchers to report results in only the most self-serving way? Is it really feasible to explain all the potential risks to a patient (a requirement for securing his or her "informed consent") when the purpose of the trial is to learn about such risks? How do you balance the desire to test a drug candidate comprehensively with the desire to make lifesaving treatments available to patients quickly? The list of questions goes on. Under pressure from the public, the government and the companies funding medical research, clinical investigators are continually striving to cut the cost and length of the process—without sacrificing the quality controls set up to protect patients and to ensure that new treatments are safe and effective.

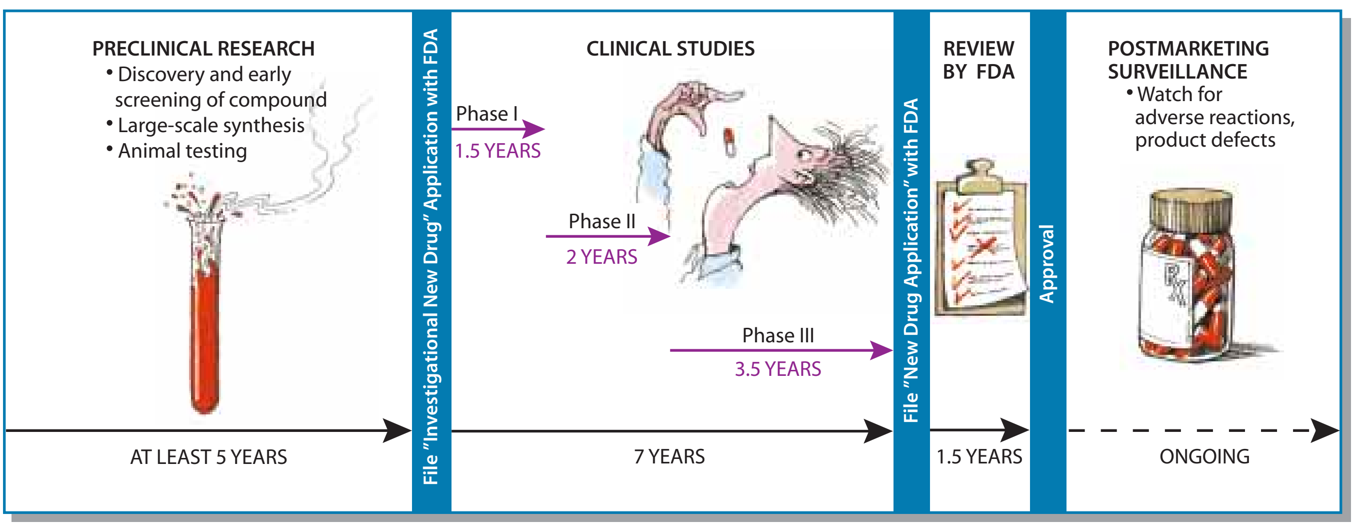
For more than 20 years, I have observed hundreds of clinical trials from a variety of perspectives: as a bench researcher, a clinical neurologist and an investigator in clinical trials. I have served as a consultant to the National Institutes of Health, the U.S. Food and Drug Administration and several pharmaceutical companies. I have also consulted for a contract research organization, a company that can be hired by drug firms to organize clinical trials. During these years, those of us involved in clinical trials have tried to develop improvements or alternatives to the traditional clinical trial. Some of these techniques may help resolve current dilemmas, but I believe that on balance the three-stage, randomized, controlled clinical trial remains the most reliable way to test new drugs and medical devices.

Protecting Patients

A leading complaint about the current formula for testing experimental therapies on humans is the need for so-called blinded, controlled clinical trials. Ideally, neither physicians nor patients know whether a subject is part of the treatment group or the control group (which receives either a placebo or the best available proven therapy)—they are "blind" to whether the test drug is being administered. Complicating the issue is the idea of randomization, the practice of randomly assigning patients to either the test group or the control group. Because of this practice, patients often complain about being powerless "guinea pigs" for the far more powerful drug companies. They argue that patients whose only chance could be the latest, cutting-edge treatments should have guaranteed access to them.

If researchers somehow knew a drug candidate truly was a better treatment, however, there would be no need for a trial. It is scientifically essential that the division of subjects into the test or con-

TIMELINE FOR DRUG DEVELOPMENT typically spans many years, stretching from preliminary research in the laboratory through human trials, review by a regulatory agency (such as the U.S. Food and Drug Administration) and, finally, monitoring of drugs on the market. Efforts by the FDA and clinical investigators have shortened the process somewhat, but a thorough trial takes time.



DUSAN PETRICIC (*drawings*); HEIDI NOLAND trol groups occur and that it be entirely random. Otherwise the final results will be skewed. If the test group were to consist mainly of patients for whom all other drugs had failed (and thus were more likely to be among the sickest patients), the drug candidate being screened could appear to be less effective than the placebo, even if it were not, simply because the patients receiving the drug started off in worse health. Conversely, if the leaders of the clinical trial consciously or unconsciously administered the test drug to healthier patients, it could appear to be more effective.

What is essential for science does not always make sense to patients, however, especially those with life-threatening illnesses. To protect patients from potential abuses and address their concerns, trial organizers incorporate many levels of oversight into their planning. First, doctors are bound by their ethics to provide patients with the best care possible, whether or not they are part of a trial. Physicians are never required to enroll people in an experimental study, and patients cannot be forced to join. When someone does decide to enroll, doctors must provide a complete explanation, both orally and in writing, about the nature of the study and all available information about the potential risks and benefits of participating. If patients or their responsible guardians agree to continue, they must do so in writing. This process is called obtaining informed consent. Patients always have the right to refuse to participate or to withdraw from a trial at any time.

But because of the impossibility of knowing in advance all possible side effects of an experimental drug, hospitals in the U.S. that run clinical trials operate Institutional Review Boards, or IRBs. This second level of oversight usually consists of a committee of caregivers, patient advocates and other interested nonprofessionals (for instance, lawyers or members of the clergy). The IRB must agree to a trial before it can begin at a site, and if the members become concerned about how a trial is progressing they can stop the trial at their hospital or request changes in procedure.

As an additional layer of patient protection, each trial usually includes a Data Safety Monitoring Board, or DSMB. This group of physicians and statisticians works independently of the sponsors of the drug trial and the scientific investigators. They monitor the trial, continually checking safety and peri-


DEL BROWN *Gamma Liaison*

ENDOSTATIN, a potential anticancer drug, is now in phase I testing at the University of Wisconsin Comprehensive Cancer Center.

PHASE 1: Screening for Safety

Number of volunteers: 10–100 people, typically healthy

What researchers hope to learn: Maximum safe dose of drug

Typical length: 1.5 years

Typical cost: $10 million

In the first stage of a clinical trial, researchers gather information about whether a drug is safe to give to humans and, if so, how much they can tolerate. Administering a drug for the first time can be a frightening experience because the volunteers (who are usually perfectly healthy and are also usually paid) are taking a very real risk. The initial dose is typically very low, to minimize the possibility of a major reaction, but as doctors escalate the dose the potential for problems increases. If the possibility of extremely serious side effects exists, phase I testing is conducted in patients with the condition that the medication is intended to treat. Potential harm then is balanced by potential benefit.

Of course, before human testing begins, the general safety of the drug has been established in animals. But animals cannot express whether they are dizzy, nauseated or experiencing psychiatric symptoms; humans can and frequently do. And although such an outcome is extremely rare, volunteers occasionally suffer life-threatening side effects that were not apparent during animal testing.

The trial team monitors the participants closely, constantly observing their behavior and asking how they feel. Additionally, to spot problems early the researchers usually measure blood pressure and temperature, collect blood and urine samples, and monitor for any other danger signs warranted by the animal studies. The scientists also measure the level of drug in the bloodstream or tissues to determine how it is distributed in the body, how rapidly it reaches a therapeutic level and how the body eliminates the compound. When combined, these data help to determine the safe dosing regimen. *—J.A.Z.*

odically evaluating other aspects. If necessary, the board can be unblinded during the course of the trial. If the DSMB finds that the treatment group is doing substantially better than the control group (or vice versa), the board can recommend the trial be terminated.

In some instances, physicians can offer experimental treatments to patients outside of a clinical trial. Therapies that have not been approved by the FDA can be made available to people who are extremely ill for what doctors call "compassionate use." But because such treatments have not been adequately tested in humans, recipients have no assurances that the drug or new medical procedure will help—or that it is safe. Moreover, the results of such experiments will not help anyone else, because they were not part of a properly designed clinical trial.

From what we now know about the phase I gene therapy trials that involved the deaths of some subjects, oversight committees can be misinformed [see "Gene Therapy Setback," by Tim Beardsley, News and Analysis, February]. In several of the trials now under investigation (several of which have been halted), the researchers did not inform the NIH of certain health hazards associated with the treatment—hazards they had observed previously either in animal tests or in other patients. (Most of the researchers had reported complications to the FDA, but that agency does not release data on trials.)

Such notifications—required by federal law—could have stopped the trials and prevented the deaths. Unfortunately, when researchers think they have discovered a "magic bullet"—a therapy that cures with complete safety—it may be hard for them to recognize the risks associated with any clinical trial. But the difficulties scientists will be most likely to encounter in developing gene therapies are similar to those considered commonplace in the testing of more traditional treatments. The recent deaths should remind all clinical investigators how vital it is to conduct our studies according to the well-established rules.

The public, physicians and pharmaceutical companies all agree that drug candidates should be tested quickly yet thoroughly so that useful new medications can be made available as soon as possible. The public's considerations are fairly clearly humanitarian. Physicians' motivations may be mixed, however. They want patients to get the best treatment, but they also benefit financially from entering patients into the trial—drug companies typically pay doctors for each new patient enrolled. And as the events of the gene therapy trials reveal, professional pride can be at stake as well. Pharmaceutical companies, of course, have a definite financial interest in moving trials along rapidly: the longer a trial runs, the more it costs them. In addition, a short successful trial allows a company to start selling its product sooner (and take advantage of patent protection on its drugs for a longer time).

Speeding Up the Process

The rate at which a trial can be conducted depends predominantly on the number of participating investigators and patients. The faster the data are collected, the sooner researchers can begin to interpret the information. This is particularly true for therapies that may offer important benefits to only a relatively small number of patients and for those that provide only modest benefits for many people. For instance, taking aspirin daily prevents strokes every year in approximately 1.5 percent of patients who have suffered a previous stroke. Only by administering aspirin to a very large number of patients could researchers prove that such an effect existed. Although this benefit may seem small, aspirin costs only a few dollars a year, whereas the costs of taking care of one stroke survivor total about $50,000 a year. And viewed from a larger perspective, out of one million cases, some 15,000 people should benefit from aspirin treatment.

As a way to enroll as many patients as possible, as quickly as possible, trial leaders now run their studies at numerous sites around the world. More sites mean more patients and a diverse group of people who are more representative of those who will one day be taking the medication or using the medical device.

Despite the benefits of international trials, however, such efforts have come under criticism. Detractors argue that some drug companies take advantage of people in the developing world, testing new lifesaving therapies in these regions (particularly for HIV/AIDS) but then withdrawing access to treatment that is too expensive for most patients to purchase on their own. This issue, as troubling as it is, does not reflect a poor clinical trial design; who has access to medicine instead reflects current politics and economics. Ensuring that patients can get needed medicines that they cannot afford must and should be addressed by legal and financial means.

As trials grow in size, investigators accumulate increasingly vast amounts of information. The reports generated for just one patient frequently consume more than 100 pages of a notebook. The process of collecting such a mountain of data and checking it for accuracy accounts for much of a trial's price tag.

An alternative approach, known as the large simple trial, attempts to remedy part of this problem. In this method, physicians collect only the absolutely necessary details—usually just identifying information and a simple check-off list indicating whether the patient ended up better, unchanged or worse. The whole record can then be sent into the coordinating center on a postcard. Large

PHASE 2: Establishing Protocol

Number of volunteers: 50–500 patients with the disease being studied

What researchers hope to learn: Who and how many people should be included in the final phase of testing; end points of trial; preliminary estimates of effective doses and duration of treatment

Typical length: 2 years

Typical cost: $20 million

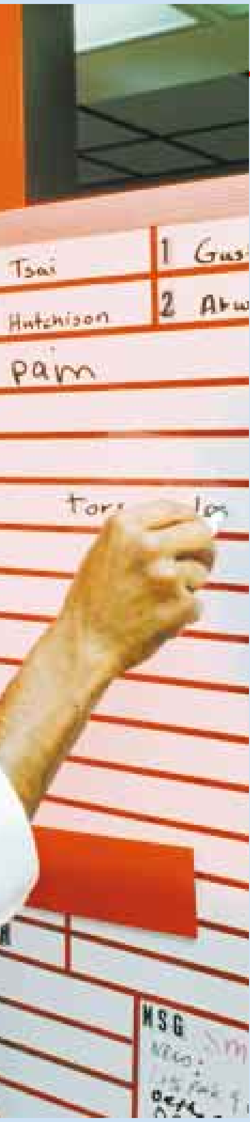
The main goal of phase II testing is pragmatic: to find the experimental conditions that will allow the final phase of the trial to give a definitive result. (The purpose of a phase II trial is not, as some people assume, to prove that a drug candidate is an effective treatment.) In particular, researchers try to establish an optimal dosing regimen. One criterion that must be established immediately is the primary end point. End points describe unambiguous results that indicate exactly what the treatment can do. For instance, the usual end point sought when screening a new antibiotic is whether a patient is free of infection after treatment. Many ailments cannot be so readily cured, however, so an alternative end point might be whether the progression of, say, HIV/AIDS has slowed or whether the death rate from cancer has fallen.

Phase II marks the introduction of the control group to the trial. Almost all diseases are highly variable in their progression, with remissions sometimes occurring spontaneously. Researchers must be able to distinguish between a natural remission and the effects of treatment. Inclusion of a control group—which receives either a placebo or the best available therapy—makes it possible to perform this comparison.

Similarly, having a control group enables doctors to account for people in whom health problems unrelated to a drug candidate develop. For example, a medication being tested for treatment of high blood pressure might be suspected of causing nausea. But nausea can occur in just about anyone. Only if its incidence is significantly higher in the treatment group than in the control group will it be considered a problem.

Ideally, neither the physicians nor the patients know whether they are part of the treatment group or the control group—in other words, they are "blind" to the type of therapy being administered. During phase II, investigators work hard to ensure that the blinding procedure is successful. For instance, if a placebo pill is used, it is made to look exactly like the drug, and the patients are treated with either the drug or placebo in exactly the same way.

Yet in some cases, keeping a trial blind is simply impossible. If the test drug causes some kind of mild side effect, patients will quickly figure out that they are in the treatment group. Also, it is usually considered unethical to subject a patient to anesthesia and placebo surgery when surgical procedures are being evaluated. Researchers can compensate for the loss of blinding, however, and phase II enables them to work out how to do so before entering phase III. —*J.A.Z.*



CORBIS

PATIENT RECORDS must be carefully reviewed during phase II, when trial organizers refine the dose and duration of treatment to be used in phase III.

simple trials offer a far more economical plan for collecting data on huge numbers of patients; such trials routinely enroll tens of thousands of subjects for a small fraction of what it would otherwise cost. And with such large numbers of people, even small effects of a medication can be detected.

Large simple trials have a major drawback, however: they cannot be used to test a *new* drug candidate, because the side effects are unknown. Giving large numbers of patients an experimental medication that has never been screened for safety and has uncertain benefits is unethical. As a result, researchers typically run large simple trials to evaluate the relative effectiveness of known, approved treatments.

Progress in accelerating the clinical trial process is already apparent. According to a 1999 report from the Tufts Center for the Study of Drug Development, the average length of all clinical trials under way between 1996 and 1998 was 5.9 years—down from 7.2 years between 1993 and 1995. But even with timesaving measures in place, clinical trials still represent a large investment of time and money. So when the results are ambiguous, leaders of a clinical trial usually try to extract some useful information out of their hard work.

Often a phase III trial will show a trend in favor of a drug, but the effect will be too small to serve as statistically convincing proof. In many instances, additional trials give mixed results as well. For such cases, statisticians have developed methods for pooling data from all the previous trials to conduct what they term meta-analysis. Such evaluations remain controversial, however. The appeal of trying to salvage a valuable result from a collection of near-misses is strong. But questions remain about the validity of meta-analysis: the technique is subject to potential bias in terms of which studies were selected for inclusion and the comparability of those studies. The findings from a meta-analysis can be useful for interpreting a large amount of conflicting data, but the results are not generally considered definitive.

Financial Dealings

Money—who pays for the research and who takes home the profits—looms over every clinical trial. For many years, the pharmaceutical companies have done most of the work of clinical trials themselves, hiring physicians to organize and run the trials, monitors to verify that the data have been collected accurately, statisticians to analyze the results, clerks to enter findings into the databases, and a variety of support people to handle the administrative functions involved in coordinating such a massive endeavor. All of this is in addition to the local physicians and nurses who care for patients enrolled in the trial. The price tag for this enterprise quickly becomes substantial, running into hundreds of millions of dollars. As a result, no one should be surprised that drug companies want to recover their costs as expeditiously as possible.

Stories of unethical behavior on the part of the pharmaceutical companies running clinical trials are relatively rare, but they do surface. Researchers involved in trials have sometimes complained that sponsoring drug companies restrict what they can report to their colleagues and the general public if a treatment appears not to work. One alternative to having the pharmaceutical industry finance so many studies is to have the NIH sponsor all clinical trials. Such an arrangement—which does happen on occasion even now—dramatically reduces the profit motive of the people conducting the trial and usually assures that the resulting studies will be of the highest quality.

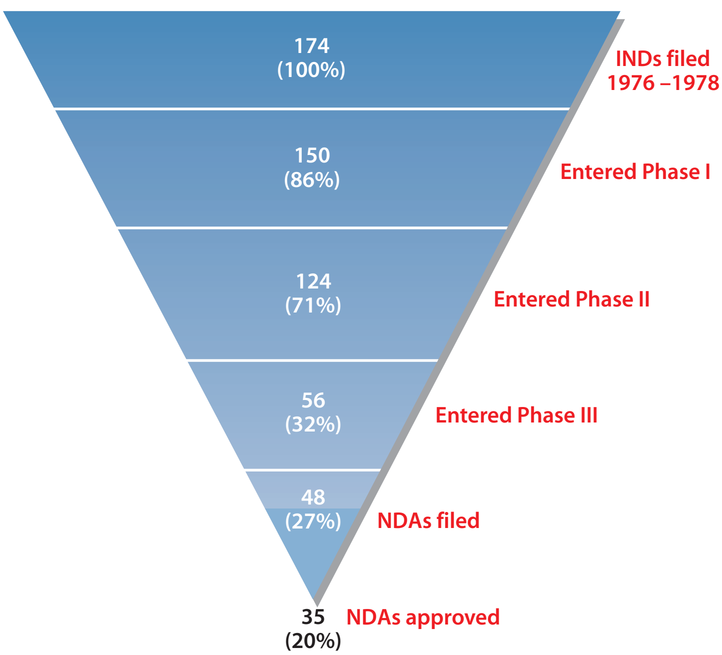
But devoting tax dollars to research into new drugs, many of which will eventually result in large profits for pharmaceutical companies, is troubling. In the past, government support has been reserved for the trials of drugs that are unlikely to result in substantial profits or for highly speculative studies that are too risky for industry to attempt. For example, the NIH sponsored the trials indicating that aspirin reduced the occurrence of strokes in patients who had already suffered one. Although the number of patients who benefit from this finding is quite extensive, aspirin is so inexpensive that none of the manufacturers was willing to sponsor the studies, because the subsequent profits would not justify the costs.

A third approach to conducting trials has been tried in recent years: turning them over to a contract research organization, or CRO. These companies operate independently from pharmaceutical companies and are hired specifically for conducting clinical trials. The CROs generally do nothing but manage trials and often have the capacity to test various drugs in many countries simultaneously. Theoretically, then, CROs should be more efficient, and by relying on them drug companies ought to be able to reduce the costs of conducting large studies at numerous hospitals. Also, if a drug development program fails, the companies do not have to fire or transfer the sizable number of people needed to conduct the research.

Because CROs do not profit from the sale of pharmaceuticals, they should be less subject to conflicts of interest than the drugmakers are. They benefit financially only from the sale of their services. Presumably, then, companies will hire a CRO only if it conducts trustworthy trials that stand up to FDA scrutiny.

In an attempt to minimize potential problems over financial conflicts, most medical societies and major journals now require from researchers a disclosure statement that describes how the work discussed was financed, along with any other details relevant to conflicts of interest. The U.S. government requires a similar declaration from investigators who participate in government-sponsored trials or from consultants involved in grant or regulatory decisions at organizations such as the NIH or FDA. Some people even argue that researchers who own stock in a drug company that supports their research should sell it. These considerations are relatively recent, and it is not at all clear yet what—if any—effect they have.

For the near future, the basic framework of clinical trials is here to stay, although efforts are under way to fine-tune the process. But the extent to which it can be refined has limits. I like to say that we can describe the conduct of a trial three ways: it can be trustwor-



HEIDI NOLAND; SOURCE: "SUCCESS RATES FOR NEW DRUGS ENTERING CLINICAL TESTING IN THE UNITED STATES," J. A. DIMASI IN *Clinical Pharmacology and Therapeutics*; JULY 1995

DIMINISHING RETURNS are the norm in the clinical trial process. Only about 20 percent of Investigational New Drug, or IND, applications filed with the FDA make it to the final step, many years and many tests later: approval of a New Drug Application (NDA), which clears a treatment for marketing to the public.

PHASE 3: The Final Test

Number of volunteers: 300–30,000 or more patients with the disease being studied

What researchers hope to learn: Whether treatment is effective and what the important side effects are

Typical length: 3.5 years

Typical cost: $45 million

The final stage of the clinical trial process, phase III, is most familiar to the general public. Hundreds, thousands, even tens of thousands of patients take part in such tests, and results often receive much publicity. By this point, the scientists running the trial have defined at least one group of patients who are expected to benefit, how they benefit and the best way to administer treatment. The phase III trial can provide authoritative confirmation that a drug works.

If, after careful statistical analysis, the drug candidate proves to be significantly more effective than the control treatment, the trial is called pivotal. Ordinarily two pivotal trials are needed to prove the value of a new therapy to regulatory agencies such as the U.S. Food and Drug Administration or the European Agency for the Evaluation of Medicinal Products. But if the first result is sufficiently persuasive, one trial can be enough. If an agency is convinced, it approves the drug for sale as a treatment for the disease.

If the results of phase III testing are not positive, several options remain. By poring over the tremendous amounts of collected data, clinicians might be able to discover a cluster of patients within the larger group who seem to have benefited. Researchers must then conduct another full-scale phase III trial, this time with a more restricted set of patients, to prove whether the drug actually did help. In practice, initial phase III trials frequently fail to show adequate proof of a drug candidate's efficacy, and several follow-up trials must be carried out. —*J.A.Z.*

UNIVERSITY OF VERMONT/AP PHOTO

HOPING FOR GOOD RESULTS, doctor and patient in this phase III trial of laser therapy for Barrett's esophagus disease await an answer to the crucial question: Does the treatment work?

thy, fast or cheap. Generally speaking, a trial can have only two of these characteristics. If a trial is fast and cheap, it is unlikely to be trustworthy.

No drug will ever be perfect, a complete cure for everyone with no side effects for anyone. The clinical trial remains a crucial proving ground for any new drug or medical device. A good way to evaluate the reliability of trials is to compare them to matters requiring medical judgment. How often is unnecessary surgery performed? How often are false bills sent to insurance companies or Medicare? Going one step further, how well tested are other items that consumers purchase and how accurate are advertising claims? The validity of medical claims is far better substantiated than in almost any other area of commerce.

The vast majority of the medical profession accepts randomized, controlled clinical trials as the required gold standard for deciding whether a treatment is useful. The methodology is still evolving, and some of the newer approaches to testing should prove to be of help. With increasing cooperation among investigators and regulatory agencies around the world, we can expect even better treatments and continued elimination of older medications and procedures that do not work. A long, dismal history tells of charlatans who make unfounded promises and take advantage of people at the time when they are least able to care for themselves. The clinical trial process is the most objective method ever devised to assess the efficacy of a treatment. It is expensive and slow, and in need of constant refinements and oversight, but the process is trustworthy. SA

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Further Information

GUIDE TO CLINICAL TRIALS. Bert Spilker. Raven Press, New York, 1991.

TISSUE PLASMINOGEN ACTIVATOR FOR ACUTE ISCHEMIC STROKE. National Institute of Neurological Disorders and Stroke rt-PA Stroke Study Group in *New England Journal of Medicine*, Vol. 333, No. 24, pages 1581–1587; December 14, 1995.

INTERNATIONAL STROKE TRIAL (IST): A RANDOMIZED TRIAL OF ASPIRIN, SUBCUTANEOUS HEPARIN, BOTH, OR NEITHER AMONG 19,435 PATIENTS WITH ACUTE ISCHEMIC STROKE. International Stroke Trial Collaborative Group in *Lancet*, Vol. 349, No. 9065, pages 1569–1581; May 31, 1997.

OVERSIGHT MECHANISMS FOR CLINICAL RESEARCH. Ralph Snyderman and Edward W. Holmes in *Science*, Vol. 287, No. 5453, pages 595–597; January 28, 2000.

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THE DISCOVERY OF BROWN DWARFS

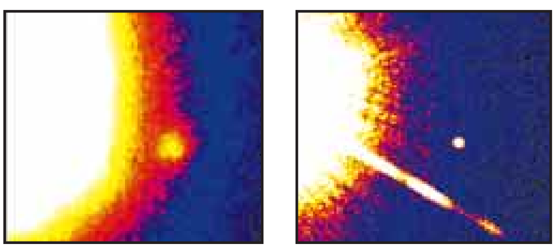
Less massive than stars but more massive than planets, brown dwarfs were long assumed to be rare. New sky surveys, however, show that the objects may be as common as stars

by Gibor Basri

A brown dwarf is a failed star. A star shines because of the thermonuclear reactions in its core, which release enormous amounts of energy by fusing hydrogen into helium. For the fusion reactions to occur, though, the temperature in the star's core must reach at least three million kelvins. And because core temperature rises with gravitational pressure, the star must have a minimum mass: about 75 times the mass of the planet Jupiter, or about 7 percent of the mass of our sun. A brown dwarf just misses that mark—it is heavier than a gas-giant planet but not quite massive enough to be a star.

For decades, brown dwarfs were the "missing link" of celestial bodies: thought to exist but never observed. In 1963 University of Virginia astronomer Shiv Kumar theorized that the same process of gravitational contraction that creates stars from vast clouds of gas and dust would also frequently produce smaller objects. These hypothesized bodies were called black stars or infrared stars before the name "brown dwarf" was suggested in 1975 by astrophysicist Jill C. Tarter, now director of research at the SETI Institute in Mountain View, Calif. The name is a bit misleading; a brown dwarf actually appears red, not brown. But the name "red dwarf" was already taken. (It is used to describe stars with less than half the sun's mass.)

In the mid-1980s astronomers began an intensive search for brown dwarfs, but their early efforts were unsuccessful. It was not until 1995 that they found the first indisputable evidence of their existence. That discovery opened the floodgates; since then, researchers have detected dozens of the objects. Now observers and theorists are tackling a host of intriguing questions: How many brown dwarfs are there? What is their range of masses? Is there a continuum of objects all the way down to the mass of Jupiter? And did they all originate in the same way?

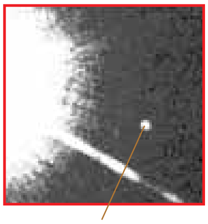


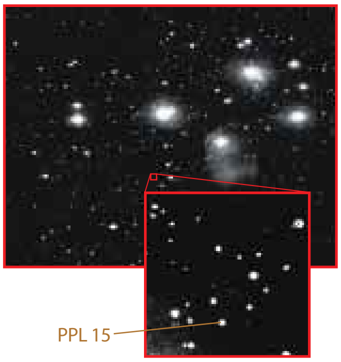
BROWN DWARF GLIESE 229B gives off a red glow in this artist's conception (*opposite page*). The object is believed to be slightly smaller than Jupiter but about 10 times hotter and 30 to 40 times more massive. It was discovered in 1995 as a companion to the red dwarf star Gl 229A (*shown in background*). Astronomers detected the brown dwarf in images from the Palomar Observatory's 1.5-meter telescope (*left inset*) and from the Hubble Space Telescope (*right inset*) that show the object as a faint spot next to the red dwarf. Gl 229B is actually more than six billion kilometers from its companion star—farther than Pluto is from our sun.

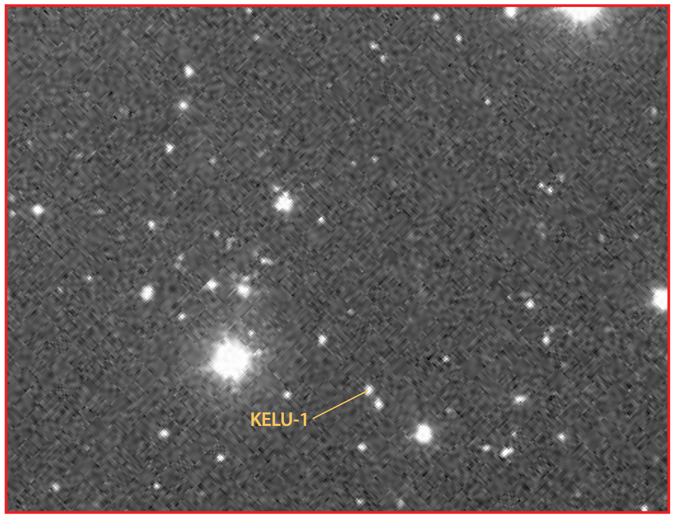
PAT RAWLINGS (*opposite page*); T. NAKAJIMA *California Institute of Technology* AND S. DURRANCE *Johns Hopkins University* (*left*); S. KULKARNI *Caltech*, D. GOLIMOWSKI *Johns Hopkins University* AND NASA (*right*)

Finding Brown Dwarfs

Search Methods







OBSERVING FAINT OBJECTS such as brown dwarfs requires special strategies. One approach is to focus telescopes on areas near known stars and to look for companions; astronomers used this method to find Gl 229B (*above left*). Another strategy is to concentrate on young star clusters, because brown dwarfs are brightest when they are young. Scientists searched the 120-million-year-old Pleiades cluster (*above center*) to find the brown dwarf PPl 15 (*center inset*) as well as many others. Last, astronomers can find "field" brown dwarfs by imaging large sections of sky with instruments that are sensitive to faint, red sources. The discovery of the first field brown dwarf, Kelu-1 (*above right*), was announced in 1997.

T. NAKAJIMA *California Institute of Technology* AND S. DURRANCE *Johns Hopkins University (left)*; SPACE TELESCOPE SCIENCE INSTITUTE *(top, center)*; JOHN STAUFFER *Harvard-Smithsonian Center for Astrophysics (bottom, center)*; EUROPEAN SOUTHERN OBSERVATORY *(right)*

The search for brown dwarfs was long and difficult because they are so faint. All astrophysical objects—including stars, planets and brown dwarfs—emit light during their formation because of the energy released by gravitational contraction. In a star, the glow caused by contraction is eventually supplanted by the thermonuclear radiation from hydrogen fusion; once it begins, the star's size and luminosity stay constant, in most cases for billions of years. A brown dwarf, however, cannot sustain hydrogen fusion, and its light steadily fades as it shrinks [*see box on page 81*]. The light from brown dwarfs is primarily in the near-infrared part of the spectrum. Because brown dwarfs are faint from the start and dim with time, some scientists speculated that they were an important constituent of "dark matter," the mysterious invisible mass that greatly outweighs the luminous mass in the universe.

Astronomers assumed that a good place to look for very faint objects would be close to known stars. More than half the stars in our galaxy are in binary pairs—two stars orbiting their common center of gravity—and researchers suspected that many stars that seemed to be alone might actually have a brown dwarf as a companion. One advantage of such a search is that astronomers do not have to survey large sections of sky for brown dwarfs—they can focus their telescopes on small areas near known stars.

The strategy looked good early on. In 1984 researchers at the University of Arizona's Steward Observatory announced the discovery of a faint binary companion to VB8, a low-mass star 21 light-years from the sun. The object seemed to have the right properties to be a brown dwarf, but unfortunately no one was able to confirm its presence. (It turned out to be an observational glitch rather than a real object.) The next likely candidate appeared in 1988, when Eric Becklin and Benjamin Zuckerman of the University of California at Los Angeles reported the discovery of GD 165B, a faint red companion to a white dwarf. White dwarfs are unrelated to brown dwarfs: they are the corpses of moderately massive stars and are smaller, hotter and much heavier than brown dwarfs. GD 165B may indeed be a brown dwarf, but astronomers have been unable to say for certain because the object's inferred mass is close to the 75-Jupiter-mass boundary between low-mass stars and brown dwarfs.

Another advantage of looking for brown dwarfs as companions to stars is that you don't necessarily have to observe the brown dwarf itself. Researchers can detect them with the same method used to find extrasolar planets: by observing their periodic effects on the motions of the stars they are circling. Astronomers determine the variations in the stars' velocities by measuring the Doppler shifts in the stars' spectral lines. It is actually easier to detect brown dwarfs than planets by this technique because of their greater mass.

Nevertheless, famed planet hunter Geoffrey W. Marcy of San Francisco State University and the University of California at Berkeley found no brown dwarfs in a survey of 70 low-mass stars conducted in the late 1980s. In the mid-1990s Marcy discovered half a dozen extrasolar gas-giant planets in a survey of 107 stars similar to our sun but still saw no clear-cut evidence of brown dwarfs. The failure of these efforts gave rise to the term "brown dwarf desert" because the objects appeared to be much less common than giant planets or stars.

Only one of the early Doppler-shift searches detected a brown dwarf candidate. In a 1988 survey of 1,000 stars, David W. Latham of the Harvard-Smithsonian Center for Astrophysics found a stellar companion at least 11 times as massive as Jupiter. The Doppler-shift method, though, provides only a lower limit on a companion's mass, so Latham's object could be a very low mass star instead of a brown dwarf. This issue will remain unresolved until scientists can determine stellar positions more precisely.

Meanwhile other astronomers pursued a different strategy that took advantage of the fact that brown dwarfs are brightest when they are young. The best place to look for young objects is in star clusters. The stars in a cluster all form at the same time but have very different lifetimes. The most massive stars shine for only a few million years before running out of hydrogen fuel and leaving the main-sequence phase of their lifetimes, whereas low-mass stars can keep shining for billions, even trillions, of years. The standard method for estimating the age of a cluster amounts to finding its most massive main-sequence star. The age of the cluster is roughly the lifetime of that star.

Once researchers locate a young cluster and determine its age, they need only look for the faintest, reddest (and therefore coolest) objects in the cluster to identify the brown dwarf candidates. Theory provides the expected surface temperature and luminosity of objects of various masses for a given age, so by measuring these properties astronomers can estimate each candidate's mass. Several teams began the search, imaging the areas of sky containing young clusters and picking out faint red objects.

The research teams made a series of announcements of brown dwarf candidates in young clusters, including the star-forming region in the Taurus constellation and the bright cluster called the Pleiades (better known as the Seven Sisters). Unfortunately, closer scrutiny showed that none of the candidates was really a brown dwarf. Some turned out to be red giant stars located thousands of light-years behind the cluster; because these background stars are so distant, they appear faint even though they are quite luminous. Others were low-mass stars behind or in front of the cluster. Some of the "discoveries" made it into the press, but the later retractions were not given much play. This led to further skepticism among astronomers toward all brown dwarf announcements and reinforced the widespread view that the objects were rare.

Looking for Lithium

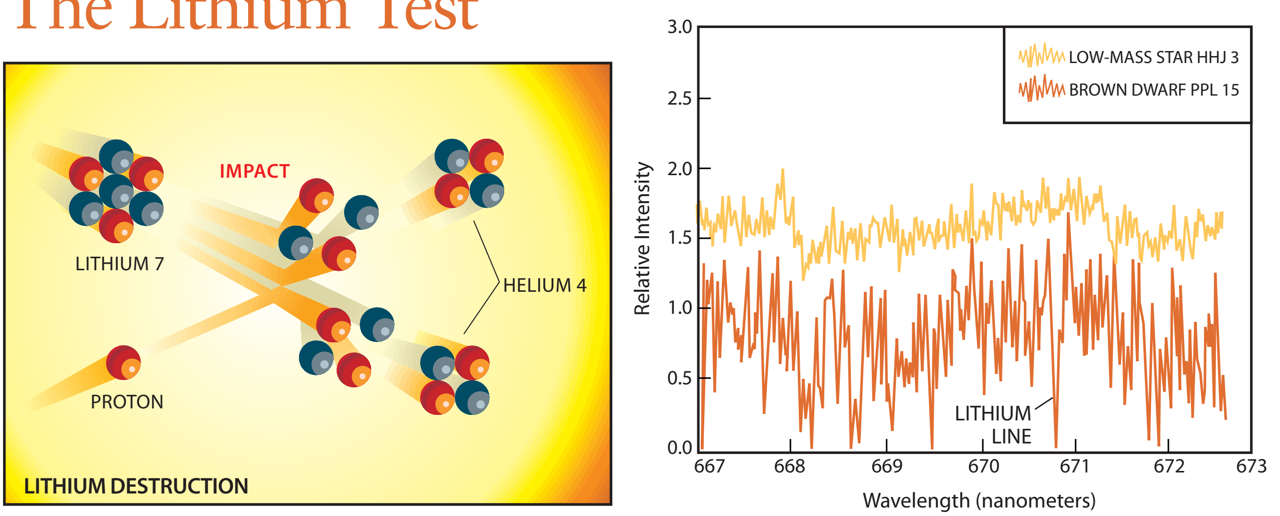
In 1992 Rafael Rebolo, Eduardo L. Martín and Antonio Magazzu of the Astrophysics Institute in Spain's Canary Islands proposed a clever new method to help distinguish low-mass stars from brown dwarfs. Called the lithium test, it exploits the fact that below a mass of about 60 Jupiter-masses, a brown dwarf never achieves the conditions necessary to sustain lithium fusion in its core. This nuclear reaction occurs at a slightly lower temperature than hydrogen fusion does; as a result, stars quickly consume whatever lithium they originally had. Even the lowest-mass star burns all its lithium in about 100 million years, whereas all but the most massive brown dwarfs retain their lithium forever. Thus, the continued presence of lithium is a sign that the object has a substellar mass.

The spectral lines produced by lithium are fairly strong in cool red objects. The Canary Islands group looked for these lines in all the coolest objects in the sky that are also bright enough to provide a spectrum of the needed quality. None showed evidence of lithium. In 1993 another team—consisting of myself, Marcy and James R. Graham of Berkeley—began to apply the lithium test to fainter objects using the newly built 10-meter Keck telescope on Mauna Kea in Hawaii. We, too, met with failure at first, but our luck changed when we focused on the Pleiades cluster.

A group of British astronomers had just conducted one of the broadest, deepest surveys of the cluster. They found several objects that by all rights should have had substellar masses. They showed that these objects shared the proper motion of the cluster across the sky and thus

Confirming the Discoveries

The Lithium Test

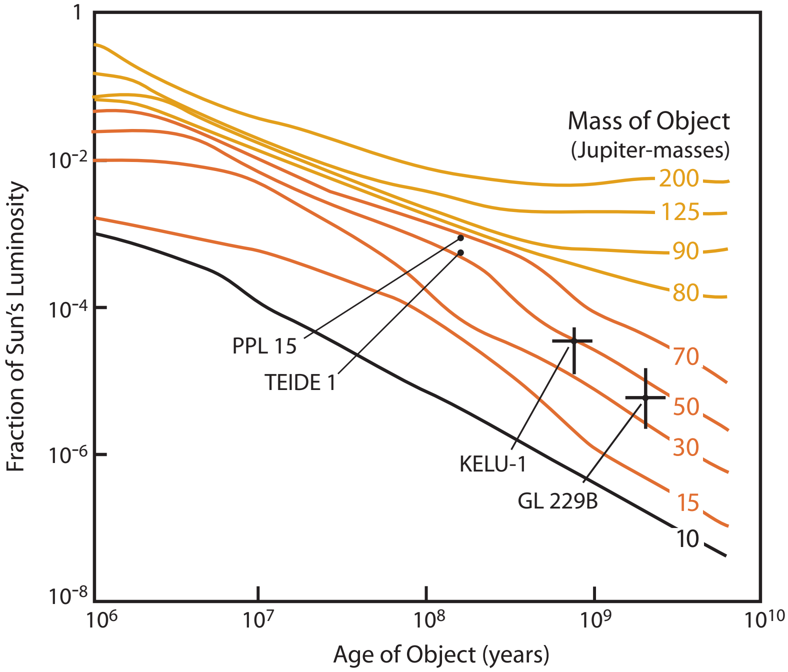


ANALYZING THE SPECTRA of faint objects can reveal whether they are stars or brown dwarfs. All stars destroy the lithium in their cores; in this reaction, a proton collides with the isotope lithium 7, which then splits into two helium atoms (*left*). In contrast, all but the most massive brown dwarfs cannot achieve the core temperature needed for lithium destruction, so they retain the element forever. The spectrum of HHJ 3 (*right, yellow line*), a low-mass star in the Pleiades cluster, shows no sign of lithium. The spectrum of brown dwarf PPl 15 (*red line*), however, has a strong absorption line indicating the presence of the element.

BRYAN CHRISTIE (*left*); LAURIE GRACE (*right*)

Comparing Stars, Brown Dwarfs and Planets

Dimming with Time



LUMINOSITY HISTORY of low-mass stars (*yellow lines*), brown dwarfs (*red lines*) and planets (*black line*) shows that only stars are massive enough to achieve a stable luminosity. The light from brown dwarfs and planets fades as they age. Data from brown dwarfs (*black crosses*) indicate how old and heavy they are.

LAURIE GRACE

had to be members of the cluster rather than background stars. We went right to the faintest one, an object called HHJ 3, expecting to find lithium. It was not present. But Smithsonian astronomer John Stauffer supplied us with another target. He, too, had been surveying the Pleiades for low-mass objects and had detected an even fainter candidate, dubbed PPl 15 (the 15th good candidate in the Palomar Pleiades survey). At last, we were successful: for the first time we detected lithium in an object for which its presence implied a substellar mass. We reported the discovery at the June 1995 meeting of the American Astronomical Society. Our results indicated that the cluster was about 120 million years old, giving PPl 15 an inferred mass at the upper end of the brown dwarf range.

In one of the interesting convergences that seem to occur regularly in science, other research teams also reported strong evidence of brown dwarfs in 1995. The Canary Islands group had also been conducting a deep survey of the Pleiades cluster and had detected two objects even fainter than PPl 15: Teide 1 and Calar 3, both named after Spanish observatories. Each had an inferred mass just below 60 Jupiter-masses. By the end of the year I had teamed up with the Canary Islands group, and we confirmed the expected presence of lithium in both objects. The astronomical community retained some skepticism about these objects for the first few months—after all, they still looked like stars—until further discoveries made it clear that now the brown dwarfs were for real.

At the same time, a very different search bore spectacular fruit. A group of astronomers from the California Institute of Technology and Johns Hopkins University had been looking for brown dwarf companions of nearby low-mass stars. They had equipped the Palomar 1.5-meter telescope with an instrument that blocked most of the light of the primary star, allowing a faint nearby companion to be more easily seen. In 1993 they observed several brown dwarf candidates. To ensure that these objects were not background stars, they waited a year, then took second images. Because the targets are relatively close to our solar system, their movements through the galaxy are perceptible against the background stars. If a candidate is truly a companion, it will share this motion. One of the companions confirmed was 1,000 times fainter than its primary, the low-mass star Gliese 229A. Because the primary was already known to be faint, the companion's luminosity had to be well below that of the faintest possible star. The group kept quiet until they obtained an infrared spectrum of the object.

At a meeting of the Cambridge Workshop on Cool Stars, Stellar Systems and the Sun in October 1995, the Caltech/Johns Hopkins group announced the discovery of Gl 229B, the brown dwarf companion to Gl 229A. It was clearly substellar by virtue of its faintness, and the clincher was the detection of methane in its spectrum. Methane is common in the atmospheres of the giant planets, but all stars are too hot to allow it to form. Its strong presence in Gl 229B guaranteed that this object could not be a star. At the same meeting the Canary Islands group reported the observation of several new brown dwarf candidates in the Pleiades cluster, suggesting that these objects might be fairly numerous. In addition, a group led by Michel Mayor of the Geneva Observatory in Switzerland announced the discovery of the first extrasolar planet, a gas giant circling the star 51 Pegasi. In one morning, the frustrating search for substellar objects came to a dramatic conclusion.

Most astronomers view Gl 229B as the first indisputable brown dwarf discovered because it is a million times fainter than the sun and has a surface temperature under 1,000 kelvins—far below the minimum temperature that even the faintest star would generate (around 1,800 kelvins). It has reached this state because it is a few billion years old. We do not know its precise age, which leads to some uncertainty about its mass, but it is probably 30 to 40 times more massive than Jupiter. In contrast, PPl 15, Teide 1 and Calar 3 in the Pleiades are more massive (from 50 to 70 Jupiter-masses) and also much hotter (with surface temperatures between 2,600 and 2,800 kelvins), primarily because they are much younger.

Once the methods for detecting brown dwarfs had been proved, the discoveries came at an increasing pace. Several groups returned to the Pleiades. The Canary Islands group, now including Maria Rosa Zapatero Osorio of the Astrophysics Institute, discovered a Pleiades

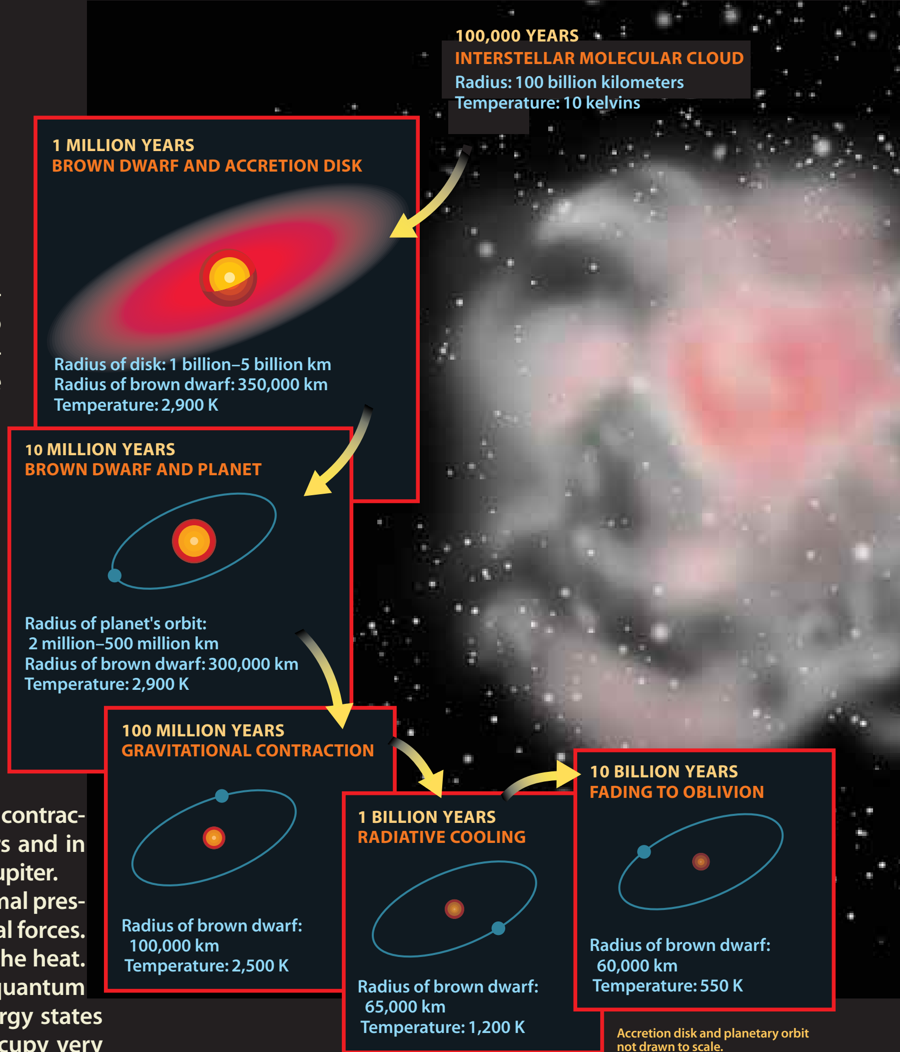
The Life Cycle of Brown Dwarfs

The early lives of brown dwarfs and stars follow the same pattern. Both are believed to originate from the gravitational collapse of interstellar clouds of gas and dust. These clouds are composed primarily of hydrogen and helium, but they also initially contain small amounts of deuterium and lithium that are remnants of the nuclear reactions that took place a few minutes after the big bang.

As young stars and brown dwarfs contract, their cores grow hotter and denser, and the deuterium nuclei fuse into helium 3 nuclei. (Deuterium fusion can occur in brown dwarfs because it requires a lower temperature—and hence a lower mass—than hydrogen fusion.) The outpouring of energy from these reactions temporarily halts the gravitational contraction and causes the objects to brighten. But after a few million years the deuterium runs out, and the contraction resumes. Lithium fusion occurs next in stars and in brown dwarfs more than 60 times as massive as Jupiter.

During the contraction of a brown dwarf, thermal pressure rises in its core and opposes the gravitational forces. All the electrons are freed from their nuclei by the heat. Because no two electrons can occupy the same quantum state, when the core is very dense the low-energy states are filled, and many electrons are forced to occupy very high energy states. This generates a form of pressure that is insensitive to temperature. Objects supported in this manner are called degenerate. One consequence of this process is that all brown dwarfs are roughly the size of Jupiter—the heavier brown dwarfs are simply denser than the lighter ones.

In stars the cores do not become degenerate. Instead hydrogen fusion provides the pressure that supports the star against its own gravity. Once fusion begins in earnest, the star stops contracting and achieves a steady size, luminosity and temperature. In high-mass brown dwarfs, hydrogen fusion begins but then sputters out. As degeneracy pressure slows the collapse of brown dwarfs, their luminosity from gravitational contraction declines. Although very low mass stars can shine for trillions of years, brown dwarfs fade steadily toward oblivion. This makes them increasingly difficult to find as they age. In the very distant future, when all stars have burned out, brown dwarfs will be the primary repository of hydrogen in the universe. *—G.B.*

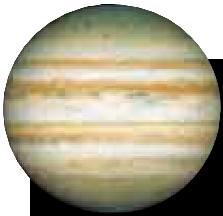


BROWN DWARF IS BORN from the contraction of a vast cloud of gas and dust. After a million years the object is a glowing ball of gas, possibly surrounded by an accretion disk from which an orbiting planet could later arise. (So far no planets have been detected around brown dwarfs; their existence and possible orbits are strictly hypothetical.) Over time the brown dwarf shrinks and cools. The radii and surface temperatures shown here are for an object of 40 Jupiter-masses.

BRYAN CHRISTIE

brown dwarf only 35 times more massive than Jupiter—the lightest brown dwarf found in the cluster. More important, the Canary Islands group conducted the first useful assessment of the number of brown dwarfs in the Pleiades by counting the most likely candidates in a small surveyed area and then extrapolating the tally for the entire cluster. Their results indicated comparable numbers of stars and brown dwarfs in the Pleiades. If true in general, this would mean that our galaxy alone contains about 100 billion brown dwarfs. But it also means that brown dwarfs are not the dominant constituent of the universe's mass, because they are much lighter than stars. The hope that they would help provide an answer to the dark matter mystery has faded.

Other researchers focused on how the brown dwarfs are distributed by mass. What is the lowest mass a brown dwarf can attain? Is there a continuum of objects down to the planetary range—below 13 Jupiter-masses—or is there a gap between the lightest brown dwarf and the heaviest planet because they are formed by different mechanisms? The best place to answer these questions is in newly forming star clusters, where even very low mass brown dwarfs are still bright enough to see. Surveys of the Taurus region by a group of Japanese astronomers and of the Orion region by the Canary Islands/Berkeley group revealed objects that seem to have masses just above the 13-Jupiter-mass boundary. Thus, it appears that brown

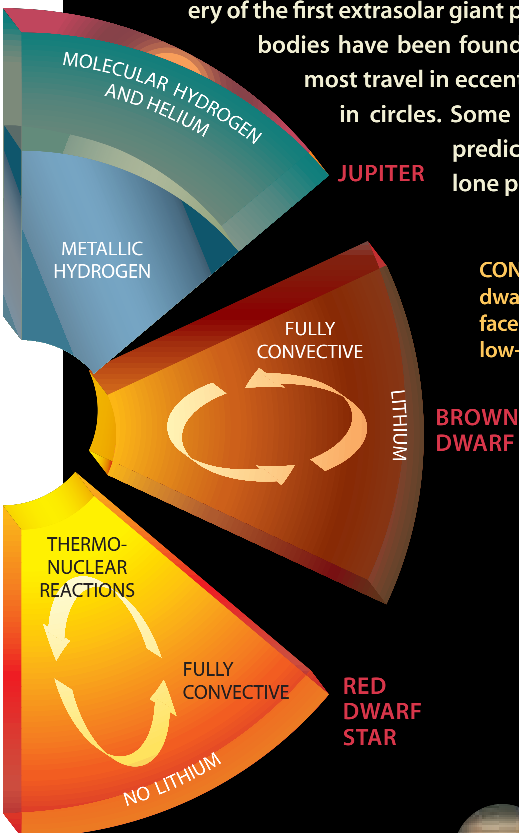


Planets versus Brown Dwarfs

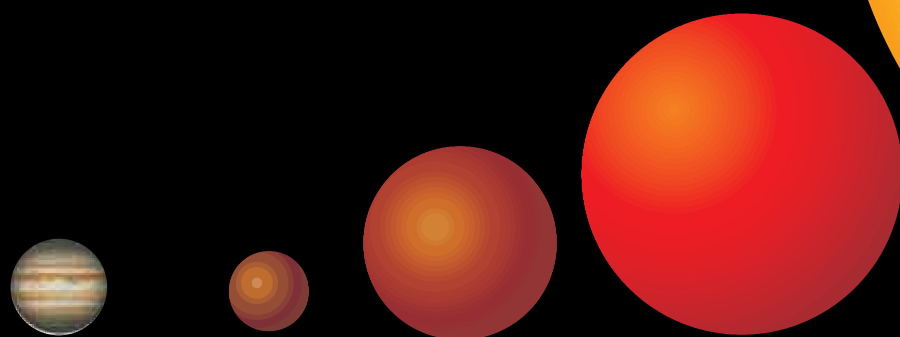
Is there a fundamental difference between the largest planets and the smallest brown dwarfs? The classical view is that planets form in a different way than brown dwarfs or stars do. Gas-giant planets are thought to build up from planetesimals—small rocky or icy bodies—amid a disk of gas and dust surrounding a star. Within a few million years these solid cores attract huge envelopes of gas. This model is based on our own solar system and predicts that all planets should be found in circular orbits around stars and that gas-giant planets should travel in relatively distant orbits.

These expectations have been shattered by the discovery of the first extrasolar giant planets. Most of these bodies have been found in close orbits, and most travel in eccentric ovals rather than in circles. Some theorists have even predicted the existence of lone planets, thrown out of their stellar systems by orbital interactions with sibling planets. This makes it very hard for observers to distinguish planets from brown dwarfs on the basis of how or where they formed or what their current location and motion is. We can find brown dwarfs by themselves or as orbital companions to stars or even other brown dwarfs. The same may be true for giant planets.

An alternative view is gaining adherents: to distinguish between planets and brown dwarfs based on whether the object has ever managed to produce any nuclear fusion reactions. In this view, the dividing line is set at about 13 Jupiter-masses. Above that mass, deuterium fusion occurs in the object. The fact that brown dwarfs seem to be less common than planets—at least as companions to more massive stars—suggests that the two types of objects may form by different mechanisms. A mass-based distinction, however, is much easier to observe. —*G.B.*



CONTINUUM OF OBJECTS from planets to stars (*below*) shows that older brown dwarfs, such as Gliese 229B, are fairly similar to gas-giant planets in size and surface temperature. Younger brown dwarfs, such as Teide 1, more closely resemble low-mass stars, such as Gliese 229A. Brown dwarfs and low-mass stars are fully convective, meaning that they mix their contents (*left*). Thermonuclear reactions in the stars' cores destroy all their lithium, so its presence is a sign that the object may be a brown dwarf.



NAME	JUPITER	GLIESE 229B	TEIDE 1	GLIESE 229A	SUN
TYPE OF OBJECT	Gas-Giant Planet	Brown Dwarf	Brown Dwarf	Red Dwarf Star	Yellow Dwarf Star
MASS (Jupiter-masses)	1	30–40	55	300	1,000
RADIUS (kilometers)	71,500	65,000	150,000	250,000	696,000
TEMPERATURE (kelvins)	100	1,000	2,600	3,400	5,800
AGE (years)	4.5 billion	2–4 billion	120 million	2–4 billion	4.5 billion
HYDROGEN FUSION	No	No	No	Yes	Yes
DEUTERIUM FUSION	No	Yes	Yes	Yes	Yes

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dwarfs are produced in all possible masses between planets and stars [*see box on opposite page*].

In 1997 the group led by Mayor reported the detection of about 10 brown dwarf candidates in their Doppler-shift search for substellar companions around 600 stars similar to our sun. The idea of the brown dwarf desert remained, however, because the success rate for finding brown dwarf companions was lower than that for extrasolar planets—and brown dwarfs are much easier to find using the Doppler-shift method. More recently, careful analysis of results from the Hipparcos satellite (which made precise measurements of star positions) showed that at least half of Mayor's brown dwarf candidates are actually low-mass stars. This rendered the desert even emptier. Marcy's continuing study of a larger sample of solar-type stars confirms the paucity of brown dwarf companions to such stars.

Brown dwarfs may be more common, though, as companions to lower-mass stars. In 1998 Rebolo and his collaborators discovered one orbiting the young star G196-3. Despite its youth, this brown dwarf is already quite cool, which means it must be light, perhaps only 20 Jupiter-masses. Several brown dwarf companions have also been detected around newly forming stars. And now the first binary systems involving two brown dwarfs have been identified. Working with Martín, I determined that the Pleiades brown dwarf PPl 15 is really a close pair of brown dwarfs, with an orbital period of six days! Together with German astronomer Wolfgang Brandner, we also recently imaged a close pair of nearby brown dwarfs that should yield within a decade the first dynamical confirmation of brown dwarf masses.

These observations suggest that the brown dwarf desert is only a lack of brown dwarfs as companions to more massive stars. When looking near low-mass objects (either stars or brown dwarfs), the likelihood of finding a brown dwarf companion is much greater. This variance probably results from the process that gives birth to binary systems, which is still poorly understood. Apparently this process is less likely to produce a system in which the primary object is more than about 10 times the mass of the secondary.

Brown Dwarfs Everywhere

Astronomers found still more brown dwarfs using another search technique: looking for them at random locations in the sky. These "field" brown dwarfs are easily lost among the myriad stars of our galaxy. To locate such objects efficiently, one must image large sections of sky with great sensitivity to faint red sources. The first field brown dwarf was announced by Maria Teresa Ruiz of the University of Chile in 1997. She dubbed it "Kelu-1" from a South American Indian word for "red" and noted that it shows lithium. At about the same time, the Deep Near-Infrared Survey (DENIS)—a European project that is scanning the southern hemisphere of the sky—found three similar objects. Researchers quickly confirmed that one contains lithium.

Continuing study of these objects has yielded clues to the composition of brown dwarf atmospheres. Their optical spectra lack the molecules of titanium oxide and vanadium oxide that dominate the spectra of many low-mass stars. These molecules do not appear in brown dwarf atmospheres, because their constituent heavy elements condense into hard-to-melt dust grains. Instead the primary optical spectral lines are from neutral alkali metals such as sodium, potassium, rubidium, cesium and sometimes lithium.

The Two Micron All-Sky Survey (2MASS) managed by the University of Massachusetts has detected even more field brown dwarfs, finding close to 100 extremely cool objects and confirming lithium in nearly 20. Most of these field objects have surface temperatures between 1,600 and 2,200 kelvins and so must be younger than about a billion years. Because of their youth, they are relatively bright and thus easier to observe than older objects.

The hunt for older field brown dwarfs was frustrated until the summer of 1999, when the Sloan Digital Sky Survey turned up two brown dwarfs containing methane in their atmospheres. The presence of methane indicates a surface temperature below 1,300 kelvins and hence an age greater than one to two billion years. At the same time, the 2MASS group reported the observation of four similar objects. The majority of brown dwarfs in our galaxy should be methane-bearing, because most formed long ago and should have cooled to that state by now. Thus, these discoveries are just the tip of the iceberg. Indeed, the 2MASS and DENIS teams have found that the number of field brown dwarfs in the surveyed areas is similar to the number of low-mass stars in those areas. Their results are consistent with the earlier findings for the Pleiades cluster: brown dwarfs seem to be nearly as common as stars.

The initial discovery phase for brown dwarfs is now almost over. Astronomers have good methods for detecting them and many targets for detailed study. Over the next few years scientists will get a better handle on the basic facts about brown dwarfs: their numbers, masses and distribution in our galaxy. Researchers will also try to determine how they form as stellar companions or solo objects and what processes take place as their atmospheres cool. It is remarkable that these objects, as abundant as stars, have only now begun to reveal their secrets. SA

The Author

GIBOR BASRI is a professor in the astronomy department at the University of California, Berkeley. He received his Ph.D. in astrophysics from the University of Colorado at Boulder in 1979. He has studied solar-type stars, low-mass stars and star formation using a variety of telescopes, including the Lick and Keck observatories, as well as space-borne instruments, including the Hubble Space Telescope. He is keen on promoting an interest in science among groups currently underrepresented in the field.

Further Information

Brown Dwarfs: A Possible Missing Link between Stars and Planets. S. R. Kulkarni in *Science*, Vol. 276, pages 1350–1354; May 30, 1997.

Planet Quest: The Epic Discovery of Alien Solar Systems. Ken Croswell. Free Press, 1997.

Brown Dwarfs and Extrasolar Planets. Edited by R. Rebolo, E. L. Martín and M. R. Zapatero Osorio. Astronomical Society of the Pacific Conference Series, Vol. 134, 1998.

More on brown dwarfs is available at astron.berkeley.edu/~basri/bdwarfs/ on the World Wide Web.

The Aleutian Kayak

The Aleuts built the baidarka to suit their life as hunters on the open ocean. The sophisticated design of this kayak is still not entirely understood

by George B. Dyson

When Russians first reached the Aleutian Islands and the coast of Alaska in the 1700s, the waters were thick with small, swift, split-prowed boats to which the explorers gave the name "baidarka." Made of driftwood, lashed with baleen fiber and covered with translucent sea-mammal skin, these craft were entirely creatures of the sea. The Aleuts paddled the lightweight, flexible kayaks at great speeds in the treacherous waters of the area, hunting whale, otter, sea lions, seals and other marine creatures with hand-launched darts, spears and harpoons.

Over time, however, the design of the baidarka was altered to suit the newcomers' needs. Certain forms of the craft—including a narrow, open-jawed, high-speed version—ceased to exist. Because the tradition of building these kayaks was largely unrecorded, a host of unanswered questions have arisen for contemporary scholars, kayakers and Aleuts. Just how fast were early baidarkas? Why the forked bow and the oddly truncated stern? Did Aleutian hunters have an intuitive understanding of design principles that continue to elude engineers and mathematicians to this day?

Although few ancient baidarkas survive, 200-year-old sketches as well as journals, oral histories and artifacts have enabled versions of these craft to be constructed today.

ALEUT HUNTERS travel in baidarkas off the coast of Unalaska. This lithograph—made in 1827 by Friedrich H. von Kittlitz, who voyaged on board the Russian naval sloop *Seniavin*—depicts two hunters; one is steadying his kayak by holding his paddle in the water so that he can launch his spear using a throwing stick.

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GEORGE B. DYSON

UPPER-ARM BONE of an Aleut hunter (*bottom*) is larger and denser than that of a Russian male who did not kayak (*top*). This rugosity, as it is called, indicates that there were more muscle attachments on the Aleut humerus than there were on the Russian humerus. This great muscle mass is typical of Aleut hunters and explains the enormous strength, stamina and speed of the kayakers, some of whom were capable of paddling at eight or more knots for long distances.

That process has allowed me and other builders—including students in a few schools on the Aleutian Islands and on Kodiak Island—some insight into the interwoven form and function of the baidarka. Many aspects of its design remain mysterious, and we may never know exactly how certain features worked. Nevertheless, it has become clear that this kayak was ideally suited for the rough water and long distances the Aleuts traveled and that the baidarka incorporates some highly advanced approaches to minimizing drag and maximizing speed.

The Aleutian Islands extend in an arc for 1,500 miles between the Kamchatka Peninsula of the former Soviet Union and the Alaskan coast. They mark the junction of the warm Pacific Ocean and the cold Bering Sea—an encounter that gives rise to relentless fog as well as to storms that rage around the volcanic mountains and through the tide-swept passages between the islands. Despite the relatively mild climate, with an average temperature of 40 degrees Fahrenheit, and a latitude within the same range as the U.K.'s, the entire island chain remains above the tree line, barren because of the constant wind.

About 15,000 years ago, toward the end of the last Ice Age, the Aleutian Islands were bigger. Glaciers reduced the volume of seawater, exposing the island chain and the Bering Land Bridge to the north. Indeed, the Bering Strait of today was then a 1,000-mile-wide stretch of land. As the climate changed and the glaciers began to melt, ocean waters swept in, causing sea level to rise a total of about 300 feet—most quickly between 12,000 and 8,000 years ago.

Living Off the Sea

Although no one is entirely sure when the Aleuts arrived, the archaeological record suggests that they inhabited Anangula off Umnak Island in the Eastern Aleutians and Hog Island in Unalaska Bay at least 9,000 years ago [*see map on opposite page*]. Whether they originally came by foot across the Bering Land Bridge or were accomplished seafaring explorers and arrived by kayak or another form of skin boat is a question that may never be resolved. However—and whenever—they first arrived, the archaeological evidence on Anangula indicates that they were fully equipped to hunt sea mammals by 7000 B.C.

As William S. Laughlin, emeritus professor of anthropology at the University of Connecticut has put it, the physical and intellectual demands of hunting at sea led the Aleuts "to shuffle a whole lot faster through the evolutionary deck." The two signature Aleut technologies—semisubterranean

ALEUTIAN ISLANDS are rugged and windswept, a difficult terrain to thrive in. Yet the Aleuts adapted to their environment, building subterranean houses to avoid the raging wind, as seen in this watercolor of Unalaska painted by John Webber in 1778. The low-profile baidarkas were designed to minimize exposure to the wind gusting across the open water.

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ALEUTIAN CHAIN stretches from Alaska to Russia. The volcanic islands of this archipelago may first have been inhabited by seafaring settlers in skin-and-frame boats or by nomads walking across the Bering Land Bridge 15,000 years ago. During the last Ice Age, the Bering Strait was a stretch of land 1,000 miles wide.

houses and semisubmersible boats—were developed to deal with the incessant wind. The islands were far enough apart so that competing styles of kayak were able to coevolve. Yet they were not so far from one another that innovation and cross-fertilization were impeded, and design changes spread rapidly from one island to the next.

The Aleuts' technology was immediately recognized as superior by the Russian traders, who arrived in clumsy ill-equipped vessels from Kamchatka and Okhotsk. Calling all kayaks by a generic name, "baidarka," the Russians commandeered the available craft and established a monopoly on the construction of new ones—homogenizing the Aleuts' design, enlarging it and, in some cases, adding a third hatch that made the craft suitable for the unskilled. In so doing, they secured a near-monopoly on the hunting of sea otters, whose pelts were worth a fortune when traded with the Chinese. Under the auspices of the Russian-American Company, which consolidated the administration of the Alaskan colonies in 1799, fleets of as many as 700 baidarkas swept each year from the Aleutians and Kodiak Island into southeastern Alaskan coastal waters, surrounding and killing entire populations of sea otters.

With the annual catch reaching about 10,000 sea otters in the early 1800s, it was inevitable that the mammals would become nearly extinct. Although some conservation measures were belatedly introduced, they were lifted in 1867, when the U.S. purchased Alaska. Limited sea-otter hunting continued until 1911, when the American government prohibited the hunt. The best-known occupation of the Aleut baidarka had come to an end and, with it, the driving force behind its design. The Aleut people, however, continued to build and use baidarkas until their wholesale dislocation as a result of World War II, when they were moved to temporary camps in southeastern Alaska by the U.S. government or taken prisoner by the invading Japanese. Few baidarkas—and the skills to build new ones—remained intact when the Aleuts were eventually allowed to return home.

A decisive advantage of the baidarka to the Russians—and against the Russians, during initial hostilities—was its speed. According to the observations of European navigators—whose lives, after all, depended on accurate reckoning and record keeping—the baidarkas were capable of traveling against the swiftest currents of the region, which ran at about six and a half knots. (Traveling at the speed of one knot means traveling one nautical mile—or about 1,852 meters—in an hour. In contrast, a mile on land is 1,609 meters.)

"We found ourselves going thro' the water above 6 knots, yet … the Indians in their Seal skin Canoes kept way with us very easily," wrote James Trevenen, a midshipman on board the *Resolution,* one of Captain James Cook's vessels, as the expedition traveled through Unalga Pass in June 1778. Another observer noted in 1820 that a ship moving at seven and a half knots was easily outpaced by baidarkas—baidarkas loaded down with codfish. (Olympic-ranked kayakers today can travel up to nine knots but only for very short stretches and only in calm water.)

Speed and Stamina

It is important to note that we can never conclude whether these great speeds resulted from the design of the baidarka, Aleut knowledge of the local currents or simply the Aleuts' physical prowess. The hunters were known for their remarkable upper-body strength. Laughlin recalls that Steve Bezezekoff, a hunter from Umnak Island, squeezed a dynamometer—a device for measuring mechanical force—so far off the scale that it broke.

The hunters' bones also testify to this strength. Laughlin notes that a humerus—an upper-arm bone—excavated in 1950 provides an example of the greatest rugosity ever recorded in humans [*see photograph on opposite page*]. Rugosity refers to the indented striations in bone where muscles attach. "When people do that much kayaking," Laughlin explains, "it should show on their skeletons, and it does." The pronounced and highly elongated marks seen on Aleutian kayakers' arm bones means that these men had more muscle than most; indeed, the humeri of contemporaneous Russians look "like pipe stems" in comparison. This extended musculature, in turn, indicates that the Aleuts would have had extreme stamina, because some parts of the muscle could be active while others rested—even though the paddler himself didn't slow or stop.

Endurance, of course, entails not just muscle but also the respiratory and circulatory systems. And it would seem that the Aleuts had the requisite wind and circulation to allow them to paddle quickly over enormous distances, although they apparently pushed themselves too far at times. Ivan Evseevich Veniaminov—a missionary and one of the first ethnologists in Alaska—described in the early 1800s the fate of an Aleut messenger who traveled 135 miles through the open ocean in about 27 hours, only to die from a chest hemorrhage soon after he arrived.

It took an unusual form of kayak to take full advantage of the strength and stamina of the Aleuts. And it took a highly elastic structure to withstand the resulting pounding at sea. This extraordinary flexibility attracted the Russians' attention almost as much as the baidarkas' swiftness did. "At first I disliked these leathern canoes on account of their bending elasticity in the water," wrote Urey Lisiansky, a Russian sea captain, after completing a 300-mile baidarka voyage in 1805. "But when accustomed to them, I thought it rather pleasant than otherwise."

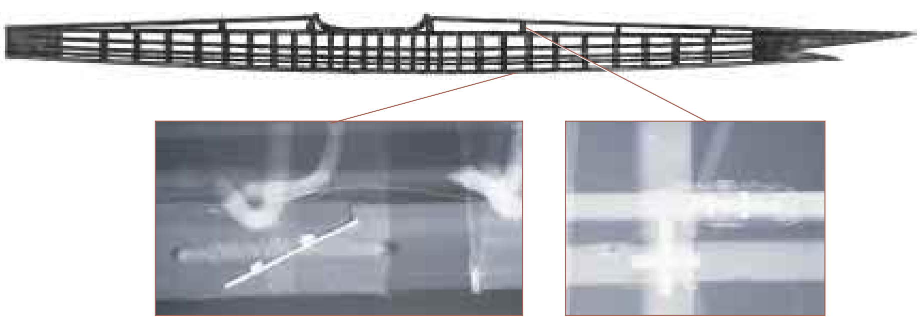
Some of this flexibility came from ivory bearings, called *kostochki* by the Russians, that the early baidarkas incorporated. Several years ago Joseph Lubischer, then a graduate student in anthropology, Chris Cunningham, currently editor of *Sea Kayaker* magazine, and I had a chance to examine some *kostochki* after we were granted permission to study a baidarka collected at Unalaska in 1826. X-rays revealed these articulated ivory bearings in many of the joints of the kayak [*see illustration below*]. We also discovered a thin strip of baleen running between the keel and the ribs for the entire length of the boat. Its purpose, however, remains unknown.

Most early baidarkas—and many later ones—also had segmented, three-part keels. The sections were joined in such a manner that the keel could freely extend and contract, permitting the entire kayak to bend unimpeded, limited only by the stiffness of the gunwales. This is a complete departure from normal boatbuilding tradition, where a uniform, intact keel forms the backbone of the hull. In the baidarka, however, the segmentations allow the craft to become flexible, like a ski, rather than rigid like a box.

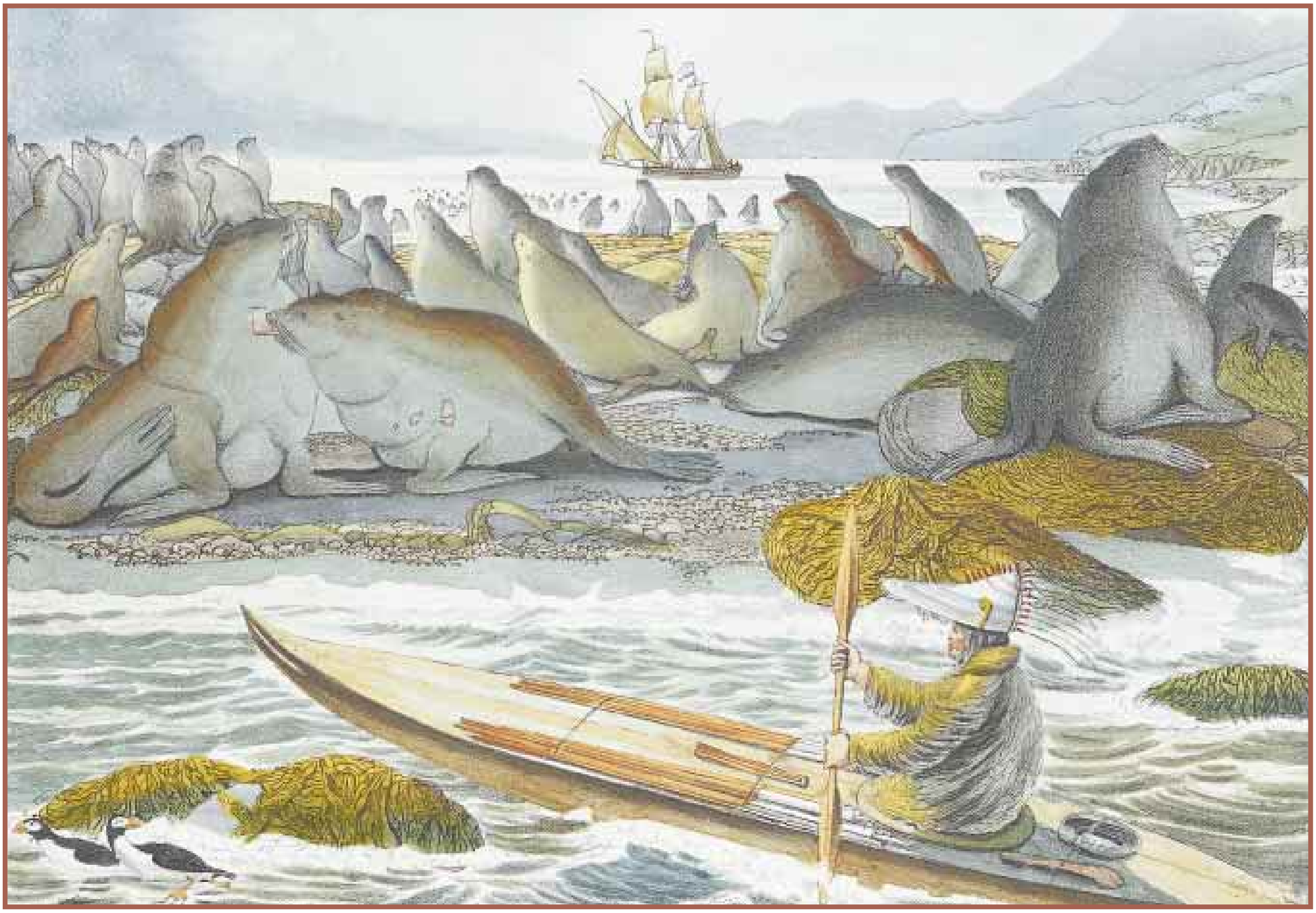
A distinct, albeit controversial, possibility exists that the dynamic flexibility of the baidarka could sometimes decrease resistance—that is, it could reduce the amount of energy expended to push oncoming waves out of the way. An easy way to understand this idea is to envision wave energy passing elastically through the skeleton of a boat. A flexible kayak moving across an undulating surface vibrates in accordance with the apparent period of the waves. The simplest mode of vibration is called two-node vertical oscillation: the ends of the kayak are deflected upward while the center of the kayak is deflected downward—and then vice versa. The two points that are not in motion are the nodes. Such oscillation is highly sensitive to how the mass is distributed in the kayak and has a large effect on the interaction between the craft and oncoming waves. Out-of-phase oscillations, for example, have the same effect as hitting speed bumps or a washboard section in a road.

Because the kayaker cannot change the wave period of the ocean, the best available strategy is to tune the oscillation, or vibration, of the boat. Indeed, observers from explorer Vitus Bering's 1741 expedition reported that Aleut kayaks carried ballast stones distributed both fore and aft. Because skilled paddlers did not require ballast for lateral stability, it is possi-

COURTESY OF SPECIAL COLLECTIONS, UNIVERSITY OF WASHINGTON (*top*); COURTESY OF BAIDARKA HISTORICAL SOCIETY, BELLINGHAM, WASH. (*middle*); GEORGE B. DYSON (*bottom*)



ONE-HATCH BAIDARKA, drawn by English navigator James Shields in the 1790s, shows the distinctive split prow cutting through the water, the upper part above the waves, the lower part below. This open-mouth design may have increased the speed of the baidarka by reducing wave resistance and providing lift, much as a water ski does. Ivory bearings (*x-ray insets*) contributed to the baidarka's flexibility for reasons that remain unknown. A different split-prow version—one that was upturned instead of open—followed the original horizontal design by some years (*bottom*). A superb example of this latter form—5.4 meters long—can be found at the National Museum of Finland in Helsinki, which graciously allowed the author and his colleagues to x-ray the craft to see its structure and bearings.



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MARINE MAMMALS, seen here in the Pribilof Islands, were hunted at close range by the Aleuts. Baidarkas were designed to be quiet, allowing the hunters to approach their prey with stealth. This lithograph from the early 1800s shows a Russian vessel, the *Rurik*, in the background. The arrival of the Russians changed the Aleuts' way of life and eventually led to the demise of certain forms of baidarkas.

ble that the mass allowed the kayaker to tune the period of two-node oscillation to suit the sea conditions at the time. In other words, by changing the placement of the stones, the paddler could change how much the kayak bounced, synchronizing the undulation of the kayak to the frequency of the waves—thus conserving the paddler's energy. Experiments to test this hypothesis have not been done.

Whether the baidarka's flexible skin enhanced its speed is even more difficult to confirm. Animal skin has a nonlinear elasticity quite unlike any other material used for boat surfaces. Whether a compliant skin can reduce friction by dampening some of the boundary-layer disturbances characteristic of turbulent flow remains conjectural. Most studies—designed for application to submarines—have concentrated on whether a compliant surface can delay the transition from laminar to turbulent flow. Results have been marginal at best. But this is the wrong question as far as a kayak paddling through a turbulent surface is concerned. The absence of significant delay in boundary-layer transition does not preclude favorable effects—in addition to stealth—under speeds and conditions that are inhospitable to laminar flow.

On the other hand, all the strategies used to maximize baidarka flexibility may have been the Aleuts' answer to a purely mechanical problem: how to keep the kayak from falling apart. Structural elasticity would have allowed local stresses to be dissipated throughout the craft, thereby keeping the structure within the physical limits of the singularly lightweight materials from which it was made.

In addition to unusual speed and flexibility, the baidarka was unique among kayaks in having a split prow. Some, now called "early" versions, had wide-open jaws. This form is documented only in illustrations from the period of initial contact, before 1800. A sketch from the 1790s by James Shields—an English shipbuilder working for the Russians—shows the lower bow beneath the water and the vertex of the mouth of the baidarka even with the surface of the sea. "Later" versions were also split but were upturned [*see illustration on opposite page*]. Hypotheses abound about why the bow was bifurcated, including the suggestion that it was a purely symbolic representation of a sea otter or that it was a means of quieting the boat as it approached prey.

Certain functions of the open-jawed form are undisputed. The lower part cuts sharply into the water, like a knife, minimizing disturbance as the craft moves through waves. The upper part acts like a water ski, producing dynamic lift that prevents the kayak from burying its nose.

Under the right conditions, a protruding lower bow also could introduce what are called phase cancellation effects—the idea behind the bulbous bows seen in some of today's oil tankers. Simply put, a moving object pushing down on a sur-

ANN E. YOW

BAIDARKA RECONSTRUCTED by the author in 1991 goes just over eight knots when paddled for 800 meters by Olympic gold medalist Greg Barton. This kayak is a modern version of the one that James Shields drew in the 1790s [*see illustration on page 88*].

face produces a wave that begins with a crest, whereas a moving object pushing up on the surface produces a wave that begins with a trough. The goal is to get the two wave systems to cancel each other. This cancellation produces measurable fuel savings at the steady speeds of an oil tanker. But benefits at the speeds of a kayak are harder to envision.

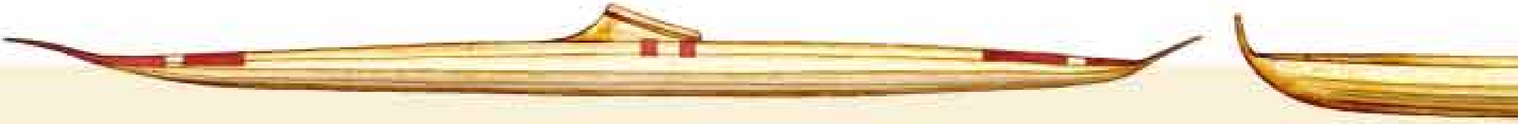
The principal advantage of the extended lower bow may have been its contribution to an apparently longer, more slender hull. Cruising speed varies with the square root of waterline length, and wave-making resistance varies as the fourth power of the ratio of beam to length. The lower bow maximizes the waterline length without increasing the overall length of the boat. The drawback of a very slender hull is usually poor seakeeping in waves. But the baidarka's upper bow could have compensated.

With all its apparent advantages, it is perplexing why this form died out so quickly after the Russians arrived. Were high-speed kayaks threatening to the colonists, who had suffered a number of initial massacres at the hands of well-equipped Aleuts? Or, as forays for sea otters became longer, did the open-jawed kayaks increasingly encounter kelp beds and become entangled in them? Certainly the emergence of huge fleets of hunters obviated the need for individual, high-speed pursuit—and so perhaps the narrow, open-jawed kayaks, designed for speed and stealth but not for carrying capacity, were no longer needed.

Square Stern

The baidarka's wide-tailed, shouldered stern was as unique a trademark as its bow—and an enduring element of design. In this case, we are better able to explain what the feature did and why. As a kayak moves through the water, the surface is divided by the bow, displaced by the hull and finally returned to equilibrium behind the craft, leaving

ROBERTO OSTI (*drawings*), AFTER E. Y. ARIMA (*left and center*) AND E. T. ADNEY AND H. I. CHAPELLE (*right*)



From Sealskin to Plastic

The baidarka was just one of the forms of kayak used by the Eskimo, Inuit and other peoples who inhabited the Arctic regions from Siberia to Greenland. The Koryak people of Kamchatka, for instance, designed short, wide boats for use in sheltered waters. Kayaks from the Mackenzie Delta in northwestern Canada had upturned bow and stern horns and were used for hunting and sometimes for tending fishing nets. In central Canada, where caribou migration routes crossed rivers and lakes, the Copper and the Netsilik Inuits made sleek, light boats for swiftly chasing down the swimming animals. And in Hudson Bay and around Baffin Island in northeastern Canada, wider, heavier kayaks with high prows and cockpit rims were designed to be stable and to transport heavy loads.

The design that people may be most familiar with today is that of the Greenland kayak. These were hunters' boats: narrow and maneuverable, with a low deck profile gracefully sweeping up into a pointed bow and stern. This lovely form has most strongly influenced modern kayak design. Despite the fact that some echoes of this form are evident in contemporary kayaks, they share little with the aboriginal kayaks in their purpose, materials or manufacture.

Although working kayaks were used for centuries, possibly millennia, recreational kayaking is relatively recent. In 1866 John MacGregor, a British philanthropist and traveler, published the first of many accounts of touring by kayak (however, his boat, the *Rob Roy,* more resembled a small decked rowboat). The first kayaking boom in the West occurred after 1907, when Hans Klepper, a German tailor, began mass-producing a skin-and-frame kayak that could be folded up. The craft fit into bags that were conveniently sized for overhead luggage racks in railway cars, thereby enabling the new urban middle class to reach navigable water.

After the Great Depression and World War II, the sport of kayaking dwindled. The skilled labor needed to handcraft kayaks increased their cost, and outdoor pursuits had become less popular. Despite the trend, kayaking enthusiasts continued experimenting with designs and materials. Fiberglass became common, and river kayaking became prominent. Meanwhile some of the ancient Greenland designs inspired original models of sea kayaks.

In the mid-1980s widespread use of a

the energy expended by the paddler to dissipate in its wake. The distance it takes the water to return to gravity-induced equilibrium is the natural wavelength of a surface wave traveling at the speed of the boat.

At a specific speed—sometimes called hull speed—the kayak produces a wave that matches the kayak's own length. Below this speed the water returns to equilibrium smoothly alongside the hull, with the path of least resistance defined by a finely tapered stern. Above this speed, however, the displaced water is no longer able to return to equilibrium alongside the kayak and instead begins to separate from the hull, producing suction and drag at the end of the boat.

As the kayak goes faster, the trough of its wave system moves aft and the stern tends to sink, exaggerating these effects. To keep the stern from sinking and to postpone separation of flow—and then to promote clean separation—the cross-sectional area of a high-speed kayak's afterbody should approximate a curve the length of a wave traveling at the speed of the boat. And the afterbody should terminate "somewhat abruptly"—as Captain Cook described the stern of the baidarka—at the end of the boat. For this reason, such sterns are common among high-speed power and sailing craft. Yet they are rare among kayaks, except for the baidarka.

Although we cannot know what was going through the minds of the Aleut hunters who designed and refined this remarkable vessel over millennia, the baidarka continues to mark an apogee of kayak design. From stem to stern—and from compliant skeleton to compliant skin—the baidarka evolved in accordance with hydrodynamic laws. The mystery of the Aleut kayak lies not in unknown principles but in the ability to synthesize so cohesive a solution to such a wide variety of problems. And it is clear that Veniaminov's observation in 1840 remains true today: "It seems to me that the Aleut baidarka is so perfect of its kind that even a mathematician could add very little if anything to improve its seaworthy qualities." SA

The Author

ANN E. YOW

GEORGE DYSON began building kayaks in 1964. Over the 25 years since his own voyages in British Columbia and southeastern Alaska (chronicled in Kenneth Brower's 1978 *The Starship and the Canoe*), he has seen recreational sea kayaking become so popular that the seasonal invasion of "sea lice" has some local residents alarmed. No such danger in the Aleutians, where a revival of traditional kayak building, thanks to a few dedicated individuals, hangs by a precarious thread. Now affiliated with Western Washington University, he is the author of *Baidarka* (1986) and *Darwin among the Machines* (1997).

Further Information

ALEUTS: SURVIVORS OF THE BERING LAND BRIDGE. William S. Laughlin. Holt, Rinehart and Winston, 1980.

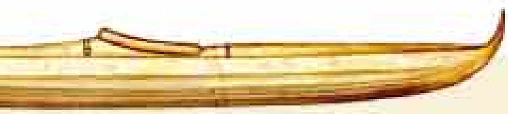
BAIDARKA: THE KAYAK. George Dyson. Alaska Northwest Books/Graphic Arts Center, 1986.

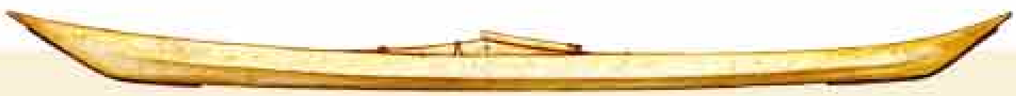
CONTRIBUTIONS TO KAYAK STUDIES. Edited by E. Y. Arima. Canadian Ethnology Service, Mercury Series, paper No. 122. Canadian Museum of Civilization, 1991.

BAIDARKA. *Scientific American Frontiers,* program No. 203, segment No. 1; 1991.

THE ALEUTIAN KAYAK. Wolfgang Brinck. Ragged Mountain Press, 1995.

Museum of the Aleutians, Unalaska, Alaska, site is available at www.aleutians.org/alt.htm on the World Wide Web.





breakthrough in manufacturing techniques helped to usher kayaking into a new era of popularity. A technique called rotomolding—in which a plastic is spread out on the inside of a rotating mold—allowed people to make durable kayaks inexpensively. For instance, a rotomolded sea kayak costs $600 to $1,500, whereas a fiberglass or skin-on-frame model costs $1,700 to $2,800. The lower price brought cheap kayaks within the purchasing ability of a wider audience at a time when outdoor sports were on the rise.

The new plastic boats in eye-popping colors can claim distant kinship with some versions of the Greenland kayak, but they are a far cry from their driftwood, ivory and sealskin forebears. No longer tools for survival in a harsh realm, kayaks are recreational items in a materially abundant culture.

—Dan Schlenoff, staff writer

INUIT AND ESKIMO KAYAKS contrast with a modern mass-produced model. Shown from left to right are a Caribou hunting kayak, with painted areas, from central Canada; a Mackenzie Delta kayak from northwestern Canada that was used to tend fishing nets in 1914; and a southwestern Greenland kayak dated to 1883. Shown below is a modern rotationally molded polyethylene kayak with an open cockpit.

HERITAGE KAYAKS

MONITORING EARTH'S VITAL SIGNS

A new NASA satellite—one of a fleet called the Earth Observing System—is using five state-of-the-art sensors to diagnose the planet's health like never before

by Michael D. King and David D. Herring

Flying 705 kilometers above the earth's surface, a satellite called Terra is conducting a comprehensive health examination of our world. Everything from clouds and plants to sunlight and temperature and fire and ice influences climate, and Terra is just beginning to collect this information every day over the entire earth. As the bus-size satellite circles the globe from pole to pole, its sensitive instruments track the planet's vital signs as each region comes into view.

Certain environmental changes are occurring today at rates never seen in our planet's recent history. Imagine, for instance, the hundreds of fires set deliberately every year to clear land for agriculture, a practice that has quadrupled during the past century. Humans today burn an average of 142,000 square kilometers of tropical forests—an area roughly the size of Arkansas—every year. Some of Terra's sensors can track the flames and gauge their intensity, whereas others measure the extent of burn scars and observe how smoke particles and gases move through the atmosphere. One of these sensors can even distinguish changes at a resolution of 15 meters—a view close enough to pick out spots where smoldering embers may again burst into flame.

Terra is the flagship of the Earth Observing System (EOS), a National Aeronautics and Space Administration satellite program that will bring scientists closer to deciphering the earth's climate well enough to predict future changes—a charge that requires an unprecedented ability to differentiate natural cycles from changes that people create. Natural geologic forces, such as volcanic eruptions, variations in ocean currents and cycles of ice ages, have been rearranging the surface and climate of our planet since its formation 4.5 billion years ago. But today compelling scientific evidence illustrates that human activities are speeding up the rate of global change and have even attained the magnitude of a geologic force [see "The Human Impact on Climate," by Thomas R. Karl and Kevin E. Trenberth; SCIENTIFIC AMERICAN, December 1999].

We need to make many measurements all over the world, over a long period, in order to supply computer simulations with the right information to enable us to forecast climate change. To that end, we and our EOS colleagues identified 24 factors that together play a major role in determining climate. These factors include the flux of sunlight and other radiant energy, concentrations of greenhouse gases, snow and ice cover, clouds and aerosols, and changes in vegetation and other land-surface features. The Terra mission is designed to measure 16 of those 24 characteristics [*see list on page 94*].

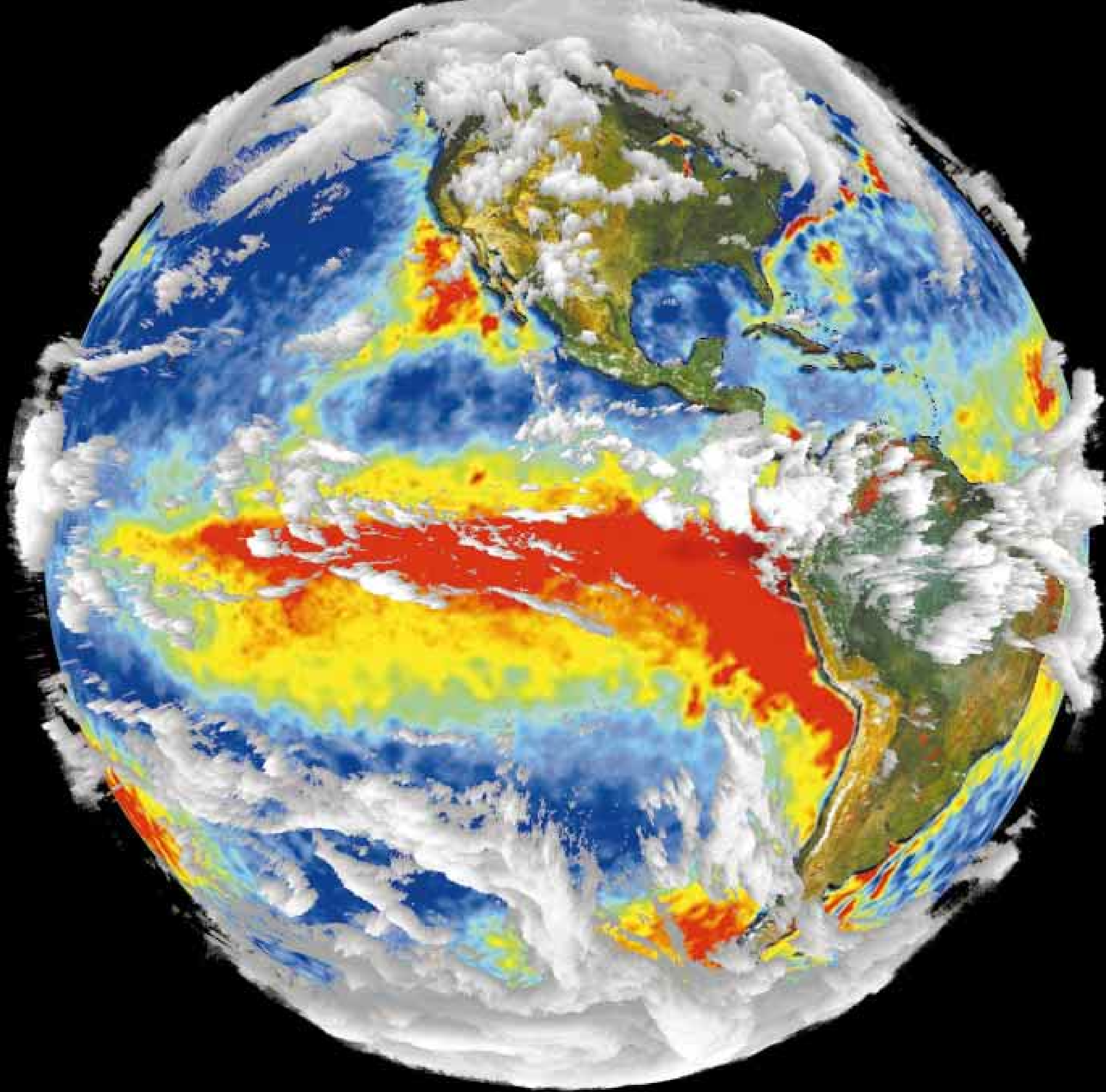
In 1988 NASA's Earth System Sciences Committee issued a report calling for a long-term strategy for measuring the earth's vital signs. This committee emphasized that the only feasible way to monitor these signs consistently for a long time is by using satellite-borne sensors that can "see" the earth from space [see "Earth from Sky," by Diane L. Evans, Ellen R. Stofan, Thomas D. Jones and Linda M. Godwin; SCIENTIFIC AMERICAN, December 1994]. Consequently, in 1991, NASA initiated the Earth Observing System, and the U.S. Congress has since earmarked $7.4 billion to design and implement the program through October 2001. Our team devoted $1.3 billion to building and launching Terra, the newest member of the EOS fleet.

A New Generation of Remote Sensors

Terra rocketed into orbit on December 18, 1999, and specialists now guide its flight and control its sensors from a command center at the NASA Goddard Space Flight Center in Greenbelt, Md. Terra's sensors are not actively scanning the surface as do instruments that transmit laser or radar beams and track the way they bounce off the planet's surface. Terra's sensors are passive, much like a digital camera.

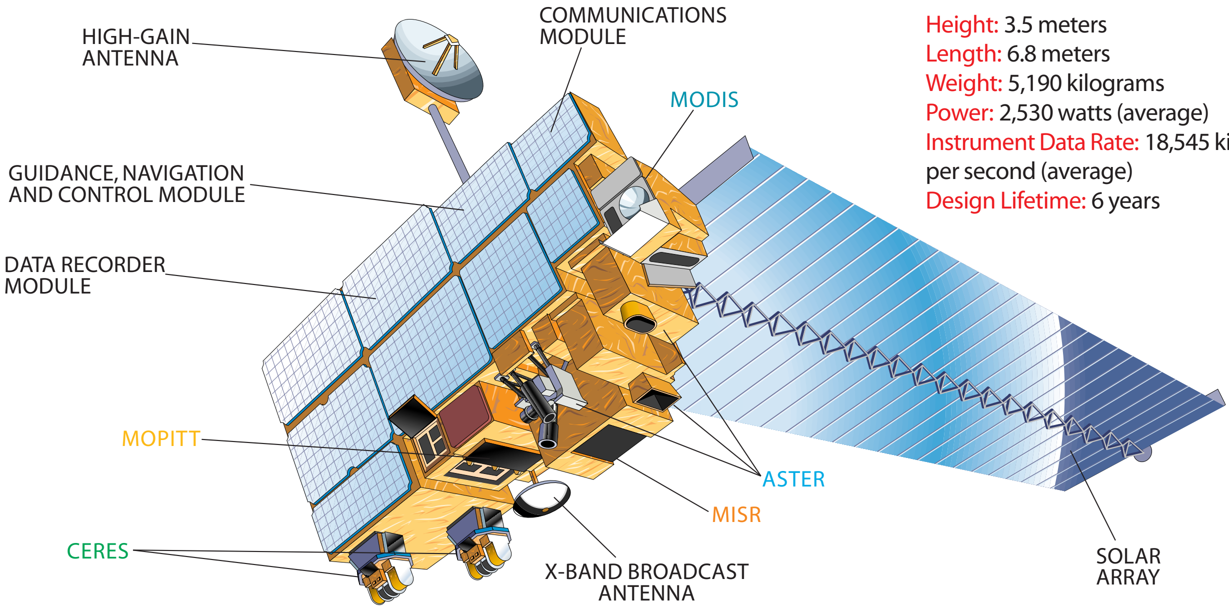
Packets of energy—sunlight and infrared light—escape the earth's atmosphere and pass through the sensors' apertures. Those energy packets then strike specially designed detectors that are sensitive to discrete wavelengths of electromagnetic energy. Similar to the way we can tune into different stations on a car radio, Terra's spectroradiometers enable researchers to detect different wavelengths of radiant energy. If those wavelengths are red, green and

IMAGE SYNTHESIZED BY R. B. HUSAR *Washington University*



LAYERS OF CLIMATE CHARACTERISTICS are just beginning to be collected by the Terra satellite every day over the entire planet. Previous satellite sensors tracked the vital signs that form this synthesized image of vegetation (*green on continents*), forest fires (*red dots on continents*), ocean temperature (*colors over oceans*) and cloud cover. The warm waters of the Pacific Ocean (*red*), off the western coast of South America, are a telltale sign of an El Niño event.

Terra and Its Five Climate-Monitoring Sensors



Height: 3.5 meters
Length: 6.8 meters
Weight: 5,190 kilograms
Power: 2,530 watts (average)
Instrument Data Rate: 18,545 kilobytes per second (average)
Design Lifetime: 6 years

ALL TERRA SENSOR ILLUSTRATIONS BY GEORGE RETSECK

Vital Signs That Terra Will Measure

 AEROSOLS

 AIR TEMPERATURE

 CLOUDS

 FIRES

 GLACIERS

 LAND TEMPERATURE

 LAND USE

 NATURAL DISASTERS

 OCEAN PRODUCTIVITY

 OCEAN TEMPERATURE

 POLLUTION

 RADIATION

 SEA ICE

 SNOW COVER

 VEGETATION

 WATER VAPOR

ICONS BY LAURIE GRACE

blue, they can easily make a color image that our eyes can see. If the measured wavelengths are invisible, such as those in the infrared or ultraviolet portions of the spectrum, scientists must assign them a visible color to make a "false-color" image that our eyes can interpret.

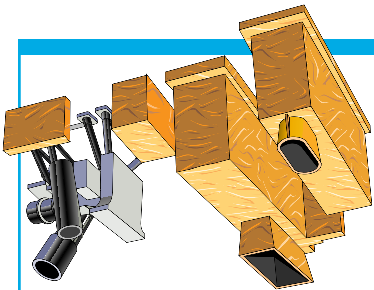
The EOS missions rely on two integral components in addition to the satellites: a system for storing the information and people to interpret it. Already the project supports some 850 scientists at government agencies and academic institutions around the world. What the satellites beam back to the earth is a voluminous stream of numbers—tens of trillions of bytes of information each week—that must be processed to become meaningful. An advanced computer network, called the EOS Data and Information System (EOSDIS), receives and processes the numbers. Four centers across the U.S. then archive the measurements from Terra and distribute them to scientists and civilians alike.

This free sharing of data contrasts sharply with many past satellite missions, for which public access was largely inaccessible to all but the highest-funded research organizations. A single image from the Landsat satellites, the first of which was launched in 1972, can cost hundreds or even thousands of dollars. Some of Terra's data, on the other hand, will be broadcast on X-band directly to anyone who has a compatible receiving station and the capacity to process and store such a huge flow of information. A variety of commercial markets can benefit from EOS data. Satellite maps of high productivity in the ocean, for instance, can guide commercial fishing outfits to likely concentrations of fish. In a similar fashion, images of agricultural fields will help farmers judge where crops are thriving and where they may be under stress. Such images can help farmers visualize patterns of runoff for particular fields and, in turn, refine their strategies for where, when and how much to irrigate and fertilize.

More Eyes in the Sky

In addition to Terra, three other EOS satellites are already orbiting the globe and measuring other vital signs of the climate, such as changes in the sun's energy output and winds blowing over the oceans. If these instruments survive their predicted lifetimes, and if Congress continues to fund the EOS effort, these satellites will be followed by 15 or more others, and together they will generate a 15-year global data set. To make accurate climate predictions, we will need such measurements spanning several decades.

Integrating observations from the sensors on board Terra and the other EOS satellites will make it possible to disentangle the myriad causes and effects that determine climate. Monitoring how patterns of deforestation correlate with rainfall and cloud cover, for example, will help researchers assess how the loss of trees affects regional water cycles. Com-



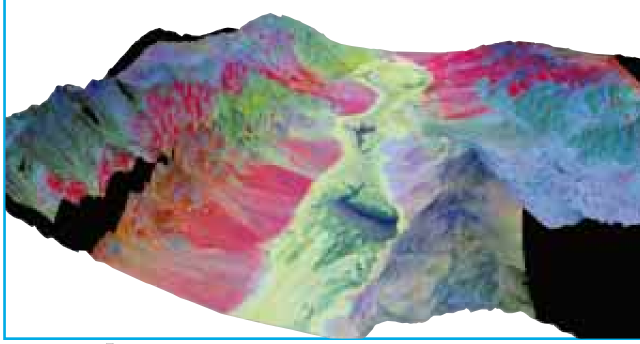
ASTER

Advanced Spaceborne Thermal Emission and reflection Radiometer

Vital Signs Measured:

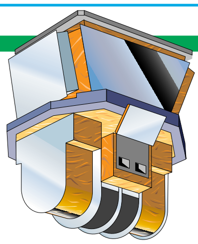
Unique Characteristics: Highest spatial resolution of all Terra sensors and the unique ability to point toward special targets
Sensors: Three distinct telescope subsystems that monitor wavelengths in the visible and near infrared, shortwave infrared, and thermal infrared portions of the spectrum
Sponsor: Japanese Ministry of International Trade and Industry
Spatial Resolution: Ranging from 90 to 15 meters

The earth's land surfaces emit energy and temperatures that ASTER measures at ultrahigh resolution. These vital signs are key to estimating the planet's radiation budget and will be particularly useful for identifying rocks, soils and vegetation. Farmers can use such high-resolution, multispectral images to assess the way changes in surface temperature, ground slope and soil type impact the health of their crops. ASTER can also monitor ongoing changes in other surface features—such as receding glaciers and ice sheets, expanding desert boundaries, deforestation, floods and wildfires—which will help researchers distinguish between natural changes and those that humans cause. Because ASTER's telescopes can be tilted toward erupting volcanoes and other special targets, they can generate detailed stereoscopic images that will greatly refine digital topographic maps of the planet. These images will extend the collection that the Landsat satellites have been gathering since 1972.



ROCKS AND VEGETATION come to false-color life in this simulated ASTER image of a 60-kilometer-wide swath of Death Valley, Calif. One sensor detects thermal infrared light (*left*), which highlights the composition of the land surface: rocks rich in quartz are red, salt deposits are light green, and so on. Shorter-wavelength infrared light and visible light recorded over the same scene (*above*) show vegetation as green, water as blue and iron-rich volcanic rocks as orange smudges.

COURTESY OF MICHAEL ABRAMS *Jet Propulsion Laboratory/California Institute of Technology*



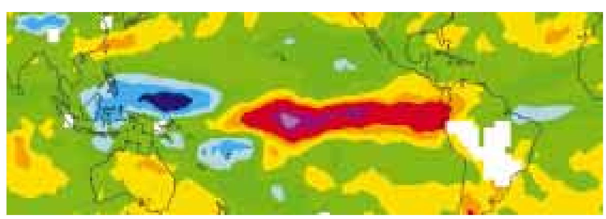
CERES

Clouds and the Earth's Radiant Energy System

Vital Signs Measured:

Unique Characteristic: First satellite sensor to record radiation fluxes throughout the atmosphere
Sensors: Two broadband scanning radiometers
Sponsor: NASA Langley Research Center
Spatial Resolution: 20 kilometers

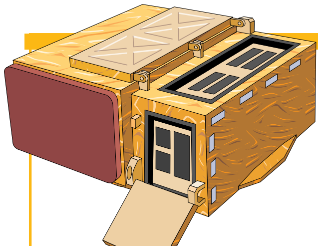
Predicting global temperature change requires a keen understanding of how much radiation, in the form of heat and sunlight, enters and leaves the earth's atmosphere. Yet to date, researchers cannot account for about 8 percent of incoming solar radiation once it enters the atmosphere. One explanation for the missing energy is that clouds and aerosols—tiny particles of smoke and dust—absorb energy and scatter it in the lower atmosphere, where satellites that track the energy fluxes have never looked. To better quantify the roles that clouds play in the earth's energy system, CERES (with input from MODIS) will measure the flux of radiation twice as accurately as previous sensors, both at the top of the atmosphere and at the planet's surface. The CERES instruments extend the heritage begun by NASA's Earth Radiation Budget Experiment (ERBE) satellite sensors, which flew in the 1980s.



EARLY CERES sensors recorded the largest changes yet observed in radiation emitted to space from the eastern Pacific Ocean in February 1998. Warmer waters, generated at the peak of an El Niño event, increased the occurrence of cumulonimbus clouds, which in turn trapped more of the heat radiating from the ocean and the lower atmosphere (*red*).

TAKMENG WONG *NASA Langley Research Center* paring similar measurements from more than one sensor will help ensure that all instruments are seeing the same signals and that onboard calibration devices are working properly. Researchers will also compare the satellite measurements with those gleaned from dozens of other instruments based in aircraft, on ships and buoys, and on the ground.

The process of diagnosing climate takes hundreds of hours of computer time. The first four-dimensional "snapshot" of our planet will probably not be ready until next winter, and scientists may need many years after that to complete the first thorough statistical evaluation. The earth's climate system is intricately interconnected. What we have described here only scratches the surface of what the Terra mission can accomplish. Many of its contributions will undoubtedly prove to be serendipitous as innovative studies and new applications emerge in the years ahead. SA



MOPITT

Measurements Of Pollution In The Troposphere

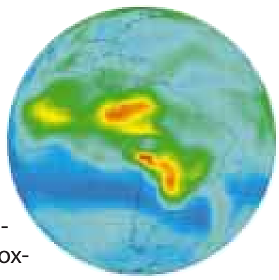
Vital Sign Measured:

Unique Characteristic: First satellite sensor to trace pollutants to their source

Sensor: Scanning radiometer that uses gas correlation spectroscopy

Sponsor: Canadian Space Agency

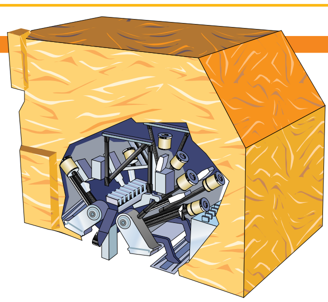
Spatial Resolution: 22 kilometers



Two trace gases won't escape MOPITT, which measures the global distribution and concentration of methane and carbon monoxide in the lower atmosphere. Methane—a greenhouse gas with nearly 30 times the heat-trapping capacity of carbon dioxide—is known to leak from swamps, livestock herds and icy deposits under the seafloor, but the output of these individual sources is not known. One way or another, methane is gathering in the lower atmosphere at a rate of about 1 percent a year. Carbon monoxide, which is expelled from factories, automobiles and forest fires, hinders the atmosphere's natural ability to rid itself of other harmful chemicals. The first satellite sensor to use gas correlation spectroscopy, MOPITT can distinguish these two gases from others, such as carbon dioxide and water vapor. As emitted heat or reflected sunlight enters the sensor, it passes through onboard containers of carbon monoxide and methane, producing a signal that correlates with the presence of these gases in the atmosphere.

CARBON MONOXIDE gathers over South America in this computer simulation. High concentrations of the gas (*red* and *yellow*) originate from fires set to clear forests, and easterly winds at the equator transport it over the Pacific Ocean.

NCAR/MOPITT TEAM, CANADIAN SPACE AGENCY



MISR

Multiangle Imaging SpectroRadiometer

Vital Signs Measured:

Unique Characteristic: Produces stereoscopic images of clouds and smoke plumes

Sensors: Nine charge-coupled device (CCD) cameras

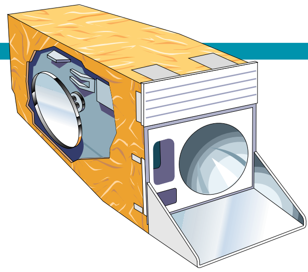
Sponsor: Jet Propulsion Laboratory

Spatial Resolution: Ranging from 1.1 kilometers to 275 meters

No instrument like MISR has ever flown in space. Viewing the sunlit earth simultaneously at nine widely spaced angles, MISR collects global images of reflected sunlight in four colors (blue, green, red and near-infrared). The way the reflections change from one view angle to another will make it possible to distinguish different types of clouds, aerosols and land surfaces. Researchers can combine MISR images with stereoscopic techniques to design three-dimensional models that will help them trace aerosols and smoke plumes back to their sources. And as MISR covers the globe at the equator once every nine days, its multiangle measurements will enable researchers to better interpret the roles that clouds and aerosols play in the planet's energy budget.

NINE SIMULTANEOUS VIEWING ANGLES make it possible for MISR to measure stereoscopically the interactions among aerosols, clouds and radiation.

COURTESY OF SHIGERU SUZUKI AND ERIC M. DE JONG *Solar System Visualization Project, Jet Propulsion Laboratory*



MODIS

MODerate-resolution Imaging Spectroradiometer

Vital Signs Measured:

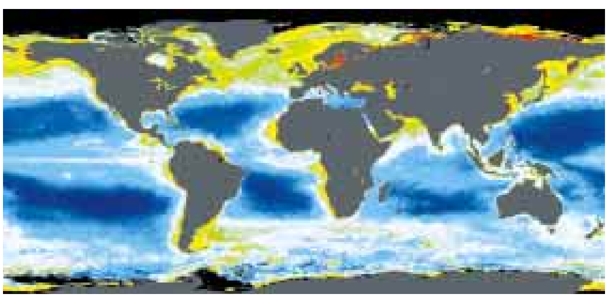
Unique Characteristic: Only Terra sensor to see the entire planet's surface every one to two days
Sensors: Four sets of detectors that are sensitive to visible light and to radiation in the near, shortwave, midwave and thermal portions of the infrared spectrum
Sponsor: NASA Goddard Space Flight Center
Spatial Resolution: Ranging from 1 kilometer to 250 meters

Seeing the entire globe in 36 discrete spectral bands, MODIS tracks a wider array of the earth's vital signs than any other Terra sensor. For instance, the sensor measures the percentage of the planet's surface that is covered by clouds almost every day with its sweeping 2,330-kilometer-wide viewing swath. This wide spatial coverage will enable MODIS, together with MISR and CERES, to determine the impact of clouds on the planet's energy budget—an important contribution considering that clouds remain the greatest area of uncertainty in global climate models. The sensor has an unprecedented channel (centered at 1.375 microns) for detection of wispy cirrus clouds that are believed to contribute to global warming by trapping heat emitted from the surface. MODIS will also monitor how smoke plumes and other aerosols mingle with clouds and alter their ability to absorb and reflect energy.

As it monitors global cloud cover, MODIS will also help investigators track changes to the land surface. The sensor is mapping the extent of snow and ice brought by winter storms and frigid temperatures, and it will observe the "green wave" sweep across continents as winter gives way to spring and vegetation blooms in response. It will see where and when disasters strike—such as volcanic eruptions, floods, severe storms, droughts and wildfires—and will help guide people out of harm's way. MODIS's bands are particularly sensitive to fires; they can distinguish flaming from smoldering burns and provide better estimates of the amounts of aerosols and gases they release into the atmosphere.

The sensor is also ideal for monitoring large-scale changes in the biosphere that will yield new insights into the workings of the global carbon cycle. Although no current satellite sensor can measure directly carbon dioxide concentrations in the atmosphere, MODIS can quantify the photosynthetic activity of plants to estimate how much of the greenhouse gas they are absorbing. In addition, the sensor will take a sophisticated look at the marine biosphere by measuring the fluorescent glow of chlorophyll in the ocean [*see image at left*].

SNOW COVER, such as this scene imaged by NASA's SeaWiFS satellite after the January 25 blizzard in the eastern U.S., is one of many climate factors that MODIS measures.



CHLOROPHYLL in microscopic ocean plants strongly reflects green light (*shown above as yellow, red and green*), which makes it possible for satellites such as SeaWiFS to track their abundance. MODIS will go a step further by monitoring how intensely the plants fluoresce, a signal of their productivity.

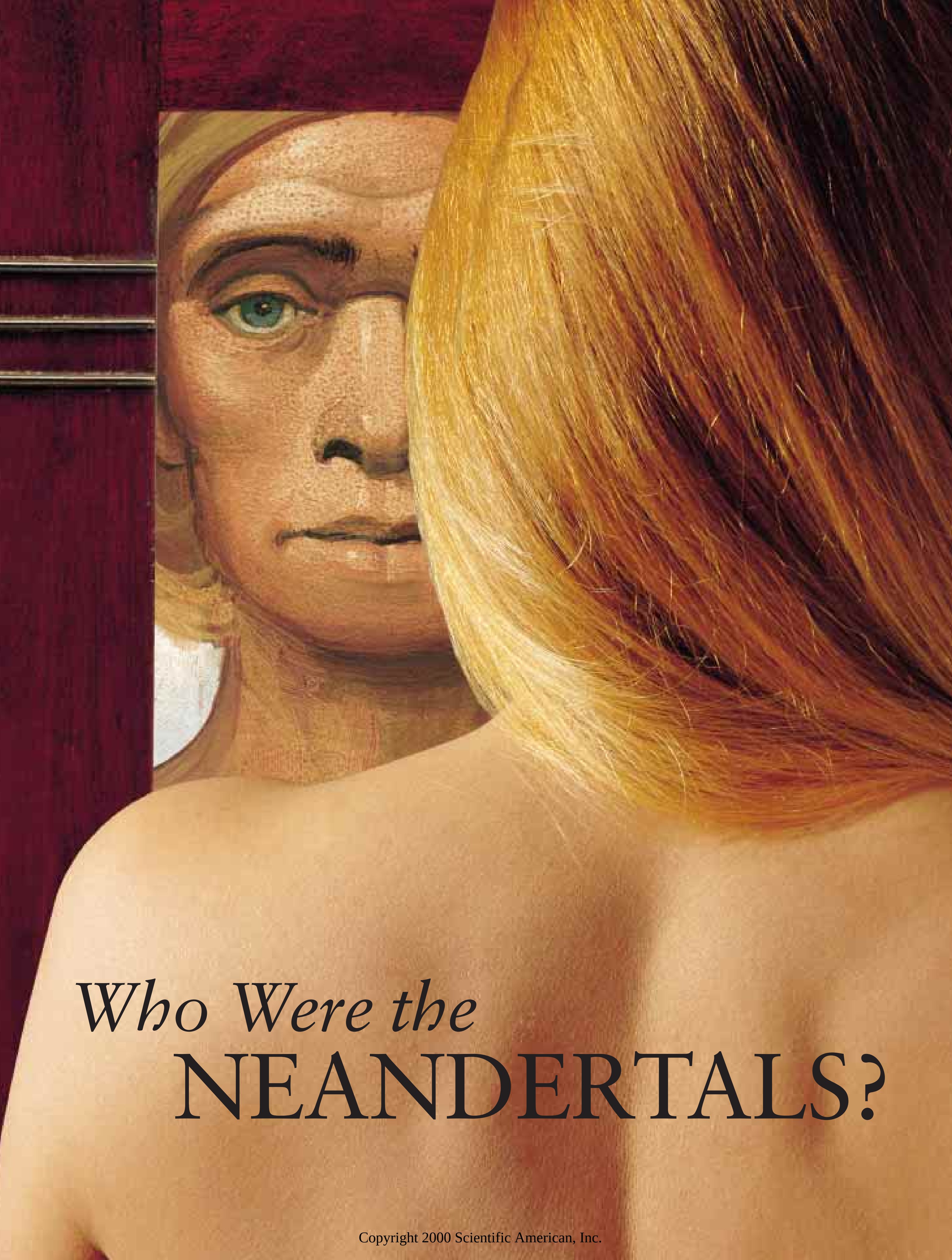
SeaWIFS PROJECT, NASA GODDARD SPACE FLIGHT CENTER

The Authors

MICHAEL D. KING is the senior project scientist of the National Aeronautics and Space Administration's Earth Observing System (EOS). From a command center at the NASA Goddard Space Flight Center in Greenbelt, Md., King supports hundreds of scientists worldwide who use EOS satellites to study global climate change. King joined the Goddard staff in 1978 as a physical scientist in the Laboratory for Atmospheres. Science writer DAVID D. HERRING works under contract for the EOS project and spearheads the team that promotes the Terra satellite to the public.

Further Information

MISSION TO PLANET EARTH: ROLE OF CLOUDS AND RADIATION IN CLIMATE. Bruce A. Wielicki, Robert D. Cess, Michael D. King, David A. Randall and Edwin F. Harrison in *Bulletin of the American Meteorological Society,* Vol. 76, No. 11, pages 2125–2154; November 1995.
EARTH FROM ABOVE: USING COLOR-CODED SATELLITE IMAGES TO EXAMINE THE GLOBAL ENVIRONMENT. Claire L. Parkinson. University Science Books, Sausalito, Calif., 1997.
EOS SCIENCE PLAN: THE STATE OF SCIENCE IN THE EOS PROGRAM. Michael D. King. NASA NP-1998-12-069-GSFC, 1998.
Visit NASA's Earth Observatory Web site at http://earthobservatory.nasa.gov



Who Were the NEANDERTALS?

Controversial evidence indicates that these hominids interbred with anatomically modern humans and sometimes behaved in surprisingly modern ways

by Kate Wong, *staff writer*

It was such a neat and tidy story. No match for the anatomically modern humans who swept in with a sophisticated culture and technology, the Neandertals—a separate species—were quickly driven to extinction by the invading moderns. But neat and tidy stories about the past have a way of unraveling, and the saga of the Neandertals, it appears, is no exception. For more than 200,000 years, these large-brained hominids occupied Europe and western Asia, battling the bitter cold of glacial maximums and the daily perils of prehistoric life. Today they no longer exist. Beyond these two facts, however, researchers fiercely debate who the Neandertals were, how they lived and exactly what happened to them.

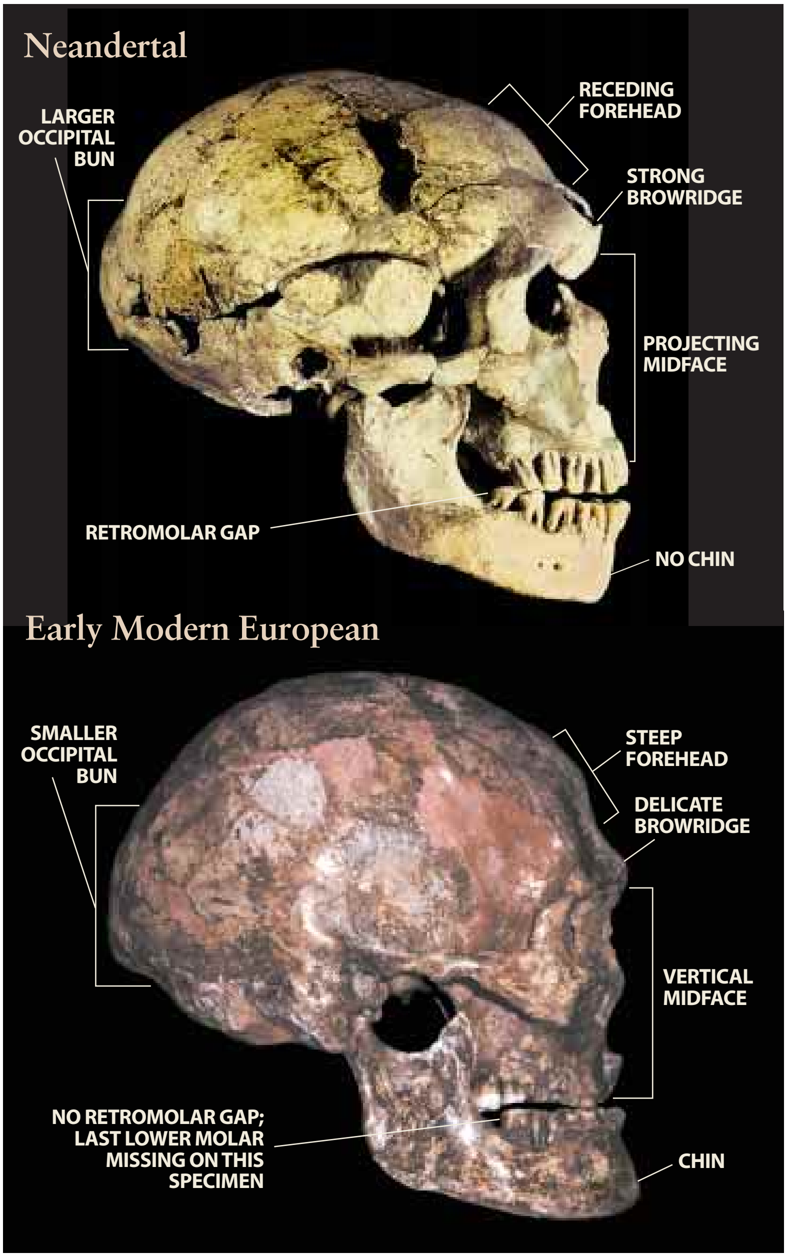
The steadfast effort to resolve these elusive issues stems from a larger dispute over how modern humans evolved. Some researchers posit that our species arose recently (around 200,000 years ago) in Africa and subsequently replaced archaic hominids around the world, whereas others propose that these ancient populations contributed to the early modern human gene pool. As the best known of these archaic groups, Neandertals are critical to the origins controversy. Yet this is more than an academic argument over certain events of our primeval past, for in probing Neandertal biology and behavior, researchers must wrestle with the very notion of what it means to be fully human and determine what, if anything, makes us moderns unique. Indeed, spurred by recent discoveries, paleoanthropologists and archaeologists are increasingly asking, How much like us were they?

Comparisons of Neandertals and modern humans first captured the attention of researchers when a partial Neandertal skeleton turned up in Germany's Neander Valley in 1856. Those remains—a heavily built skull with the signature arched browridge and massive limb bones—were clearly different, and Neandertals were assigned to their own species, *Homo neanderthalensis* (although even then there was disagreement: several German scientists argued that these were the remains of a crippled Cossack horseman). But it was the French discovery of the famous "Old Man" of La Chapelle-aux-Saints some 50 years later that led to the characterization of Neandertals as primitive protohumans. Reconstructions showed them as stooped, lumbering, apelike brutes, in stark contrast to upright, graceful *Homo sapiens*. The Neandertal, it seemed, represented the ultimate "other," a dim-witted ogre lurking behind the evolutionary threshold of humanity.

Decades later reevaluation of the La Chapelle individual revealed that certain anatomical features had been misinterpreted. In fact, Neandertal posture and

REFLECTION OF THE PAST reveals a face that is at once familiar and foreign. The 130,000-year-old skull of an adult female from the Krapina rock-shelter in northwestern Croatia inspired this Neandertal reconstruction.

CROATIAN NATURAL HISTORY MUSEUM



ERIK TRINKAUS/MUSÉE DE L'HOMME *(top)*; ARCHEOLOGICKÝ ÚSTAV AV CR *(bottom)*

CHARACTERISTIC DIFFERENCES are shown between a Neandertal, represented by a French specimen, La Ferrassie 1, and an early modern, Dolní Věstonice 16, from the Czech Republic. Each aspect can be found in both groups, varying in degree and frequency, but they tend to appear as suites of features.

movement would have been the same as ours. Since then, paleoanthropologists have struggled to determine whether the morphological features that do characterize Neandertals as a group—such as the robustness of their skeletons, their short limbs and barrel chests, prominent browridges and low, sloping foreheads, protruding midfaces and chinless jaws—warrant designating them as a separate species. Researchers agree that some of these characteristics represent environmental adaptations. The Neandertals' stocky body proportions, for example, would have allowed them to retain heat more effectively in the extremely cold weather brought on by glacial cycles. But other traits, such as the form of the Neandertal browridge, lack any clear functional significance and seem to reflect the genetic drift typical of isolated populations.

For those scholars who subscribe to the replacement model of modern human origins, the distinctive Neandertal morphology clearly resulted from following an evolutionary trajectory separate from that of moderns. But for years, another faction of researchers has challenged this interpretation, arguing that many of the features that characterize Neandertals are also seen in the early modern Europeans that followed them. "They clearly have a suite of features that are, overall, different, but it's a frequency difference, not an absolute difference," contends David W. Frayer, a paleoanthropologist at the University of Kansas. "Virtually everything you can find in Neandertals you can find elsewhere."

He points to one of the earliest-known modern Europeans, a fossil from a site in southwestern Germany called Vogelherd, which combines the skull shape of moderns with features that are typically Neandertal, such as the distinct space between the last molar and the ascending part of the lower jaw known as a retromolar gap, and the form of the mandibular foramen—a nerve canal in the lower jaw. Additional evidence, according to Frayer and Milford H. Wolpoff of the University of Michigan, comes from a group of early moderns discovered in Moravia (Czech Republic) at a site called Mladeč. The Mladeč people, they say, exhibit characteristics on their skulls that other scientists have described as uniquely Neandertal traits.

Although such evidence was once used to argue that Neandertals could have independently evolved into modern Europeans, this view has shifted somewhat. "It's quite clear that people entered Europe as well, so the people that are there later in time are a mix of Neandertals and those populations coming into Europe," says Wolpoff, who believes the two groups differed only as much as living Europeans and aboriginal Australians do. Evidence for mixing also appears in later Neandertal fossils, according to Fred H. Smith, a paleoanthropologist at Northern Illinois University. Neandertal remains from Vindija cave in northwestern Croatia reflect "the assimilation of some early modern features," he says, referring to their more modern-shaped browridges and the slight presence of a chin on their mandibles.

Those who view Neandertals as a separate species, however, maintain that the Vindija fossils are too fragmentary to be diagnostic and that any similarities that do exist can be attributed to convergent evolution. These researchers likewise dismiss the mixing argument for the early moderns from Mladeč. "When I look at the morphology of these people, I see robustness, I don't see Neandertal," counters Christopher B. Stringer of the Natural History Museum in London.

Another reason to doubt these claims for interbreeding, some scientists say, is that they contradict the conclusions reached by Svante Pääbo, then at the University of Munich, and his colleagues, who in July 1997 announced that they had retrieved and analyzed mitochondrial DNA (mtDNA) from a Neandertal fossil. The cover of the journal *Cell,* which contained their report, said it all: "Neandertals Were Not Our Ancestors." From the short stretch of mtDNA they sequenced, the researchers determined that the difference between the Neandertal mtDNA and living moderns' mtDNA was considerably greater than the differences found among living human populations. But though it seemed on the surface that the species question had been answered, undercurrents of doubt have persisted [see "Ancestral Quandary," by Kate Wong, News and Analysis, January 1998].

New fossil evidence from western Europe has intensified interest in whether Neandertals and moderns mixed. In January 1999 researchers announced the discovery in central Portugal's Lapedo Valley of a largely complete skeleton from a four-year-old child buried 24,500 years ago in the Gravettian style known from other early modern Europeans. According to Erik Trinkaus of Washington University, Cidália Duarte of the Portuguese Institute of Archaeology in Lisbon and their colleagues, the specimen, known as Lagar Velho 1, bears a combination of Neandertal and modern human traits that could only have resulted from extensive interbreeding between the two populations [see "The Hybrid Child from Portugal," on the next page].

If the mixed ancestry interpretation for Lagar Velho 1 holds up after further scrutiny, the notion of Neandertals as a variant of our species will gain new strength. Advocates of

Guide to Terminology

Neandertal can also be spelled Neanderthal. Around 1900 German orthography changed, and the silent "h" in certain words, such as "thal" (meaning "valley"), was dropped. The designation *Homo neanderthalensis* remains the same, but the common name can be spelled either way.

Paleolithic, or Old Stone Age, is the period ranging from the beginning of culture to the end of the last glaciation. It is subdivided into Lower, Middle and Upper stages.

Mousterian is a Middle Paleolithic, stone tool–based cultural tradition associated with Neandertals and with early moderns in the Near East.

Aurignacian is an Upper Paleolithic cultural tradition associated with moderns that includes advanced tools and art objects.

Châtelperronian is an Upper Paleolithic cultural tradition associated with Neandertals. It resembles both the Mousterian and the Aurignacian.

DAY IN THE LIFE of Neandertals at the Grotte du Renne in France is imagined here. The Châtelperronian stratigraphic levels have yielded a trove of pendants and advanced bone and stone tools. Such items, along with evidence of huts and hearths, were once linked to modern humans alone, but the Grotte du Renne remains suggest that some Neandertals were similarly industrious.

MICHAEL ROTHMAN

The Hybrid Child from Portugal by Erik Trinkaus and Cidália Duarte

On a chilly afternoon in late November 1998, while inspecting the Abrigo do Lagar Velho rock-shelter in central Portugal's Lapedo Valley, two archaeology scouts spotted loose sediment in a rodent hole along the shelter's back wall. Knowing that burrowing animals often bring deeper materials to the surface, one of the scouts reached in to see what might have been unearthed. When he withdrew his hand, he held in it something extraordinary: bones of a human child buried nearly 25,000 years ago.

Subsequent excavation of the burial, led by one of us (Duarte), revealed that the four-year-old had been ceremonially interred—covered with red ocher and laid on a bed of burnt vegetation, along with pierced deer teeth and a marine shell—in the Gravettian style known from modern humans of that time across Europe. Based on the abrupt cultural transition seen in archaeological remains from the Iberian Peninsula, it seemed likely that when moderns moved into the area after 30,000 years ago, they rapidly replaced the native Neandertals. So it stood to reason that this specimen, called Lagar Velho 1, represented an early modern child. In fact, it didn't occur to us at first that it could be anything else.

This wonderfully complete skeleton does have a suite of features that align it predominantly with early modern Europeans. These include a prominent chin and certain other details of the mandible (lower jaw), small front teeth, characteristic proportions and muscle markings on the thumb, the narrowness of the front of the pelvis, and several aspects of the shoulder blade and forearm bones. Yet intriguingly, a number of features also suggest Neandertal affinities—specifically the front of the mandible (which slopes backward despite the chin), details of the incisor teeth, the pectoral muscle markings, the knee proportions and the short, strong lower-leg bones. Thus, the Lagar Velho child appears to exhibit a complex mosaic of Neandertal and early modern human features.

This anatomical amalgam is not the result of any abnormalities. Taking normal human growth patterns into consideration, our analysis indicates that except for a bruised forearm, a couple of lines on the bones indicating times when growth was trivially arrested (by sickness or lack of food) and the fact that it died as a child, Lagar Velho 1 developed normally. The combination can only have resulted from a mixed ancestry—something that had not been previously documented for western Europe. We therefore conclude that Lagar Velho 1 resulted from interbreeding between indigenous Iberian Neandertals and early modern humans dispersing throughout Iberia sometime after 30,000 years ago. Because the child lived several millennia after Neandertals are thought to have disappeared, its anatomy probably reflects a true mixing of these populations during the period when they coexisted and not a rare chance mating between a Neandertal and an early modern human.

Fieldwork conducted last summer yielded major portions of the skull and most of the remaining teeth, along with more archaeological material. And in an effort to fully understand this remarkable specimen, we have organized a team of specialists to examine the skeleton further. Among the projects planned are CT scan analyses of the skull and limb bones and computer-based virtual reconstruction of the damaged skull. Rigorous study is necessary because the discovery of an individual with such a mosaic of features has profound implications. First, it rejects the extreme Out of Africa model of modern human emergence, which

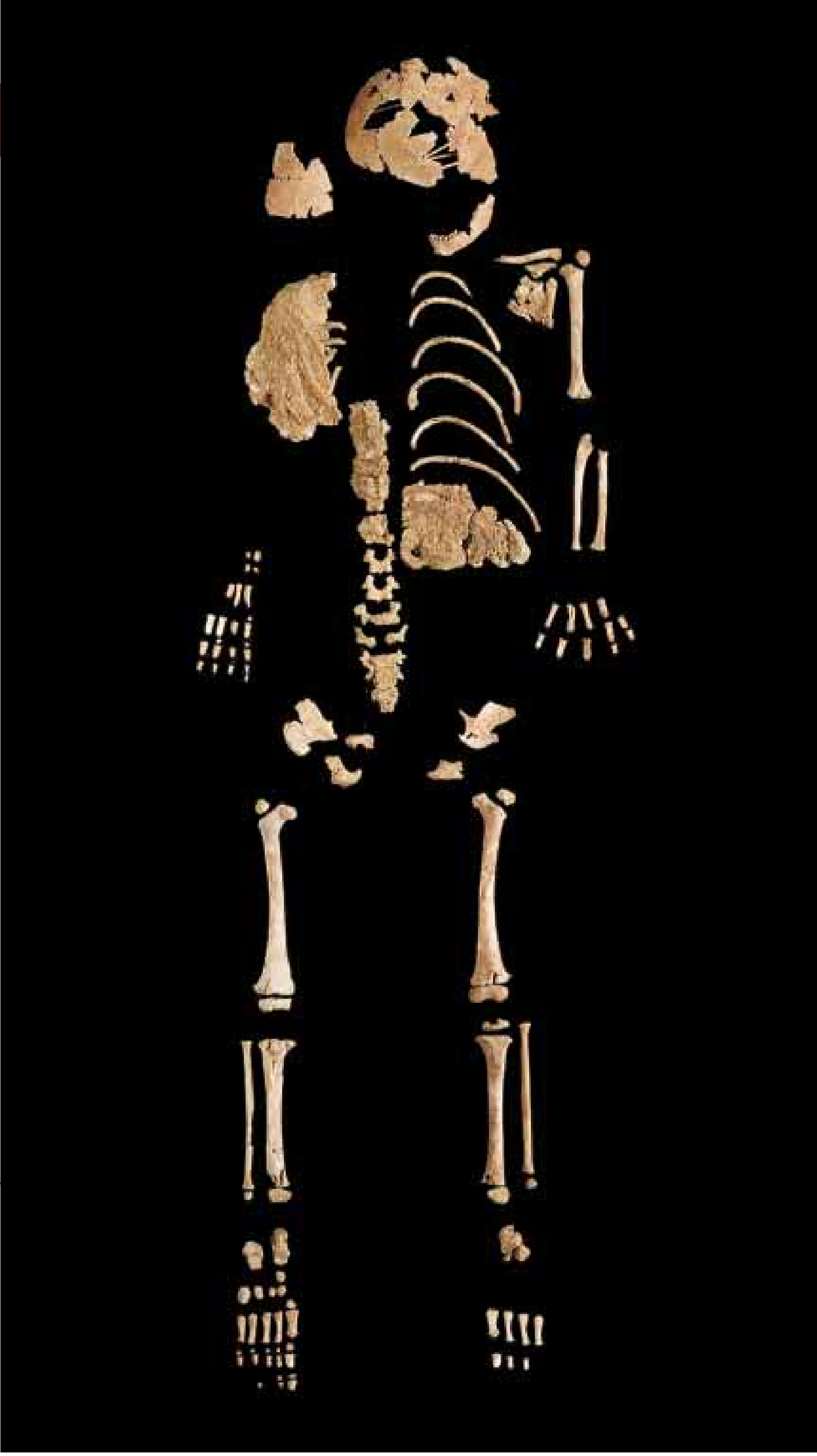
MORPHOLOGICAL MOSAIC found on this 24,500-year-old skeleton from Portugal indicates that Neandertals and modern humans are members of the same species who interbred freely. The child—Lagar Velho 1—is modern overall but bears some Neandertal traits, such as short lower-limb bones and a backward-sloping mandible.

the replacement model do allow for isolated instances of interbreeding between moderns and the archaic species, because some other closely related mammal species interbreed on occasion. But unlike central and eastern European specimens that are said to show a combination of features, the Portuguese child dates to a time when Neandertals are no longer thought to have existed. For Neandertal features to have persisted thousands of years after those people disappeared, Trinkaus and Duarte say, coexisting populations of Neandertals and moderns must have mixed significantly.

Their interpretation has not gone unchallenged. In a commentary accompanying the team's report in the *Proceedings of the National Academy of Sciences USA* last June, paleoanthropologists Ian Tattersall of the American Museum of Natural History in New York City and Jeffrey H. Schwartz of the University of Pittsburgh argued that Lagar Velho 1 is instead most likely "a chunky Gravettian child." The robust body proportions that Trinkaus and his colleagues view as evidence for Neandertal ancestry, Stringer says, might instead reflect adaptation to Portugal's then cold climate. But this interpretation is problematic, according to Jean-Jacques Hublin of France's CNRS, who points out that although some cold-adapted moderns exhibit such proportions, none are known from that period in Europe. Rather Hublin is troubled that Lagar Velho 1 represents a child, noting that "we do not know anything about the variation in children of a given age in this range of time."

Survival Skills

Taxonomic issues aside, much research has focused on Neandertal behavior, which remained largely misunderstood until relatively recently. Neandertals were often portrayed as incapable of hunting or planning ahead, recalls archaeologist John J. Shea of the State University of New York at Stony Brook. "We've got reconstructions of Neandertals as people who couldn't survive a single winter, let alone a quarter of a million years in the worst environments in which humans ever lived," he observes. Analysis of animal remains from the Croatian site of Krapina, however, indicates that Neandertals were skilled hunters capable of killing even large animals such



JOSÉ PAULO B. RUAS/PORTUGUESE INSTITUTE OF ARCHAEOLOGY

proposes that early moderns originating in Africa subsequently displaced all archaic humans in other regions. Instead the Lagar Velho child's anatomy supports a scenario that combines a dispersal of anatomically modern humans out of Africa with mixing between that population and the archaic populations it encountered. (The African ancestry of early modern Europeans is reflected in their relatively long lower-leg bones, a tropical adaptation. Lagar Velho 1, however, has the short shins of the cold-adapted Neandertals.)

Lagar Velho 1 also provides insights into the behavioral similarities of Neandertals and early modern humans. Despite the paleontological evidence indicating anatomical differences between these two groups, their overall adaptive patterns, social behaviors and means of communication (including language) cannot have contrasted greatly. To their contemporaries, the Neandertals were just another group of Pleistocene hunter-gatherers, fully as human as themselves.

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as rhinoceroses, according to University of Cambridge archaeologist Preston T. Miracle. And Shea's studies suggest that some Neandertals employed sophisticated stone-tipped spears to conquer their quarry—a finding supported last year when researchers reported the discovery in Syria of a Neandertal-made stone point lodged in a neckbone of a prehistoric wild ass. Moreover, additional research conducted by Shea and investigations carried out by University of Arizona archaeologists Mary C. Stiner and Steven L. Kuhn have shown that Neandertal subsistence strategies varied widely with the environment and the changing seasons.

Such demonstrations refute the notion that Neandertals perished because they could not adapt. But it may be that moderns were better at it. One popular theory posits that modern humans held some cognitive advantage over Neandertals, perhaps a capacity for the most human trait of all: symbolic thought, including language. Explanations such as this one arose from observations that after 40,000 years ago, whereas Neandertal culture remained relatively static, that of modern Europeans boasted a bevy of new features, many of them symbolic. It appeared that only moderns performed elaborate burials, expressed themselves through body ornaments, figurines and cave paintings, and crafted complex bone and antler tools—an industry broadly referred to as Upper Paleolithic. Neandertal assemblages, in contrast, contained only Middle Paleolithic stone tools made in the Mousterian style.

A Case for Neandertal Culture by João Zilhão and Francesco d'Errico

Ever since the discovery nearly 150 years ago of the specimen that defined the Neandertals, researchers have tended to deny Neandertals the behavioral capabilities of modern humans, such as the use of symbols or of complex techniques for tool manufacture. Instead Neandertals were characterized as subhuman, stuck in primitive technical traditions impervious to innovation. And when sophisticated cultural remains were linked to late Neandertals at several sites in western Europe, the evidence was explained away. The most spectacular of these sites, a cave in north-central France named Grotte du Renne (one in a string of sites collectively known as the Arcy-sur-Cure caves), yielded a wealth of complex bone and stone tools, body ornaments and decorated objects, found in association with Neandertal remains. Other sites in France and along the Cantabrian and Pyrenean mountain ranges bore similar artifacts made in this tradition, called the Châtelperronian.

Because early modern Europeans had a comparable industry known as Aurignacian—which often appears at the same sites that contain Châtelperronian materials—some researchers have suggested that the archaeological layers were disrupted, mixing Aurignacian artifacts into the Neandertal-associated levels. Other scholars have interpreted this to mean that Neandertals picked up these ideas from moderns, either collecting or trading for items manufactured by moderns or imitating the newcomers' practices without really grasping the underlying symbolic nature of some of the objects.

Our reassessment of the evidence from the Grotte du Renne shows that the Neandertal-associated personal ornaments and tools found there did not result from a mixing of the archaeological strata, as demonstrated by the presence of finished objects and the by-products of their manufacture in the same stratigraphic level. Moreover, the Châtelperronian artifacts recovered at the Grotte du Renne and other sites, such as Quinçay, in the Poitou-Charentes region of France, were created using techniques different from those favored by Aurignacians. With regard, for example, to the pendants—modified bear, wolf and deer teeth, among others—Neandertals carved a furrow around the tooth root so that a string of some sort could be tied around it for suspension, whereas Aurignacians pierced their pendants. As archaeologist François Lévêque and a colleague have described, even when, as they did on occasion, Neandertals put a hole through a tooth, they took an unusual approach, puncturing the tooth. Moderns, on the other hand, preferred to scrape the tooth thin and then pierce it.

Similarly, the new knapping techniques and tool types that appear among late Neandertals at other sites in France, Italy and Spain fail to show any influence from the Aurignacian. Instead they maintain affinities with the preceding local traditions, of which they seem to represent an autonomous development.

If the Neandertals' Châtelperronian culture was an outcome of contact with moderns, then the Aurignacian should predate the Châtelperronian. Yet our reanalysis of the radiometric dates for the archaeological sequences reveals that apart from a few debatable instances of mixture, wherever both cultures are represented at the same site, the Châtelper-

Yet hints that Neandertals thought symbolically had popped up. Neandertal burials, for example, are well known across Europe, and several, it has been argued, contain grave goods. (Other researchers maintain that for Neandertals, interment merely constituted a way of concealing the decomposing body, which might have attracted unwelcome predators. They view the purported grave goods as miscellaneous objects that happened to be swept into the grave.) Evidence for art, in the form of isolated pierced teeth and engraved bone fragments, and red and yellow ocher, has been reported from a few sites, too, but given their relative rarity, researchers tend to assign alternative explanations to these items.

The possibility that Neandertals might have engaged in modern practices was taken more seriously in 1980, when researchers reported a Neandertal from the Saint-Césaire rock-shelter in Charente-Maritime, France, found in association with stone tools manufactured according to a cultural tradition known as the Châtelperronian, which was assumed to have been the handiwork of moderns. Then, in 1996, Hublin and his colleagues made an announcement that catapulted the Châtelperronian into the archaeological limelight. Excavations that began in the late 1940s at a site called the Grotte du Renne at Arcy-sur-Cure near Auxerre, France, had yielded numerous blades, body ornaments and bone tools and revealed evidence of huts and hearths—all hallmarks of the Upper Paleolithic. The scant human remains found amid the artifacts were impossible to identify initially, but using computed tomography to examine the hidden inner-ear region preserved inside an otherwise uninformative skull fragment, Hublin's team identified the specimen as Neandertal.

In response, a number of scientists suggested that Neandertals had acquired the modern-looking items either by stealing them, collecting artifacts discarded by moderns or perhaps trading for them. But this view has come under fire, most recently from archaeologists Francesco d'Errico of the University ronian always underlies the Aurignacian, suggesting its priority. Furthermore, consideration of the hundreds of datings available from this period in Europe and the Near East shows that wherever the context of the dated samples is well known, the earliest occurrences of the Aurignacian are apparently from no earlier than around 36,500 years ago. The same radiometric data, however, indicate that by then Neandertals were already moving toward modernity on their own. In other words, the Châtelperronian and other late Neandertal cultures, such as the Uluzzian of Italy, emerged in Europe around 40,000 years ago, long before any moderns established themselves in those areas.

That this autonomous development included the manufacture and use of symbolic objects created for visual display on the body, as are often observed in traditional societies, reflects various social roles within Neandertal cultures. Thus, "modern" behavior seems to have emerged in different regions and among different groups of humans, as would happen later in history with the invention of agriculture, writing and state society.

An alternative explanation, taking into account the broadly simultaneous appearance of personal ornaments in many parts of the Old World, is that contacts between modern and archaic humans challenged each group's personal, social and biological identities, igniting an explosion of production of symbolic objects by all those involved. On the strength of the available data, however, we favor the hypothesis of independent invention.

Regardless of which is eventually proved correct, the behavioral barrier that seemed to separate moderns from Neandertals and gave us the impression of being a unique and particularly gifted human type—the ability to produce symbolic cultures—has definitively collapsed.

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FRANCESCO D'ERRICO is a CNRS researcher at the Institute of Prehistory and Quaternary Geology, University of Bordeaux, in France.

PENDANTS, BONE TOOLS AND KNIVES from the Grotte du Renne site seem to be the handiwork of Neandertals. That the advanced items underlie early modern human cultural remains from the same site and are manufactured according to methods different from those favored by the moderns suggests that some Neandertals independently developed a modern culture.

COURTESY OF DOMINIQUE BAFFIER (*left and right panels*), FROM "LES DERNIERS NÉANDERTALIENS." LA MAISON DES ROCHES, 1999; FRANCESCO D'ERRICO (*center panel*)

of Bordeaux and João Zilhão of the Portuguese Institute of Archaeology, who argue that the Châtelperronian artifacts at the Grotte du Renne and elsewhere, though superficially similar to those from the Aurignacian, reflect an older, different method of manufacture [see "A Case for Neandertal Culture," above].

Most researchers are now convinced that Neandertals manufactured the Châtelperronian tools and ornaments, but what prompted this change after hundreds of thousands of years is unclear. Cast in this light, "it's more economical to see that as a result of imitation or acculturation from modern humans than to assume that Neandertals invented it for themselves," reasons Cambridge archaeologist Paul A. Mellars. "It would be an extraordinary coincidence if they invented all these things shortly before the modern humans doing the same things arrived." Furthermore, Mellars disagrees with d'Errico and Zilhão's proposed order of events. "The dating evidence proves to me that [Neandertals] only started to do these things after the modern humans had arrived in western Europe or at least in northern Spain," he asserts. (Unfortunately, because scientists have been unable to date these sites with sufficient precision, researchers can interpret the data differently.)

From his own work on the Grotte du Renne body ornaments, New York University archaeologist Randall White argues that these artifacts reflect manufacturing methods known—albeit at lower frequencies—from Aurignacian ornaments. Given the complicated stratigraphy of the Grotte du Renne site, the modern-looking items might have come from overlying Aurignacian levels. But more important, according to White, the Châtelperronian does not exist outside of France, Belgium, Italy and northern Spain. Once you look at the Upper Paleolithic from a pan-European perspective, he says, "the Châtelperronian becomes post-Aurignacian by a long shot."

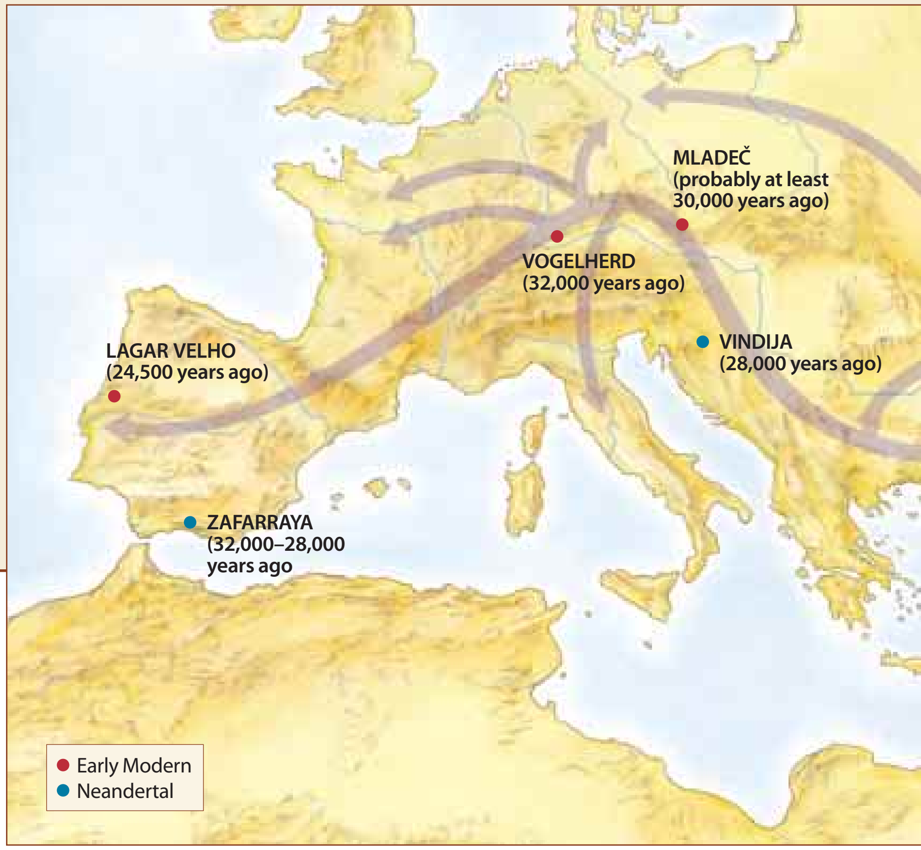
Still, post-Aurignacian does not necessarily mean after con-

The Fate of the Neandertals by Fred H. Smith

Strong evidence has accumulated in recent years that the emergence of modern humans in Europe resulted largely from the immigration of peoples into the continent, probably from the Near East, starting sometime between 40,000 and 30,000 years ago. Most researchers envision these early modern populations as having moved into Anatolia and the Balkans, then up through the plains and valleys of central Europe, and finally into northern and western Europe. Meanwhile the indigenous Neandertals, it was thought, were systematically pushed into more peripheral and undesirable parts of the landscape by these expanding populations of moderns. The Neandertals' last bastion appeared to be the Iberian Peninsula, where fossils from a Spanish site called Zafarraya have been dated to 32,000 years ago and tools attributed to Neandertals have been dated to around 28,000 years ago. Many scholars argued that after this time no traces of Neandertals remained in Europe and that Neandertals did not make any biological contributions to early modern humans. It seemed that Neandertals were sent into complete extinction by a superior human species—us.

Now new evidence from an important site in northwestern Croatia calls aspects of this conventional wisdom into question. By performing accelerator mass spectrometry dating directly on two Neandertal specimens from Vindija cave, my colleagues and I have demonstrated that Neandertals were living in some of the most desirable real estate in central Europe as late as 28,000 years ago. These dates, the most recent known for Neandertal fossils, show that these humans were not quickly relegated to the periphery; they competed quite well with intruding modern populations for a long time.

This overlap of Neandertal and early modern peoples for several millennia in the heart of Europe allowed considerable opportunity for various interactions, and Vindija may reflect some of



tact with moderns. The earliest Aurignacian sites do not include any human remains. Researchers have assumed that they belonged to moderns because moderns are known from younger Aurignacian sites. But "who the Aurignacians were biologically between 40,000 and 35,000 years ago remains very much an unanswered question," White notes.

He adds that if you look at the Near East around 90,000 years ago, anatomically modern humans and Neandertals were both making Mousterian stone tools, which, though arguably less elaborate than Aurignacian tools, actually require a considerable amount of know-how. "I cannot imagine that Neandertals were producing these kinds of technologically complex tools and passing that on from generation to generation without talking about it," White declares. "I've seen a lot of people do this stuff, and I can't stand over somebody's shoulder and learn how to do it without a lot of verbal hints." Thus, White and others do not buy the argument that moderns were somehow cognitively superior, especially if Neandertals' inferiority meant that they lacked language. Instead it seems that moderns invented a culture that relied more heavily on material symbols.

Researchers have also looked to Neandertal brain morphology for clues to their cognitive ability. According to Ralph L. Holloway of Columbia University, all the brain asymmetries that characterize modern humans are found in Neandertals. "To be able to discriminate between the two," he remarks, "is, at the moment, impossible." As to whether Neandertal anatomy would have permitted speech, studies of the base of the skull conducted by Jeffrey T. Laitman of the Mount Sinai School of Medicine suggest that if they talked, Neandertals had a somewhat limited vocal repertoire. The significance of such physical constraints, however, is unclear.

Fading Away

If Neandertals possessed basically the same cognitive ability as moderns, it makes their disappearance additionally puzzling. But the recent redating of Neandertal remains from Vindija cave in Croatia emphasizes that this did not happen them. Work by my Croatian colleagues Ivor Karavanić of the University of Zagreb and Jakov Radovčić of the Croatian Natural History Museum has revealed a combination of Mousterian and Aurignacian tools in the same stratigraphic level as the dated Neandertal fossils, suggesting that Neandertals either made advanced implements or traded with moderns for them. Morphologically, the Vindija Neandertals look more modern than do most other Neandertals, which suggests that their ancestors interbred with early moderns.

The likelihood of gene flow between the groups is also supported by evidence that Neandertals left their mark on early modern Europeans. Fossils representing early modern adults from central European sites such as Vogelherd in southwestern Germany and Mladeč in Moravia (Czech Republic) have features that are difficult to explain unless they have some Neandertal contribution to their ancestry. For example, Neandertals and early modern Europeans virtually all exhibit a projection of the back of the skull called an occipital bun (aspects of the shape and position of the buns differ between them because the overall skull shapes are not the same). Yet fossils from the Near Eastern sites of Skhul and Qafzeh, which presumably represent the ancestors of early modern Europeans, do not have this morphology. It is hard to explain how the growth phenomenon responsible for this bunning could reappear independently and ubiquitously in early modern Europeans. Instead it is far more logical to recognize this morphology as a link to the Neandertals. The Portuguese child discovered recently offers more intriguing clues [see "The Hybrid Child from Portugal," on page 102].

I believe the evidence shows that the behavioral and biological interactions between Neandertal and early modern human populations were very complex—too complex for the origins of modern humans in Europe to have involved a simple, complete biological replacement of the Neandertals. Neandertals as organisms no longer exist, and Neandertal genes may not have persisted to the present day, but those genes were there in the beginnings of modern European biological history.

FRED H. SMITH is chairman of the department of anthropology at Northern Illinois University.

SUSAN CARLSON

MOVEMENT OF MODERNS (*purple*) into Europe did not displace the Neandertals, who were still living in central and western Europe 28,000 years ago. A number of the early modern European specimens bear some Neandertal features, which suggests that during the long period of overlap the two populations mixed.

overnight. Smith and his colleagues have demonstrated that Neandertals still lived in central Europe 28,000 years ago, thousands of years after moderns had moved in [see "The Fate of the Neandertals," above]. Taking this into consideration, Stringer imagines that moderns, whom he views as a new species, replaced Neandertals in a long, slow process. "Gradually the Neandertals lost out because moderns were a bit more innovative, a bit better able to cope with rapid environmental change quickly, and they probably had bigger social networks," he supposes.

On the other hand, if Neandertals were an equally capable variant of our own species, as Smith and Wolpoff believe, long-term overlap of Neandertals and the new population moving into Europe would have left plenty of time for mingling, hence the mixed morphology that these scholars see in late Neandertals and early moderns in Europe. And if these groups were exchanging genes, they were probably exchanging cultural ideas, which might account for some of the similarity between, say, the Châtelperronian and the Aurignacian. Neandertals as entities disappeared, Wolpoff says, because they were outnumbered by the newcomers. Thousands of years of interbreeding between the small Neandertal population and the larger modern human population, he surmises, diluted the distinctive Neandertal features, which ultimately faded away.

"If we look at Australians a thousand years from now, we will see that the European features have predominated [over those of native Australians] by virtue of many more Europeans," Wolpoff asserts. "Not by virtue of better adaptation, not by virtue of different culture, not by virtue of anything except many more Europeans. And I really think that's what describes what we see in Europe—we see the predominance of more people."

From the morass of opinions in this notoriously contentious field, one consensus emerges: researchers have retired the old vision of the shuffling, cultureless Neandertal. Beyond that, whether these ancient hominids were among the ancestors of living people or a very closely related species that competed formidably with our own for the Eurasian territory and eventually lost remains to be seen. In either case, the details will most likely be extraordinarily complicated. "The more we learn, the more questions arise, the knottier it gets," muses archaeologist Lawrence G. Straus of the University of New Mexico. "That's why simple explanations just don't cut it." SA

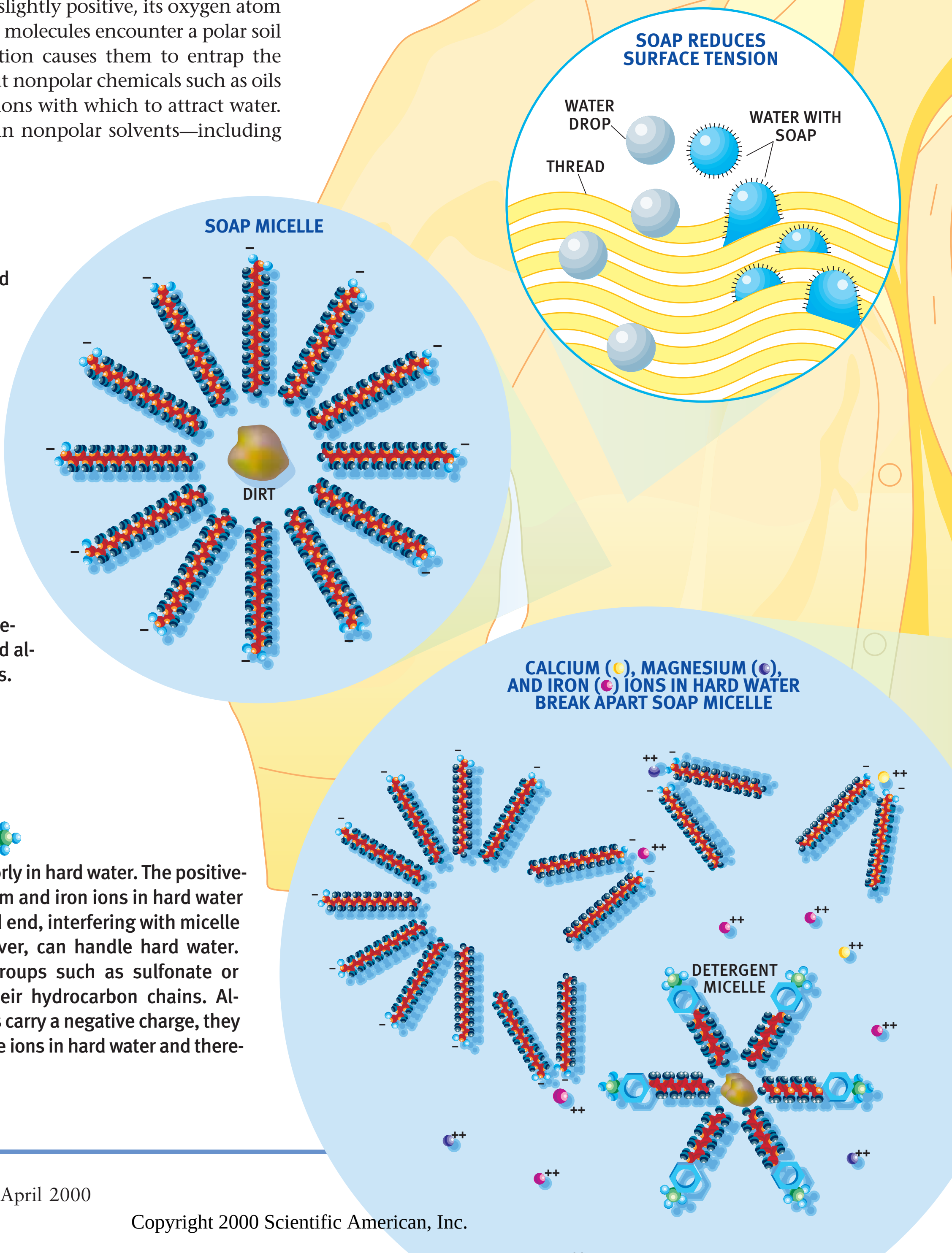
Cleaning Agents

Cleaning clothes, dishes and hair would be easy if all soils and stains dissolved in water—washing would consist of a simple rinse. But solvents such as water are finicky liquids that dissolve some chemicals better than others. It's a matter of attraction: if solvent molecules are more strongly attracted to one another than to a soil molecule, they will have trouble dissolving it. Unfortunately, many of the soils we want to remove don't bind well to water.

Water is an excellent solvent for polar chemicals—including salts, which dissociate easily into electrically charged ions, or sugars, which have charged regions. Water itself is a polar molecule; its hydrogen atoms are slightly positive, its oxygen atom slightly negative. When water molecules encounter a polar soil molecule, electrostatic attraction causes them to entrap the molecule and carry it away. But nonpolar chemicals such as oils and fats have no charged regions with which to attract water. These soils can be dissolved in nonpolar solvents—including perchloroethylene and naphtha—but those chemicals are noxious and damaging to the environment.

Therein lies the beauty of soaps and detergents. Their molecules are polar at one end, nonpolar at the other; they are equally at home in polar and nonpolar environments. In water, these molecules form tiny spherical shells called micelles, with their polar ends turned outward and their nonpolar ends turned inward. The nonpolar insides of these micelles dissolve oily molecules, so that when you clean with soapy water, its micelles catch the nonpolar molecules and carry them away.

—Louis A. Bloomfield



SOAPS 

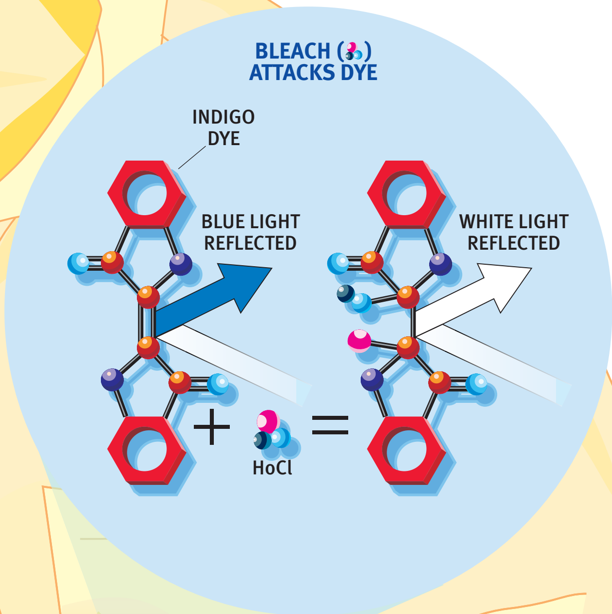
Most soaps are salts derived from fats or oils and consist of positively charged sodium ions and negatively charged molecular chains. Each negative ion's charge is located at one end, where its nonpolar hydrocarbon chain ends in a polar carboxylate group. When you add soap to water, its sodium ions dissolve, and the now negatively charged chains form micelles. The chains also coat the surface of water molecules, reducing their surface tension and allowing them to penetrate fabrics.

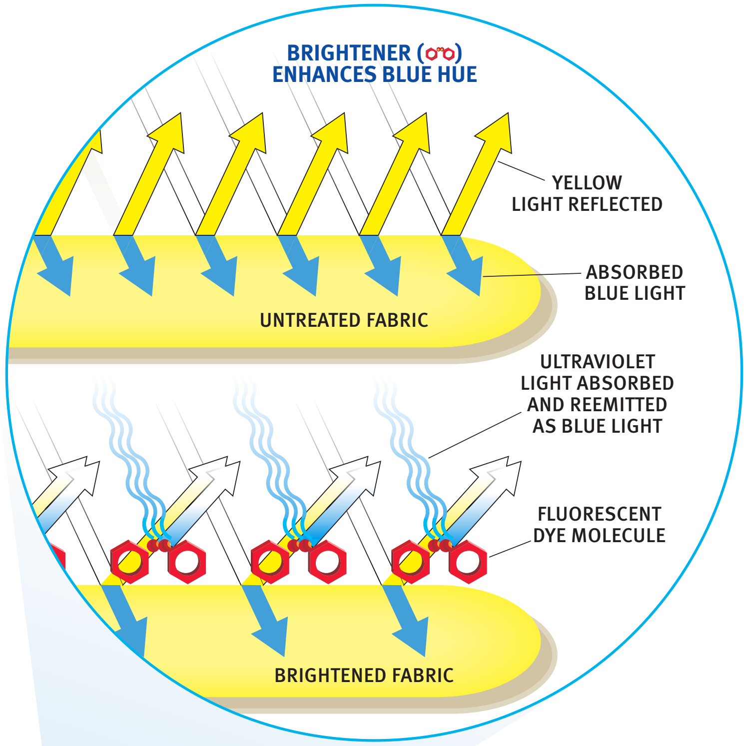
DETERGENTS 

Unfortunately, soap works poorly in hard water. The positively charged calcium, magnesium and iron ions in hard water bind to the negatively charged end, interfering with micelle formation. Detergents, however, can handle hard water. They have synthetic polar groups such as sulfonate or ethoxysulfate attached to their hydrocarbon chains. Although those synthetic groups carry a negative charge, they are only weakly attracted to the ions in hard water and therefore continue to clean well.

Bleaches

Some stains, like ink spots, are bound so tightly in place that they can't be dissolved and must be destroyed instead. Their colors are often associated with weakly bound electrons, such as those involved in double bonds between atoms. Bleaches attack those vulnerable electrons and use electron-withdrawing atoms—such as oxygen and chlorine—to snap them up. The stain molecules then become colorless and invisible.





Brighteners

As they age, white fabrics acquire a yellowish cast because they begin to absorb light at the blue end of the spectrum instead of reflecting it. To replace this "missing" blue light, brighteners are added to many detergents. These fluorescent dyes absorb invisible ultraviolet light and use its energy to emit blue light. This extra blue hides the fabric's yellowed appearance. When exposed to sunlight, brightened fabric has a strong bluish glow and appears brilliantly white. We are so used to this glow that nearly all white fabric is predyed with brighteners to make it look white enough for our tastes.

LOUIS A. BLOOMFIELD is a professor of physics at the University of Virginia and author of *How Things Work: The Physics of Everyday Life.*

Did you know ...

● When wet, hair and many fabrics acquire a weak negative charge. This charge gently repels both the negatively charged soap and detergent micelles and keeps them from redepositing greasy soil molecules. But the molecular ions in most conditioners and fabric softeners have positively charged ends that attract them to hair and fabric, causing them to remain there as the water evaporates. They then release their softening or hydrating molecules.

● It's hard to combine shampoo and conditioner in a single bottle because the negatively charged shampoo ions and the positively charged conditioner ions tend to interfere with one another. The hair cleaners that contain both ingredients trap the conditioner molecules in crystalline shells or complexes that open only when exposed to excess water. So the conditioner molecules are hidden while you're lathering your hair but are released when you rinse.

● Many fibers carry polar chemical groups to which water molecules bind tightly, making them swell and stretch when wet. As those fibers dry, they return to their original sizes but not their original shapes. The result is structural damage to the garment. To avoid such damage, these fabrics can be dry-cleaned with nonpolar, albeit toxic, solvents such as perchloroethylene. Detergents added to these solvents form inverse micelles that can dissolve polar soils.

BRYAN CHRISTIE

EXTREME_HEAT

A Furnace in a Thermos

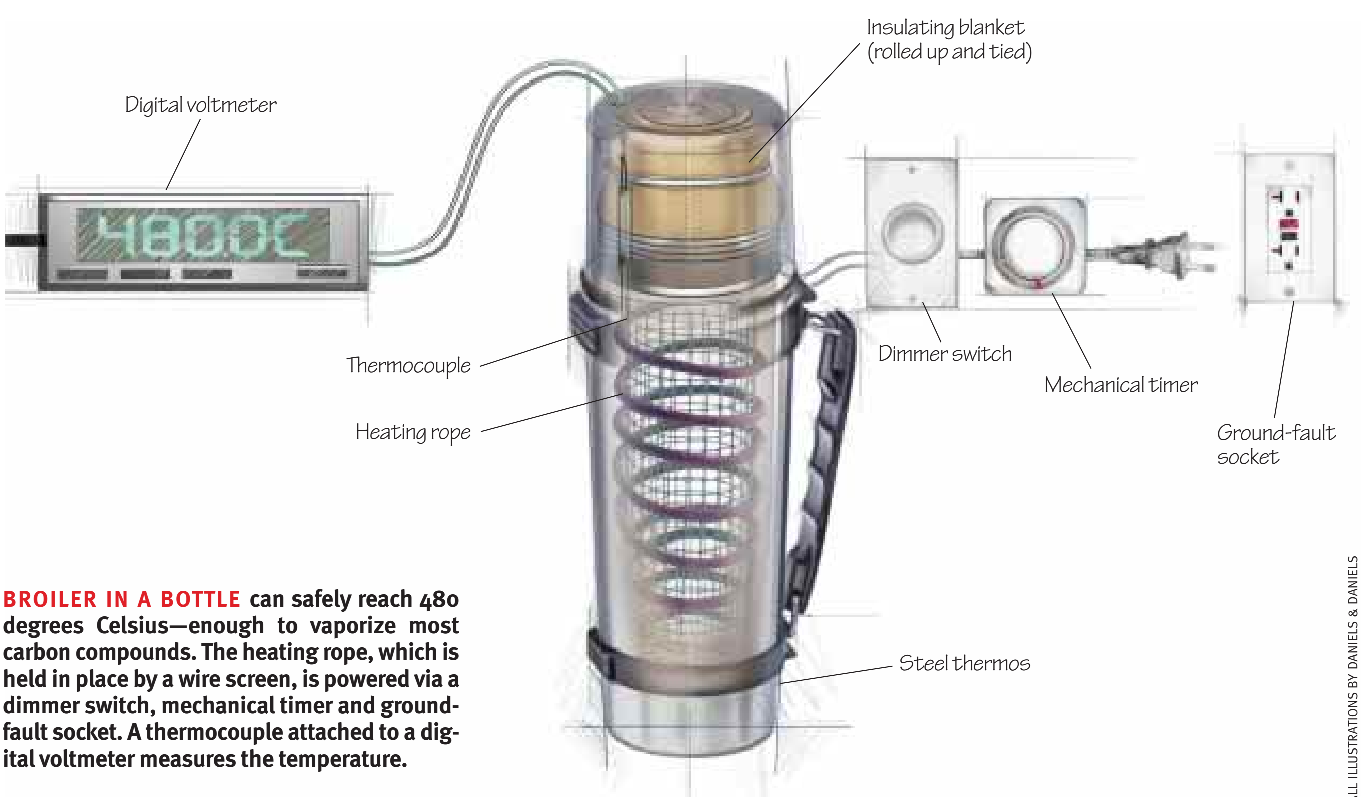
An easy-to-build oven is an essential tool for any basement lab, explains **Shawn Carlson**

When set at its maximum temperature of about 260 degrees Celsius (500 degrees Fahrenheit), a kitchen oven is quite capable of rapidly reducing an expensive steak into a sizzling mass of crunchy carbon. This I know from sorry experience. But ordinary ovens are still not hot enough for many research needs. Measuring the organic content of soils is one example. Fertile earth contains all sorts of biochemical and microbial goodies that higher plants cannot live without. To discover how organically rich a soil is, you have to weigh a sample, remove the organics and then weigh it again. The only way I know to eliminate all the organic material is to bake the soil at a high temperature. At around 450 degrees C (840 degrees F), organics break down into their constituent elements, and the carbon bonds to atmospheric oxygen to create carbon monoxide and carbon dioxide gases. The charred residue evaporates, leaving the soil devoid of all the trappings of life.

Because the same process that cooks organic material out of soil will also remove it from the surface of glass, a furnace that approaches 500 degrees C can be used to clean the most intricate laboratory glassware. Likewise, baking sorbents at this temperature drives away chemical contaminants and recharges them for reuse in, say, pumps for producing ultraclean vacuums (the topic of the October 1996 column). Such a furnace would have other uses as well, including melting enamels, activating glass beads for use in chemical separators, annealing glass and metals, and making electrical feed-throughs for laboratory glassware.

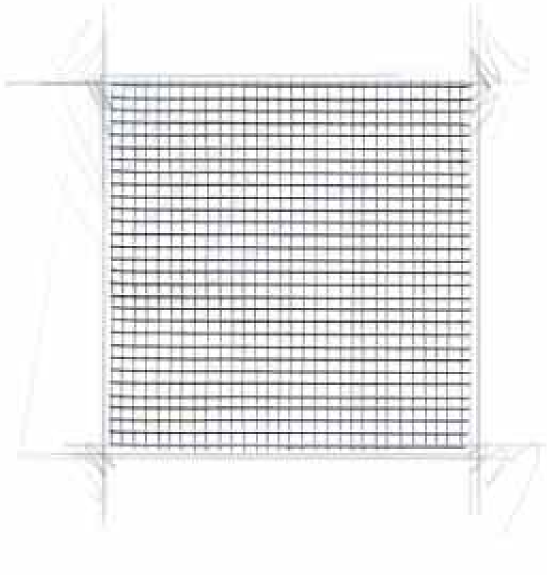
So you can see why I was thrilled to learn that Roger Daschle, a talented musician and hiking buddy of mine, had developed a small furnace that is safe to operate at these temperatures. It consumes a scant 80 watts, heats up in less than an hour and can be built for as little as $60.

Roger and I are part of an informal ensemble of self-absorbed iconoclasts who hike every Friday in the San Diego County foothills to get away from our offices and talk tech. His ingenious innovation came to him while he was pouring a cup of hot chocolate during a lull in our discussions of chaos theory and homemade infrared detectors. Roger wanted to build a stout furnace to service a small chemical separator he was developing. When he poured a cup of cocoa from his thermos and saw the rising steam in the cold afternoon air, he realized that he had found the perfect container. A thermos is inexpensive and has negligible thermal mass. He knew that if he could secure a high-temperature electric heater inside a suitable thermos and plug the top with an insulator, he would have a fully functional and highly efficient desktop furnace.

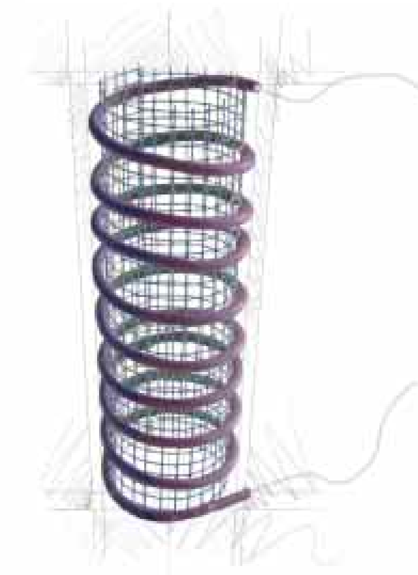


BROILER IN A BOTTLE can safely reach 480 degrees Celsius—enough to vaporize most carbon compounds. The heating rope, which is held in place by a wire screen, is powered via a dimmer switch, mechanical timer and ground-fault socket. A thermocouple attached to a digital voltmeter measures the temperature.

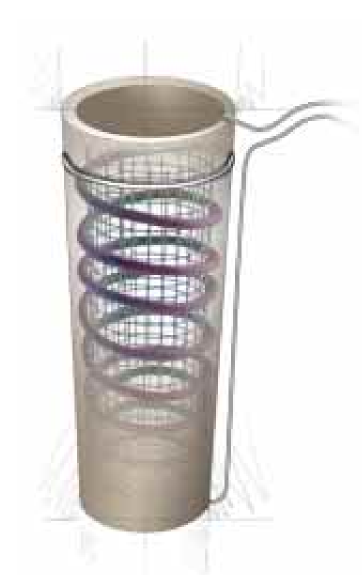
ALL ILLUSTRATIONS BY DANIELS & DANIELS



WIRE SCREEN is bent into a thermos-size cylinder ...



... around which the heating rope is then wrapped ...



... and encased in insulating Fiberfrax or muffler packing.

Roger showed off his invention at our next hike. He had purchased a Stanley-brand wide-mouth thermos (the kind typically used to hold soup) for $25 from a local discount store. But the brand doesn't matter. Just make sure the vacuum bottle is made of steel and not glass, which might break, or aluminum, which might soften and implode. Roger got things cooking with a rope heater: a prefabricated bundle of Nichrome wire wrapped around an insulating core and covered with an insulating sheath. These cords run on wall current and are much safer than bare wire. Omega Engineering sells them in three-foot lengths for $22 (www.omega.com, part no. FGR-030). The rope is rated for operation at 480 degrees C (900 degrees F). This sets the safe operating temperature of the furnace. The device will get much hotter if you run too much current through it. You can keep the current at a safe level by wiring in a household dimmer switch and monitoring the temperature. As a precaution, Roger wisely wired in a one-hour mechanical timer to make sure that his unit could not be accidentally left on.

To install the heater in the thermos, Roger fashioned a cylinder out of a wide-mesh steel screen, available at a well-stocked hardware store. He loosely coiled the heating rope around the cylinder and covered the entire assembly with a centimeter-thick blanket of Fiberfrax, a clothlike material made of spun alumina fibers. (Because you can't purchase Fiberfrax in small quantities, the Society for Amateur Scientists will provide it for $5.) Muffler packing, available at a motorcycle parts store, would also do. The whole thing snugs into the thermos through its wide mouth. Finally, Roger tightly rolled a strip of Fiberfrax into a plug that just fit into the thermos mouth. A single twist of steel wire wrapped around the plug prevents it from unraveling.

The most economical way to measure the temperature is a K-type thermocouple, which produces a voltage in proportion to the temperature. The voltage can be read with a high-end digital voltmeter that has internal circuitry to interpret this sensor. Otherwise, you can estimate the temperature by measuring the voltage developed between the leads using a digital voltmeter. The temperature in Celsius is given approximately by multiplying the voltage in millivolts by 27.7; for Fahrenheit, multiply by 50. I tested Roger's furnace using a bare-wire thermocouple from Omega Engineering (part no. CHAL-015). I insulated it using a short length of Nextel sleeving (Omega part no. XC4-116) and installed the sensor near the top of the furnace. At 480 degrees C inside, the exterior was uncomfortably warm but not too hot to touch. When, as a safety test, I pushed the device to 600 degrees C using an ultra-high-temperature heating tape, the outer casing got far too hot to handle.

So make sure to monitor the temperature at all times and keep it at or below 480 degrees C. Keep it well away from curious children and pets. Wire in a timer switch. And connect the heating unit through a ground-fault switch, such as those often seen in bathroom wall outlets these days. These switches contain an internal circuit breaker that blows when a short circuit occurs. That way, if the furnace should overheat and short out, the power will be cut off.

Using the furnace, you can easily measure the organic content of soil. First, carefully weigh about 100 grams of dirt from your garden and dry it in your kitchen oven for one hour at 120 degrees C (about 250 degrees F). Then weigh it again. The soil in my garden turned out to contain 33.2 percent water by weight. Tightly wrap the dry soil in aluminum foil and bake it in your thermos furnace for two hours at 480 degrees C. The charring organics liberate a ghastly waft of smelly smoke, so use a fume hood or keep the device outdoors. A final weigh-in revealed that my garden dirt is 8.6 percent (dry weight) organic material. Sand from a nearby playground weighed in at just 3.2 percent water and contained a scant 0.7 percent organics (dry weight).

It would also be interesting to monitor the weight continuously, in order to look for physical processes that occur at different temperatures. SA

As a service to the amateur community, the Society for Amateur Scientists will provide enough Fiberfrax insulation to build this project (until April 2001). The cost is $5 + $2.50 domestic shipping, $5 foreign shipping. For more information about this and other projects from this column, check out the Society for Amateur Scientists's Web page at sas.org. You may write the society at 4735 Clairemont Square, PMB 179, San Diego, CA 92117, or call 619-239-8807.

Counting the Cattle of the Sun

Some problems are too big to solve by trial and error, says **Ian Stewart**

In his 1917 book *Amusements in Mathematics,* English puzzle maker Henry Ernest Dudeney described a fanciful problem based on the Battle of Hastings, the famous confrontation in 1066 between the Saxons under King Harold and the Normans under William the Conqueror. According to Dudeney, an ancient chronicle of the battle stated: "The men of Harold stood well together, as their wont was, and formed sixty and one squares, with a like number of men in every square thereof.... When Harold threw himself into the fray the Saxons were one mighty square of men." What, asked Dudeney, is the smallest possible number of men in King Harold's army?

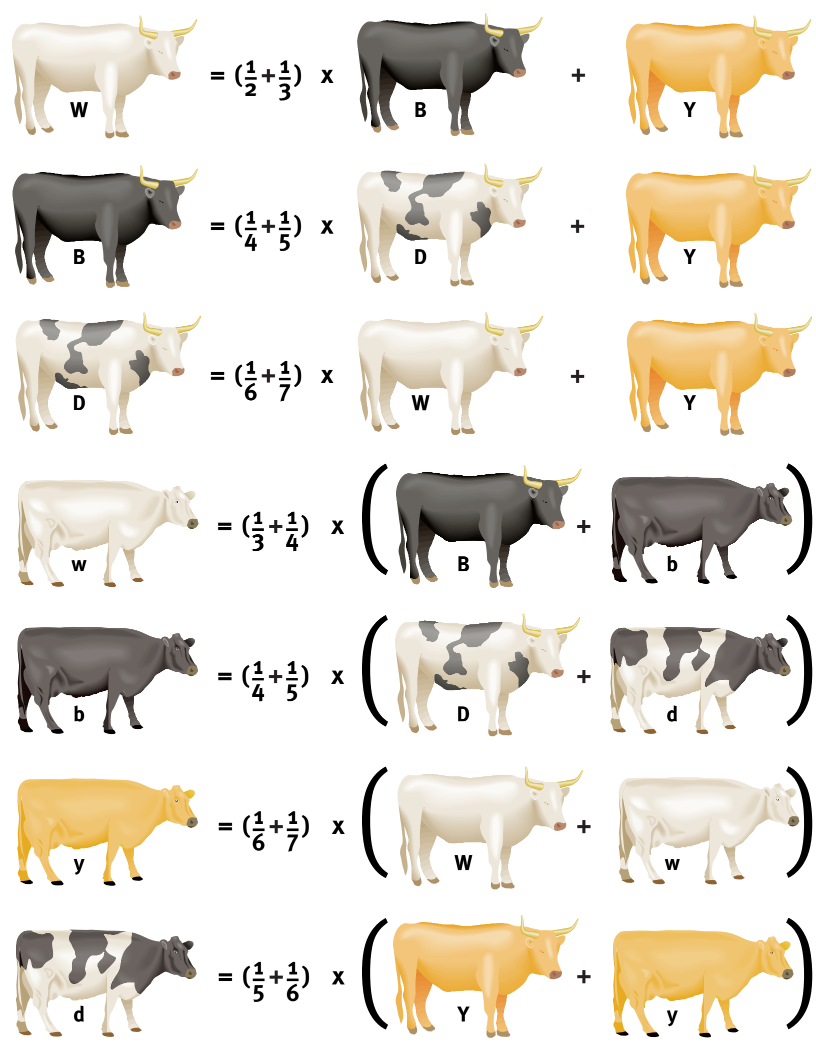
Mathematically, we want to find a perfect square that, when multiplied by 61 and increased by 1, yields another perfect square. That is, we want integer solutions of the equation $y^2 = 61x^2 + 1$. This is an example of a Pell equation, mistakenly named after an obscure 17th-century English mathematician whose contributions to the field were not original. Equations of this general kind—in which 61 can be replaced by any nonsquare positive integer—always have infinitely many solutions. The technique for calculating the solutions is called the continued-fractions method, which can be found in most number theory textbooks.

As a warm-up, let's take a look at the lesser-known Battle of Brighton, where King Harold's men formed 11 squares, all else being unchanged [*see illustration on opposite page*]. Now the equation is $y^2 = 11x^2 + 1$. A little trial and error reveals the smallest solution: $x = 3$, $y = 10$.

Trial and error, though, will not solve Dudeney's puzzle—except perhaps on a computer—because the smallest solution is $x = 226{,}153{,}980$, $y = 1{,}766{,}319{,}049$. Solutions of the Pell equation $y^2 = Dx^2 + 1$ vary wildly with D, the positive nonsquare coefficient. The "difficult" values of D below 100—that is, those that yield a smallest solution for x that is greater than 1,000—are D = 29, 46, 53, 58, 61, 67, 73, 76, 85, 86, 89, 93, 94 and 97. By far the most difficult value is 61, so Dudeney chose wisely. With a bit of effort you should be able to find out what happens for D = 60 and D = 62, on either side of Dudeney's cunning 61 (the answers are provided at the end of the column).

Mind you, Dudeney could have made the puzzle a lot harder: with D = 1,597, the smallest solutions for x and y are approximately 1.3×10^{46} and 5.2×10^{47}. And D = 9,781 is even worse.

The Pell equation is also the key to solving a much more famous puzzle called the Cattle of the Sun. In 1773 German dramatist Gotthold Ephraim Lessing discovered a manuscript containing the problem, which was expressed in the form of a poem: 22 elegiac couplets supposedly written by Greek mathematician Archimedes of Syracuse around 250 B.C. and sent in a letter to Eratosthenes of Cyrene, the chief librarian at Alexandria. It begins, "If thou art diligent and wise, O stranger,



COW CRUNCHING: In the Cattle of the Sun problem, the numbers of bulls and cows of each color are determined in part by these seven equations.

ALL ILLUSTRATIONS BY BRYAN CHRISTIE

compute the number of cattle of the Sun, who once upon a time grazed on the fields of the Thrinacian isle of Sicily."

The cattle of the sun are mentioned in Homer's *Odyssey*. The epic poem claimed that there were 350, but Archimedes had a larger figure in mind. According to his puzzle, the herd is divided into white bulls (W), black bulls (B), yellow bulls (Y) and dappled bulls (D), together with the corresponding varieties of cows (w, b, y and d). The number of cattle is specified by seven easy-to-satisfy conditions and two difficult ones. The easy conditions can be expressed as seven equations relating the eight variables [*see illustration on opposite page*]. The first difficult condition is that the total number of white and black bulls (W + B) must be a perfect square. The second is that the total number of yellow and dappled bulls (Y + D) must be a triangular number—that is, it must equal a sum $1 + 2 + 3 + \ldots + m$, where m is a positive integer.

The first seven conditions boil down to a single fact: all eight unknowns are proportional to one another by fixed ratios. Unraveling the equations, we find that the solutions are (for any integer n):

W = 10,366,482n, B = 7,460,514n,
Y = 4,149,387n, D = 7,358,060n,
w = 7,206,360n, b = 4,893,246n,
y = 5,439,213n, d = 3,515,820n

The challenge now is finding the smallest n that satisfies the two difficult conditions. In 1830 German mathematician J. F. Wurm solved a simpler version of the problem, which ignored the condition that W + B be a perfect square. The condition that Y + D be a triangular number leads, after some algebra, to the requirement that 92,059,576n + 1 be a square. If we plug in the smallest value of n that fulfills this requirement, the total number of cattle is a mere 5,916,837,175,686.

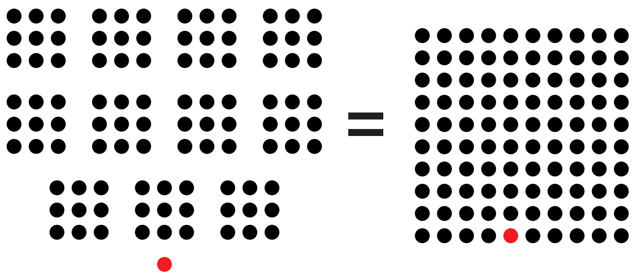
Wurm's equation, however, has infinitely many solutions for n, and among them we can seek the smallest that also satisfies the condition that W + B be a perfect square. In 1880 A. Amthor—another German mathematician—proved that n must equal 4,456,749m^2, where m satisfies a Pell equation: 410,286,423,278,424m^2 + 1 = a perfect square. The continued-fractions method can now be used to find the smallest such m. The calculations were too intractable for Amthor to complete, but he determined that the total size of the herd is a number with 206,545 digits, the first four of which he was able to identify. Between 1889 and 1893 the Mathematical Club in Hillsboro, Ill., calculated the first 32 digits, 30 of which turned out to be correct. The first complete solution was found in 1965 by mathematicians at the University of Waterloo in Ontario. The list of all 206,545 digits was published in 1981 by Harry L. Nelson. He used a CRAY-1 supercomputer, and the calculation took 10 minutes.

There, until recently, the matter rested. Today's mathematicians, however, have ultrafast computers that can do arithmetic to hundreds of thousands of digits in the blink of an eye. Ilan Vardi of Occidental College found that the computer algebra package called Mathematica could redo all the above analysis in a few seconds. Pushing a little harder, he discovered that Mathematica could also produce an exact formula for the size of the herd; previously, mathematicians had not suspected that such a formula existed. On a Sun workstation—an appropriate choice given the owner of the cattle—the computation took an hour and a half. The details are described in Vardi's article "Archimedes' Cattle Problem," in *American Mathematical Monthly* (April 1998). The upshot of all this is that the total number of cattle is the smallest integer that exceeds $(p/q)(a + b\sqrt{4{,}729{,}494})^{4{,}658}$, where

p = 25,194,541
q = 184,119,152
a = 109,931,986,732,829,734,979,866, 232,821,433,543,901,088,049
b = 50,549,485,234,315,033,074,477,819, 735,540,408,986,340.

Scholars debate whether Archimedes actually posed this problem. The consensus view is that he did, although he may not have written the poem. What is more certain is that Archimedes could not have solved the problem—it is simply too big. Calculation by hand would have taken far too long. Did Archimedes even know that a solution existed? Probably not. He was certainly clever enough to figure out that some type of equation was required, but it seems unlikely that he could have known that such an equation would always have a solution. The moral of the story: Beware of Greeks bearing puzzles. SA

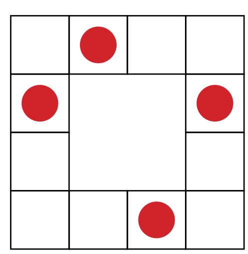
ANSWERS: For D = 60, x = 4, y = 31
For D = 62, x = 8, y = 63



SMALLEST SOLUTION: **Army of 99 soldiers (*black dots*) and King Harold (*red dot*) can be arrayed in 11 squares led by Harold (*left*) or in one big square including Harold (*right*).**

READER_FEEDBACK

In response to "The Synchronicity of Firefly Flashing" [March 1999], Cindy Eisner of Zichron Yaacov, Israel, has done a complete analysis for all moderate-size boards, finding in each case the largest group of fireflies for which no pair ever converges and the number of initial states that never lead to any synchronization. On a four-by-four board, for example, the largest group of fireflies for which no pair ever converges contains four fireflies, which start at positions 1, 4, 7 and 11 (*below*). On a 15-by-15 board the largest group of nonconverging fireflies contains 15, which start at positions 0, 4, 6, 8, 11, 13, 17, 21, 24, 27, 31, 37, 41, 46 and 51. On this board there are 124,523 initial states that never lead to synchronization, out of a total of 7.20576×10^{16} possibilities.



Moreover, for a board of any size, there are always initial states for two fireflies that ensure that they will never converge. For example, put them at positions 0 and $2n - 3$ on an n-by-n board. Eisner conjectures that these states are the only nonsynchronizing ones for two fireflies. —*I.S.*

REVIEWER_DEAN H. HAMER

A Three-Billion-Year Memoir

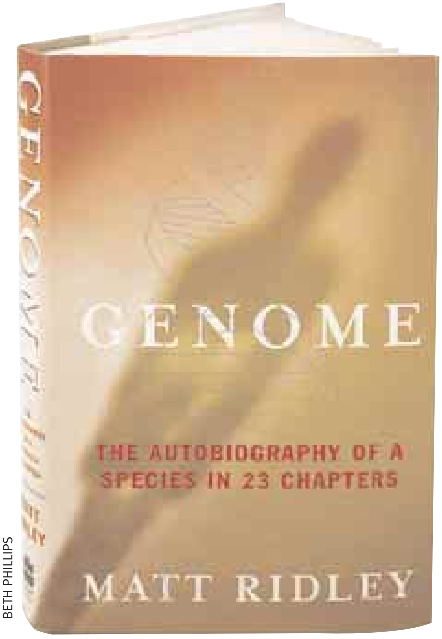
Thanks to **Matt Ridley,** the human genome now has its own autobiography

The human genome is becoming a celebrity. It already has its own fan magazines, in the form of two professional journals devoted exclusively to genome research, and its own Web sites, including www.gdb.org. It also has its own publicists, at the government's National Human Genome Research Institute and at the private company Celera Genomics. The unveiling of the first draft of its complete primary sequence—which Celera has promised to produce within the year—is as eagerly anticipated as the next Madonna album. Now, thanks to science writer Matt Ridley, it even has its own autobiography: *Genome: The Autobiography of a Species in 23 Chapters.*

It is no surprise that Ridley, an avid proponent of the Darwinian view of the world, perceives the genome not as a cookbook or a manual but as a quintessentially historical document—a three-billion-year memoir of our species from its beginnings in the primal ooze to the present day. The first popular book written by Ridley, who has a Ph.D. in zoology and covered science for *The Economist* for nine years, was *The Red Queen,* an engrossing account of sexual selection. His second volume, *The Origins of Virtue,* delved into the sociobiology of good and evil. *Genome* continues the author's interest in evolution and at the same time offers excursions into molecular biology, medicine and biotechnology.

Unlike many celebrity autobiographies, *Genome* is largely free of gossip and personal digs; for example, the vicious catfight between Francis S. Collins, leader of the government-supported Genome Project, and Craig Venter, president of Celera, is barely mentioned. Nor is it a long recitation of "disease-gene-of-the-month" discoveries, for as Ridley reminds us more than once, "Genes are not there to cause diseases." Instead he gives us a freewheeling, eclectic, often witty tour of modern molecular biology, illustrated by picking one gene from each of our 23 chromosomes.

It is an exciting voyage. We learn about the homeobox genes, which guide the development of the entire human body from a single cell. The gene for telomerase, an enzyme that repairs the ends of frayed chromosomes, is the focus for a discussion of aging and immortality. Ethnic differences in the frequency of a particular breast cancer gene are used to describe the relations among population genetics, prehistoric migrations, and linguistic groups, while the gene for the classical ABO blood groups is the springboard for a discussion of genetic selection and drift. The book describes genes that we share with all living creatures and those that are unique to our species, genes that are essential to every cell and those that seem to serve no useful purpose at all, genes that predict disease with complete certainty and those that only tilt the scales.



BETH PHILLIPS

Genome: The Autobiography of a Species in 23 Chapters
by Matt Ridley
HarperCollins, New York, 2000 ($26)

Although Ridley covers a broad range of topics, his love of evolutionary psychology is evident from the number of chapters devoted to behavior. He writes about recent evidence of genetic links to memory and intelligence, personality, language and even free will. But Ridley is no genetic determinist. He sees the brain as part of a complex, interconnected system, equally influenced by genes and environment, with no one force predominant: "You are not a brain running a body by switching on hormones. Nor are you a body running a genome by switching on hormone receptors. Nor are you a genome running a brain by switching on genes that switch on hormones. You are all of these at once.... Many of the oldest arguments in psychology boil down to misconceptions of this kind. The arguments for and against 'genetic determinism' presuppose that the involvement of the genome places it above and beyond the body."

Ridley includes just the right amount of history and personal anecdotes to spice up the science. He's a good storyteller. I have read many versions of the discovery of DNA as the carrier of genetic information, from Friedrich Miescher's extraction of pus-soaked bandages to Watson and Crick's elucidation of the structure of the molecule, but still found Ridley's version captivating. His capsule descriptions of some of the modern genome researchers are concise yet revealing.

It is clear that Ridley is a big fan of the Genome Project. He writes with gusto about the rapid advancement of the science, the thrill of discovery and the power of the new technology it has unleashed. But at times his enthusiasm may lead him astray. For instance, Ridley advocates that people be tested for the *APOE* gene that is a predictor of susceptibility to Alzheimer's disease. His argument is that people who are genetically at risk should avoid sports such as football and boxing because of the connection between head injury and disease onset. But given that there is no true prevention or treatment for Alzheimer's disease, it seems likely that such information would cause at least as much harm as good. For example, a person who could have become a millionaire professional athlete might instead decide to take a lower-paying job, even though he is destined to die of other causes long before Alzheimer's would ever have set in. Or another individual who never would have played sports at all might not be able to obtain desperately needed health insurance because of his test results. Although Ridley clearly understands the scientific distinction between genetic determinism and predisposition, he sometimes fails to consider the policy implications.

At times Ridley's enthusiasm about the science even causes him—like a devoted fan who believes every one of Madonna's songs is perfect in every way—to gloss over potential weaknesses and inconsistencies in the evidence. For example, the "intelligence gene" and "language impairment gene" described in chapters 6 and 7 are merely statistical linkages, not actual genes, and the results have yet to be replicated by independent scientists. And the dopamine receptor gene highlighted in the chapter on personality was originally thought to be involved in thrill seeking but now appears to be more important in attention-deficit disorder.

On the other hand, Ridley's excitement about the science has the benefit that the book is very much up-to-date, with many of the references from just the past year. And even the most speculative of his ideas is made palatable by the consistently graceful language and imaginative use of metaphors.

To biologists, the genome is simply the complete set of genes contained in our 23 pairs of chromosomes, and the Genome Project is merely a funding strategy to make sure it gets decoded. But different people have different views of the genome, just as they often do of celebrities. To advocates, it is the "Human Blueprint" or, more grandiosely, the "Book of Life." To critics, it is a Doomsday book, full of unwanted information just waiting to be abused by unscrupulous insurers, employers, eugenicists and social Darwinists. And to Wall Street investors it is cold cash; despite negative earnings, shares in Celera have soared almost 20-fold in less than one year. But what the Genome Project really is, above all else, is a beginning—the start of a new way of doing biology, of understanding diseases, of comparing organisms, of tracing our origins and even of understanding ourselves. *Genome* provides a delightful introduction to all who wish to follow the career of this rising star. SA

DEAN H. HAMER *is a molecular biologist, co-author of* Living with Our Genes *and* The Science of Desire, *and chief of gene structure and regulation at the National Cancer Institute.*

Books

EDITORS_RECOMMEND

LISA JARDINE'S *Ingenious Pursuits: Building the Scientific Revolution*. Doubleday, New York, 1999 ($35).

Jardine's engrossing book consists mainly of well-told stories of scientific work during the intellectual revolution of the 17th and early 18th centuries. She has three objectives in telling the stories: to give a sense of the "exuberant intellectual exchanges that provide the foundation for each ... advance in knowledge"; to show that "imaginative problem-solving is at the root of all human inventiveness, both in the sciences and the humanities"; and to demonstrate that "the scientist is not a malevolent Dr. Frankenstein, creating monsters beyond his control."

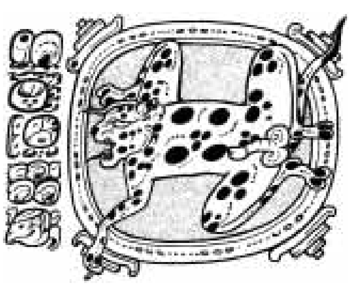
And so she takes the reader intimately into the personalities and achievements of prominent scientists of those centuries, enriching her account with illustrations of the people and the work. Among her topics are what Robert Hooke and Antonie van Leeuwenhoek saw under their primitive microscopes, what Edmond Halley and Isaac Newton discovered about the orbits of comets, and what Gian Domenico Cassini and Christian Huygens contributed to determining longitude and to cartography. Jardine, professor of Renaissance studies at the University of London, says of her stories: "When the tales are told in this way, we put back the people into the laboratory, and the laboratory into its wider community."


FROM *INGENIOUS PURSUITS*

MICHAEL D. COE'S *Breaking the Maya Code*. Revised paperback edition. First published 1992. Thames & Hudson, New York, 1999 ($18.95).

The decipherment of the Maya script was, Coe states, "one of the most exciting intellectual adventures of our age, on a par with the exploration of space and the discovery of the genetic code." He presents the story eloquently and in detail, with many illustrations of the mysterious Maya inscriptions and the people who tried to decipher them. Most of the credit, he says, goes to the late Yuri V. Knorosov of the Russian Institute of Ethnography, but many others participated. They did not always agree, and some of them went up blind alleys. Coe—emeritus professor of anthropology at Yale University—vividly describes the battles, missteps and successes. What is now established, he writes, is that "the Maya writing system is a mix of logograms and syllabic signs; with the latter, they could and often did write words purely phonetically."

Coe concludes with a swipe at "dirt archaeologists" who believe the decipherment of Maya writing "is not worthy of notice." According to them, he asserts, "the Maya inscriptions are 'epiphenomenal,' a ten-penny word meaning that Maya writing is only of marginal application since it is secondary to those more primary institutions—economy and society—so well studied by the dirt archaeologists." Coe sees that attitude as "sour grapes" and ascribes it to "the inability or unwillingness of anthropologically trained archaeologists to admit that they are dealing with the remains of real people, who once lived and spoke."


FROM *BREAKING THE MAYA CODE*

JEANNE GUILLEMIN'S *Anthrax: The Investigation of a Deadly Outbreak*. University of California Press, Berkeley and Los Angeles, 1999 ($27.50).

In April 1979 the Soviet city of Sverdlovsk was suddenly struck by an epidemic of anthrax. At least 64 people died; the number may have been much higher. The official explanation was that contaminated meat had been sold in the city. Guillemin, professor of sociology at Boston College, was a member of a Russian-American team that Russia allowed years later (in 1992) to "piece together what information time and political censorship had not destroyed." What the team discovered was that a plume of aerosolized anthrax spores had escaped from Compound 19, a military base that had "a biological facility," a few days before anthrax spread among animals and people downwind.

What Compound 19 was doing with anthrax remains unclear. The work may have been part of a biological warfare program. Because bioterrorism with anthrax is a concern today, Guillemin considers what might be done about it. She thinks the approach of the U.S. government—focusing on vaccination, civil-defense drills and a buildup of public health facilities—is wrong-headed. "Is the growth of a new 'threat industry' the best we can do? Are landscapes of fear the American environments of the future? Or is there a middle ground, where reasonable tactics for legal restraints can be combined with reasonable tactics to identify real threats to national security?"

CHRISTOPHER COKINOS'S *Hope Is the Thing with Feathers: A Personal Chronicle of Vanished Birds.* Penguin Putnam, New York, 2000 ($24.95).

Cokinos's title is the first line of one of Emily Dickinson's gossamer-steel poems. He gives us, poetically and movingly, the stories of six bird species that human actions have driven to extinction. His hope, as it applies to living things in general, is that "we can work to protect the still-astonishing nonhuman lives that have come to depend on us for patience and care." And, as it applies in particular to things with feathers, that maybe—just maybe—the techniques of cloning will someday make it possible to resurrect a vanished bird species.

FROM HOPE IS THE THING WITH FEATHERS

Cokinos (professor of English at Kansas State University, poet and amateur ornithologist) got interested in his subject when he saw in Kansas a colorful bird that did not belong there—a parrot that had apparently escaped from a faraway cage. That experience led him to ponder the fate of another bird, the Carolina parakeet, that "once colored the sky 'like an atmosphere of gems,' as one pioneer wrote," but had become extinct early in the 20th century. And so for years he traveled to libraries and museums of natural history tracing the habits and fate of the parakeet and "other vanished lives: the Ivory-billed Woodpecker, the Heath Hen, the Passenger Pigeon, the Labrador Duck and the Great Auk." Thinking of lives not our own, Cokinos says, we sense sometimes "how we are the degraders, we the deciders." But also we realize, "sometimes, though not yet enough times, [that] we can be the rescuers, the restorers."

FRED HOYLE, GEOFFREY BURBRIDGE AND JAYANT V. NARLIKAR'S *A Different Approach to Cosmology: From a Static Universe through the Big Bang towards Reality.* Cambridge University Press, 2000. ($59.95)

For modern readers, raised on *1984* and Kurt Cobain, anything that smacks of the mainstream arouses suspicion. So after every cosmology article in *Scientific American,* editors brace for an onslaught of letters demanding that alternatives to conventional theories be given their due. This book describes the best-developed such alternative: the quasi-steady-state theory, the latest incarnation of the steady-state theory that Fred Hoyle first devised in 1948. It argues that the famous cosmic microwave background radiation is diffuse starlight rather than the afterglow of a hot big bang; that stars synthesized the chemical elements usually attributed to the bang; and that matter is continuously created and ejected from the cores of galaxies. The heterodoxy is seductive. But in a commentary in the April 1999 issue of *Physics Today,* cosmologist Andreas Albrecht outlined the failings of the theory and the tests it would need to pass before being taken seriously by most cosmologists. If nothing else, a critical reading of this book shows that "mainstream" isn't such a dirty word after all. Science is tricky. Seemingly plausible ideas can have subtle flaws, and it takes a collective effort of problem solving to find them out.

APOSTOLOS DOXIADIS'S *Uncle Petros and Goldbach's Conjecture.* Bloomsbury, London, 2000 ($23.95).

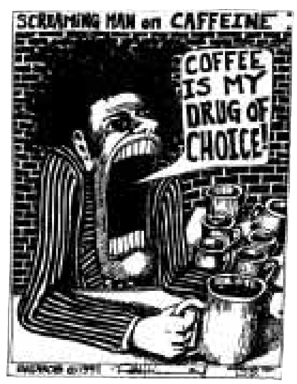
Petros Papachristos, born in Athens in 1895, was sent to the University of Berlin after his teachers discovered his enormous talent for mathematics. He earned his doctorate in 1916 and left for England, where he began an intensive collaboration with G. H. Hardy, J. E. Littlewood and Srinivasa Ramanujan, the world's leading number theorists. In 1919 he was appointed professor at the University of Munich. Over the years, he withdrew into almost complete isolation, directing his research to one of the great unsolved problems of his discipline: the Goldbach Conjecture, which states that every even number is the sum of two primes. He lived an uneventful life up to the moment he claimed to have succeeded in his efforts, whereupon he died, leaving a mystery surrounding his proof as perplexing as the one that enshrouds Fermat's Last Theorem.

Petros Papachristos is of course the invention of Apostolos Doxiadis. But the story of his life is enriched with so many authentic details from history in general and from science in particular that one feels tempted to look him up in a biographic dictionary. Doxiadis manages to keep the reader's attention until the tragic end—but don't be misled: he implies that a first-tier mathematician either dies early or goes mad, referring to Cantor, Gödel and Uncle Petros. But this is definitely a biased selection. Gauss, Hilbert and lots of others lived to a ripe old age in complete mental health, and so far Andrew Wiles doesn't show the slightest sign of madness.

MARK PENDERGRAST'S *Uncommon Grounds: The History of Coffee and How It Transformed Our World.* Basic Books, New York, 1999 ($30).

Coffee, one learns in this scholarly and entertaining book, was the subject of an early skirmish in the struggle for women's rights. In 1674, when coffeehouses were the rage in London but admitted only men, a pamphlet entitled *The Womens Petition against Coffee* appeared. It declared that "Excefsive Ufe of that Drying, Enfeebling LIQUOR" sapped the sexual vigor of men, causing "Grand INCONVENIENCIES" to women. That pamphlet provoked another: *The Mens Anfwer to the Womens Petition,* "VINDICATING Their own Performances, and the Vertues of their Liquor."

Pendergrast describes himself as a journalist and scholar. The scholar has done an enormous amount of research, evidenced by a bibliography running to more than 34 closely printed pages and a list of 244 people whom he interviewed. The journalist has produced a splendid tale, setting out all one could hope to know about coffee.



FROM UNCOMMON GROUNDS

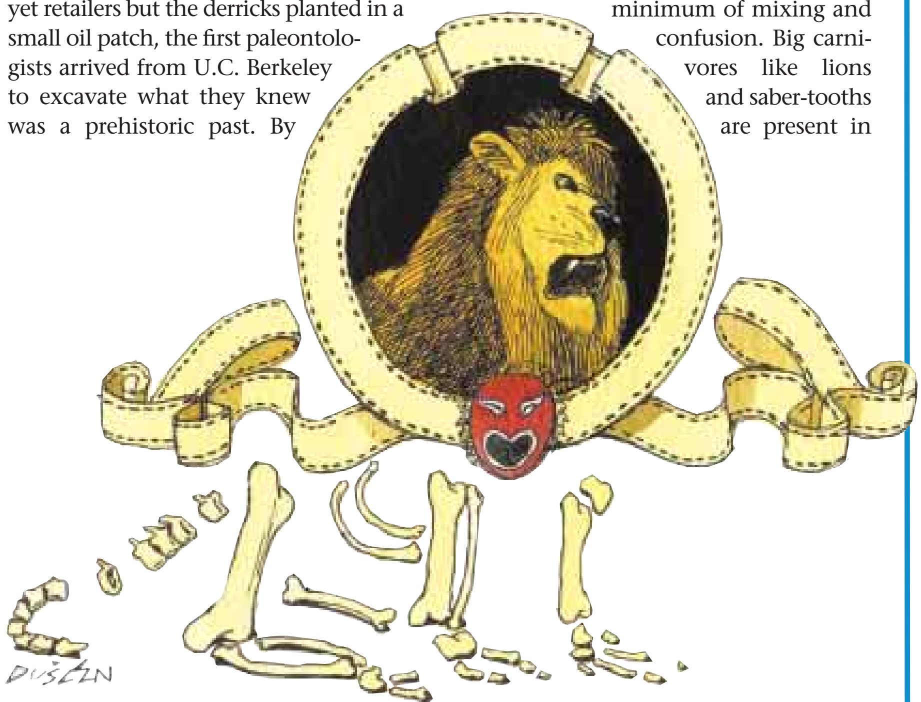
The Lion Emperors

Once Los Angeles was a match for the present plains of the Serengeti, declare **Philip & Phylis Morrison**

Several years ago the celebrated Disney studio produced an animated musical feature that won universal praise (and piled up a heap of dollars). *The Lion King* was an exciting morality play, set on the grassy plains among talkative creatures with Swahili names. From it arose a tour de force of the live theater, superb for costume, dance and mime.

Lions are certainly nothing new in Greater Hollywood. Since the early talkies of the mid-1920s, moviegoers worldwide have watched many films open with a signature shot: a princely maned lion slowly turns his sidelong glance to your eyes, his jaws opening into a full-faced, coughing roar. The cameo bore a label with a famously cynical tag, "Art for Art's Sake," put elegantly into Latin. That was, of course, the logo of classical MGM; its old studio still stands about 12 miles south and west from Disney's big atelier at the edge of the level San Fernando Valley. Not far from the halfway point of a line that joins those two cinematic landmarks, busy Wilshire Boulevard runs along a small grassy park. Within that place the remains of nearly 100 ancient lions have been painstakingly disinterred, no mere pumas or cougars but kings of the wild Los Angeles plains. Once again the realities of that metropolis, from its wonderful spacecraft and precision mechanisms to its unending inequities and crimes, support stories to surpass the fertile imaginations of its finest image makers.

Those lions are only one among some 600 species of animals whose bones have been recovered from their natural entombment in the La Brea tar pits in Hancock Park's two dozen acres. Petroleum and gas seepage infiltrated the soils and slowly floated their way up over geologic time. Close to the surface the evaporating mix left the familiar black, tarry residue. An irregular mixture of clay, gravel and tar, bearing many bones in the black mass, lay in patches across the windswept flats. The heat of summer had often softened the uppermost tar into a sticky morass, forming a relentless quicksand, sticky enough to entrap cattle even where it was shallow. In those tar pits, big bones were long visible, unsurprising because they fit some local rancher's sense of long-forgotten cattle loss.



In 1901, when the neighbors were not yet retailers but the derricks planted in a small oil patch, the first paleontologists arrived from U.C. Berkeley to excavate what they knew was a prehistoric past. By now meticulous excavations have opened and sifted through more than 100 pits, some to depths of about 10 yards, down to an oil-free base of marine sand. From insects to mammoths, the harder parts of animals and of many plants as well have been extracted from the tar, cleaned, identified, pieced together and dated by radioactive carbon decay. In the hands of the chemists, these radiocarbon dates became reliable, in spite of the intruding tar, to fix the age of each fragment. The first animal victims of the tar date about 40,000 years back.

This extraordinary location is analogous to the rich dinosaur bone deposits of Utah and Alberta in Canada. Local circumstances rarely open a magnifying window into evolving life over some range of time and space. The La Brea (Spanish for "tar") pits have yielded animal parts in the hundreds of thousands, all of them geologically recent fauna of our country. Many forms now extinct are represented by their skeletal remains, reassembled with a minimum of mixing and confusion. Big carnivores like lions and saber-tooths are present in large numbers; their herbivore prey as well. Birds, mainly birds of prey, are found much more frequently than in other fossil contexts; their light bones are soon protected by the tar, although on the open plains they would have been lost to weather and small scavengers. The imagined melodrama of 100 big lions, all howling captives of the tar, is stilled by considering the depth of time. On the average, one lion was caught every three centuries. Once Wilshire Boulevard was a match for the present plains of the Serengeti, lions as North American then as they are African today.

The Sasan Gir National Park in northwest India protects the remaining lions of India—few others are now to be found in

Continued on page 119

DUSAN PETRICIC

Water Music

In which we visit singers, fiddlers, fertilizers and health freaks—and, **James Burke** observes, it all goes down the drain

DAVE PAGE

I was sploshing about in a hotel bath recently and, as is my wont, giving my favorite aria the full monty, when it occurred to me to wonder if Enrico Caruso ever did the same. The greatest tenor of the early 20th century (and the highest paid) spent most of his life in hotels. In 1908 he shared the New York Savoy Hotel with the Metropolitan Opera's new conductor, Gustav Mahler. The two massive egos got on pretty well, perhaps because misery loves company: Caruso's paramour had just run away with the chauffeur, and Mahler's own married life was suffering from similar lack of drive.

Mahler had just arrived from Vienna, hounded out of the city principally by anti-Semitic attacks in the press but also partly because the prickly maestro tended to have rather too many rows with the opera administrators. This, in spite of having been the protégé of big B. Well, one of the three big B's, as they were known at the time: Beethoven, Bach and (Mahler's musical godfather) Brahms. I have to confess a bias here, since I used to play the clarinet, and the Brahms clarinet quintet featured in my first (and last!) public performance as an instrumentalist at the age of 17. Back in the late 19th century, although a few crazy hip-hop types who were into really avant-garde stuff like Wagner and Liszt thought him a little old-fashioned, pretty much everybody else in the music world of the day played second fiddle to big B.

Including a nice doctor who did so literally. Theodor Billroth played second violin in his Viennese home music group, where Brahms dropped in from time to time. (Brahms eventually even dedicated a couple of sonatas to him.) Billroth was able to stomach this position of admirer and groupie-to-the-great because he was such a dab hand with the knife that to this day he is known as the father of abdominal surgery. He was also one of the first European surgeons to introduce antiseptic techniques into the operating theater (which could be one reason for his extraordinary success rate).

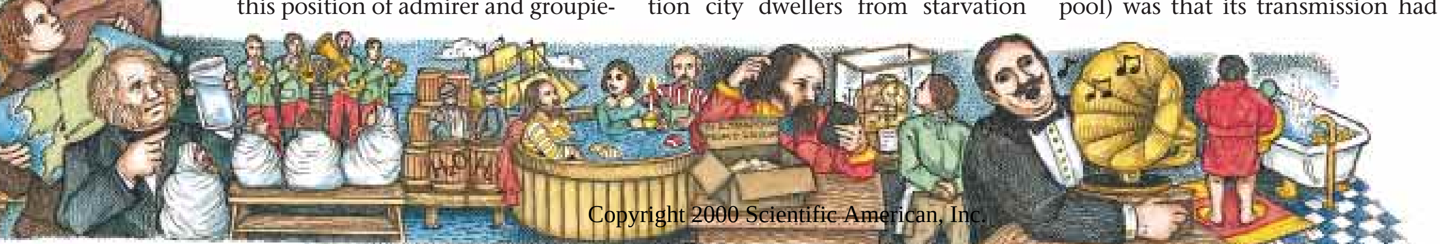
In 1851, while still a student at Göttingen, Billroth went to Trieste to study the nerves of the electric ray with a fellow medic, Georg Meissner. Two years later Meissner had moved on to Munich, to the research lab of Justus von Liebig (who more or less invented the research lab). Liebig is the fellow you love to hate if you're a strictly an organic-foods type, because in 1840 he came up with the idea of the artificial fertilizer. The key thing being to compensate, chemically, for those nutrients a plant wasn't getting enough of from the air or rainwater. This was an amazing thought, because at the time it was thought that the root of all nourishment for a plant came through the root.

> ***Priessnitz made hypochondriacs sit in icy water and listen to an oompah band.***

By 1847 Liebig's opus on agricultural chemistry (a new term in science) was into six editions and changing the face of the countryside. In the long run, fertilizer would increase crop yields dramatically and, I suppose, help to disprove the contemporary Malthusian thesis that while population growth rose geometrically, food supplies only increased arithmetically, so we were all headed for famine. As a result, Liebig probably saved millions of Industrial Revolution city dwellers from starvation and, in keeping them alive, kept them productive and did the economy good. So Liebig went down particularly well in England, the most heavily industrial nation at the time. His translator there was an ex-student, Lyon Playfair. A man who, in an age of pomposity and verbosity, had more than his fair share. No surprise that he was also one of the first-ever government scientists.

Playfair returned from Liebig's lab and became a chemistry bigwig, deputy speaker of the House of Commons, adviser to the prince consort, postmaster-general, and other posts too harrumph to mention. One, however, not so. Playfair spent time on a committee whose report on living conditions in the cities (it said they were "bad," as in: 10 to a bed, ankle-deep in raw sewage, starvation wages, widespread child prostitution, laborer's average age of death 22, rampant incest, families in rags, etc.) shocked the complacent Victorians into realizing they were on the edge of a revolution if they didn't do something quick. The committee boss was one Edwin Chadwick, sanitation freak and social reformer. And the immediate cause of all the angst was cholera, ripping through the cities and killing thousands of people (not surprising, given the conditions).

Chadwick's sidekick, William Farr, crunched the numbers, and one of his many theories on why cholera struck where it did (he noted, for instance, that you seemed to be safer the farther you lived from a line drawn between Brighton and Liverpool) was that its transmission had



PATRICIA J. WYNNE

something to do with dirty water. Which turned out to be right.

Ironically, water was reputed to be a cure (for cholera and anything else) when applied externally by a German named Priessnitz, who, at his Grafenberg hydrocenter, wrapped hypochondriacs in cold wet sheets, hosed them down, and made them sit in icy water, eat dreadful food, and listen to an oompah band. Couldn't fail, really. Two Brit doctors, James Wilson and James Gully, who turned up for the cure (Wilson drank 3,500 glasses of water during his treatment), went home and set up their own health spa in Malvern, England, and started the craze for dabbling in the morning dew, knee jets, head affusions and other dubious matters. Went over very big with such luminaries as Charles Dickens and famous nurse Florence Nightingale. And Alfred Lord Tennyson, poet laureate, whose historical poems, replete with knights in burnished armor dipping their lances to fair maidens in wimples, were pure fanfare.

Speaking of which, it was to Tennyson that Thomas Edison was to send one of his freebie first examples of the phonograph, so that the Great English Scribbler could mournfully intone some of his stuff down the horn onto the rotating wax cylinder and thus help Edison's invention go down on record. Which, as it happens, he didn't. That honor would go to yet another product of the American Dream (an immigrant, then store clerk, then odd-job man, then bottle washer, then inventor, then tycoon). Because the genius in question happened to see, in a museum case in Washington, D.C., an out-of-use gizmo that a Frenchman named Léon Scott Martinville had invented: a bristle, attached to a membrane placed in the narrow end of a horn, that traced a wiggly line in lampblack spread on paper, when the membrane vibrated in response to a voice.

You're there before me, right? All Emil Berliner had to do was find a way to etch the wiggly line in metal and then stamp shellac disk copies, and bingo—there was the gramophone record and the company Berliner set up, the U.S. Gramophone Company. Which really took off in 1902, when the young man whom Berliner had pinched from Edison's phonograph company, Fred Gaisberg, was in Milan and persuaded a local warbler to lay down a track for him. As a result of which, we know Caruso was one of the first recording stars.

Alas, we still don't know if he sang in the bath. SA

Wonders, continued from page 117

all of Asia—in a modest area, though they remain conspicuous in Indian art and lore. In India the lion prides range open plains from dawn to dusk, but the solitary tiger hunts in deep forests by night.

The late Björn Kurtén, Helsinki paleontologist and a brilliant writer, examined the fossil distribution of lions from their first appearance. Lions of our modern species, differing over time by subspecies distinctions that do not make them unrecognizable, have been at home over a very wide range. The first lions in the record—in those days lion and tiger were still one—are found near Olduvai Gorge in Tanzania and in South Africa, just as they are today, around three million years ago. They spread slowly to Europe, at first "outsize, even for cave lions," then eastward to the Pacific. At least one is known from the cave of Peking man. More than a dozen fossil finds of lion are present in Siberia, and their trail extends across the land bridge to Alaska and the Yukon. By the time of the tar pits, lions were roaming the open country of our own continent everywhere south of the ice.

The southern frontier of leonine conquest in the Americas was reached in Mexico. At that time of climax, lions reigned over the beasts of the plain in four continents, a single species in many lands. Their versatility is not easy to explain: they lived and ruled in the humid tropics, the steppe, temperate forest edges, mountains and the cold, dry tundra. Save for our own kind and our mammalian domesticates and camp followers—dog and cat, mouse and ship rat, pig, cattle and more—"no other species of land mammal has ever conquered such an area." They were no mere kings, but Lion Emperors.

Among cats the lion is an unusually social species, and it is unusually large of brain as well. Lions—better, lionesses, who are the main hunters—regularly hunt in teams. Our status among primates was once similar. Our human head count has grown inordinately, by about 500-fold since the retreat of the ice, whereas lion numbers have fallen to a mere fraction. Are we two distinct predators gifted with intelligence? The decline of lionhood probably reflects what we have done to lions, to their large-animal prey, and even to the plains that sustain both predator and prey, save for Africa, where the lions and the hominids have coexisted for a very long time. We now bear the responsibility of conscious empire. SA

MERVIN STYKES

Mind Reading This?

Why exclude the poor from participating in forthright flim-flammery? asks **Steve Mirsky**

I sensed you would eventually read this column. Well, I checked our subscription list and saw that you would read it. Unless you bought this issue at a newsstand, in which case rest assured that my amazing psychic powers told me that you would find this column. In fact, my uncanny abilities actually caused you to turn to this page and begin reading. Yeah, that's it.

Of course, my talents come naturally. Not so for a handful of New York City former welfare recipients who suddenly became big news in late January. Unbeknownst to most of the unfortunate nonpsychic majority of the population, the city's Human Resources Administration was arranging for some on the welfare rolls to find honest work with the Psychic Network, a telephone service offering psychic and tarot card readings. And honest work it was, in the sense that there was nothing illegal about it, provided that the ads hawking it clearly acknowledge, in the finest of print, that the entire enterprise is "for entertainment only." Such logic is interesting, as it apparently means that I could label the proprietors of such services as charlatans, bunko artists and general rat finks without fear of legal action, as long as I included the disclaimer that my comments were for entertainment only, which of course they are. Yeah, that's it.

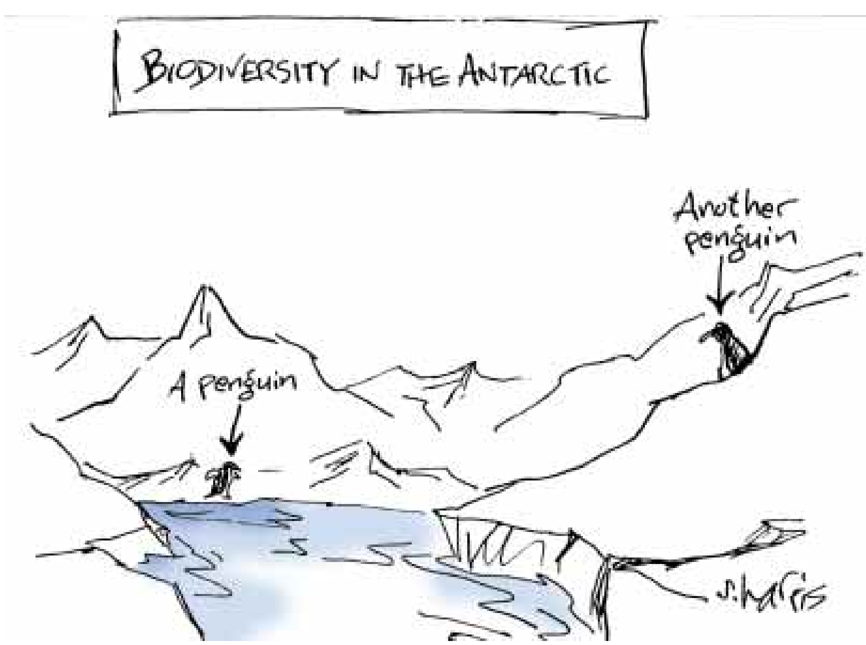
According to published reports, 15 people on welfare wound up reading minds and turning tarots at a minimum starting salary of $10 an hour, which buys a lot of tea leaves. Not to worry if they happened to be without the gift of psychic abilities—citizens no longer in need of public assistance received the best training that money can buy. This money used to belong to people (a.k.a. suckers) who called such services without fully understanding that they are meant to be used for entertainment only.

When the news broke, the city erupted in shock and mockery. One of the officials involved in the program defended the link, saying that the jobs paid well and offered mothers with young children the chance to work at home. Nevertheless, this logical response to the uproar was insufficient to stop the suddenly embarrassed city from severing the psychic connection. Those on the welfare rolls can still find work with more pedestrian businesses that have arrangements with the city, such as Rite Aid drugstores, which I predict will indeed have your photos ready the next day; Macy's, which I sense will have a sale at the end of May; and Madison Square Garden, which I absolutely guarantee will be Stanley Cup–free in 2000.

Some who need solace may seek so-called psychics.

Astrology might be considered to fall into the same category as psychic ability and tarot, but the stars do influence our daily lives. Okay, one star does. A study out of the University of Massachusetts at Amherst recently found that downward mood swings, too mild to be termed clinical depression or seasonal affective disorder, are related to winter itself and the lessened light from our star, the sun. And I sense that some of those who need solace around the colder solstice may be seeking succor from the so-called psychics (which happens to be fun to say out loud).

Of course, to make sport of this whole psychic business—and business it is—is easy. Most every New York newspaper and television station had its moment of fun with our wacky town and its wondrous ways. Why, you couldn't trip over a crystal ball without stumbling onto some of the stories, which I did right after not checking my horoscope in the same lampooning papers. And I saw some of the jeering TV reports on the very stations that sell advertising time to these same psychic services. All of which means that suddenly I feel the presence of William Shakespeare. Yes, I am definitely channeling him. He speaks. "The fault," he says, "is not in our stars, but in ourselves." He adds, "I wrote that for entertainment only." SA



SIDNEY HARRIS