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SCIENTIFIC AMERICAN

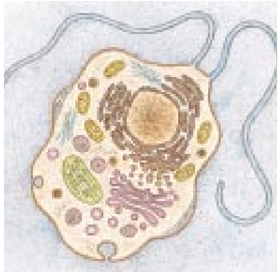
APRIL 1996 $4.95

SMART ROOMS:
THEY UNDERSTAND HOW YOU FEEL, WHAT YOU ARE DOING, AND HOW THEY CAN HELP

Prehistoric termites trapped in amber yield 25-million-year-old DNA

SCIENTIFIC AMERICAN

April 1996 Volume 274 Number 4



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REVIEWS AND COMMENTARIES

About the Cover
This piece of amber and its entombed insects, specimens of the termite genus *Mastotermes,* are on display at the American Museum of Natural History in New York City. Photograph by David A. Grimaldi.

From the Editors

Changing to Stay the Same

Why, yes, the magazine does look a little different this month. *Scientific American* has always evolved with the times, occasionally refining its graphics and typography to stay abreast of readers' requirements. The minor changes in the packaging only reinforce the greater consistency of what we deliver.

Back in 1845, our founder, Rufus Porter, described his fledgling broadsheet as "The Advocate of Industry and Enterprise, and Journal of Mechanical and Other Improvements." It was, he wrote, "a new scientific paper, for the advancement of more extensive intelligence in Arts and Trades in general, but more particularly in the several new, curious and useful arts, which have but recently been discovered and introduced." He intended *Scientific American* as a survival handbook for people trying to make sense of the Industrial Age. In a way, it prefigured Douglas Adams's *Hitchhiker's Guide to the Galaxy* as a compendium of useful facts under the reassuring slogan, "Don't Panic."


SCIENTIFIC AMERICAN

A GOOD START,* *though fashions have changed.

The underlying need has not changed. The 1990s overflow with disjointed facts. In response, *Scientific American* continues to do what it has always done: to report on the widest possible range of new advances; to offer the best-informed opinion on the promise of those developments for our readers; to present that information verbally and visually with lucid, beautiful style—"our object being to please and enlighten," in Porter's words.

Longtime fans will still find all the features they relish, along with new things to enjoy. Within "News and Analysis," for example, beginning on page 16, readers will find "In Brief," a quick tour through what's happening in diverse fields, and "Cyber View," a column sorting out the most important trends in the ever mutable world online. "Working Knowledge," on the last page, gives an insider's view of a familiar technology.

In this issue, we also kick off a three-part series on the shadows over nuclear technology. It begins, on the eve of the 10th anniversary of the world's worst nuclear accident, with an assessment by Ambassador Yuri M. Shcherbak from Ukraine of the damage done at Chornobyl (see page 44). Future installments will examine the technical questions surrounding how best to clean up and dispose of nuclear wastes.

We think Porter would agree that we are still providing "those who delight in the developement of those beauties of Nature, which consist in the laws of Mechanics, Chemistry, and other branches of Natural Philosophy—with a paper that will instruct while it diverts or amuses them, and will retain its excellence and value, when political and ordinary newspapers are thrown aside and forgotten."

JOHN RENNIE, *Editor in Chief*

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LETTERS TO THE EDITORS

CONSCIOUS COMMENTS

I found David J. Chalmers's article, "The Puzzle of Conscious Experience" [December 1995], extremely interesting, but I question his statement that "to explain life...we need to describe how a physical system can reproduce, adapt and metabolize." Such knowledge would not explain what is unique about a single-cell organism that causes it to do these things. Chalmers also does not discuss whether simpler organisms—insects, plants or one-celled organisms—are aware or possess consciousness. I suggest that neither consciousness nor life can be explained without taking the other into consideration. Perhaps they are opposite sides of the same coin.

SYDNEY B. SELF, JR.
Bedford, Va.

Chalmers offers no compelling evidence of a scientific basis for his distinction between physical process and experience. It would seem more sensible to assume that conscious experiences are physical processes and then to get on with the study of those processes. Neuroscientists might make more progress if they were not being distracted by philosophers proposing modern versions of vitalism.

ROBERT IRWIN
Monument, Colo.

I am surprised that Chalmers classified the question "Why does consciousness exist?" as the "hard" problem. I'd take the simple Darwinian approach of observing what we use consciousness for. We use it to look out for our best interests, and it is working well, as evidenced by the human population explosion. Apparently, no "unconscious automaton" can outperform a worried mind at staying alive.

ROGER LASKEN
Gaithersburg, Md.

I believe the consciousness "problem" is inherently insoluble. To explain a phenomenon is to compare it with another phenomenon of which we have knowledge and which we believe to be in need of no explanation itself. Our consciousness cannot be subjected to such comparison, because we have nothing with which to compare it—it is, by definition, all that we know.

ROBERT J. SULLIVAN
Alpharetta, Ga.

Science requires communication. If you believe that conscious experience is something that can be communicated, you will end up working on Chalmers's "easy" problems. If you believe it cannot be communicated, you'd best shave your head, grab your saffron robe and run—don't walk—to the nearest Zen monastery. Perhaps to understand consciousness fully, you have to do both!

CHARLES G. MASI
Bullhead City, Ariz.

FIGHTING THE GOOD FIGHT

Familiarity with the *Terminator* movies may have taught Somali gunmen to fear U.S. laser sights, as suggested by Gary Stix in "Fighting Future Wars" [December 1995]. But the same movies may have also given them the idea for their "technicals," pickup trucks mounted with automatic weapons. Perhaps, too, our videos inspired them to think that ragged, ill-equipped guerrillas could inflict casualties on a sophisticated, heavily armed force; that antipersonnel devices could be defeated with discarded lumber; that telemetry intercepts could be frustrated with drums and handwritten notes. In preparing for future conflicts, we should pay attention to what our adversaries are watching on their VCRs.

EDWARD MCSWEEGAN
Crofton, Md.

BREAST-FEEDING BONUS

As a health care worker, I enthusiastically read Jack Newman's article, "How Breast Milk Protects Newborns" [December 1995]. It seems absurd that a majority of mothers do not choose to breast-feed. I believe an improvement could be made by emphasizing that a nursing mother loses the weight gained during pregnancy much more easily than one who chooses not to. A nursing mother produces a daily average of 30 ounces of breast milk—this amounts to 600 calories lost a day.

CHARLES ANSTETT
Mount Vernon, Ind.

SOUND OF SILENCE

James Boyk's essay, "The Endangered Piano Technician" [December 1995], describes one part of a more general decline in American purchases of musical instruments since the mid-1980s. This trend raises a larger issue. A connection between music and mathematics is frequently noted but never satisfactorily explained. If there is a cognitive constellation of music and math, what will be the effect on the sciences of a persistent decay in instrument sales?

D. W. FOSTLE
Sparta, N.J.

BUTTER LUCK NEXT TIME

We need not question God's motives when a slice of bread falls buttered-side down, as Ian Stewart does in "The Anthropomurphic Principle" ["Mathematical Recreations," December 1995]. Paraphrasing an old Yiddish joke, a better conclusion is that we buttered the wrong side of the bread.

FRANKLIN BLOU
Hoboken, N.J.

Letters may be edited for length and clarity. Because of the considerable volume of mail received, we cannot answer all correspondence.

ERRATA

In "Investigating Miracles, Italian-Style," by James Randi ["Essay," February], *Serratia marcescens* should have been described as a bacterium, not a fungus. Also, "Explaining Everything," by Madhusree Mukerjee [January], included an incorrect affiliation for Ronen Plesser. He is at the Weizmann Institute of Science in Rehovot, Israel.

50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

APRIL 1946

The Altitude Wind Tunnel at the new Cleveland Aircraft Engine Laboratory, operated by the National Advisory Committee for Aeronautics, is probably the only one of its kind in the world. Here, flight testing is supplanted by operation of complete aircraft propulsion installations under precise temperature, humidity, and pressure conditions such as would be found at 30,000 feet. When the full 50,000 horsepower available to the tunnel is employed, air speeds as high as 500 miles per hour may be obtained."

"In peace, the h-f d-f (high-frequency direction-finding) system, popularly known as 'huff-duff,' picks up any voice or code radio signal transmitted on short-wave channels, and within a split second shows on the screen of a cathode-ray tube the direction from which the signals are arriving. The h-f d-f is now a vital instrument in the air-sea rescue system of the United States Coast Guard."

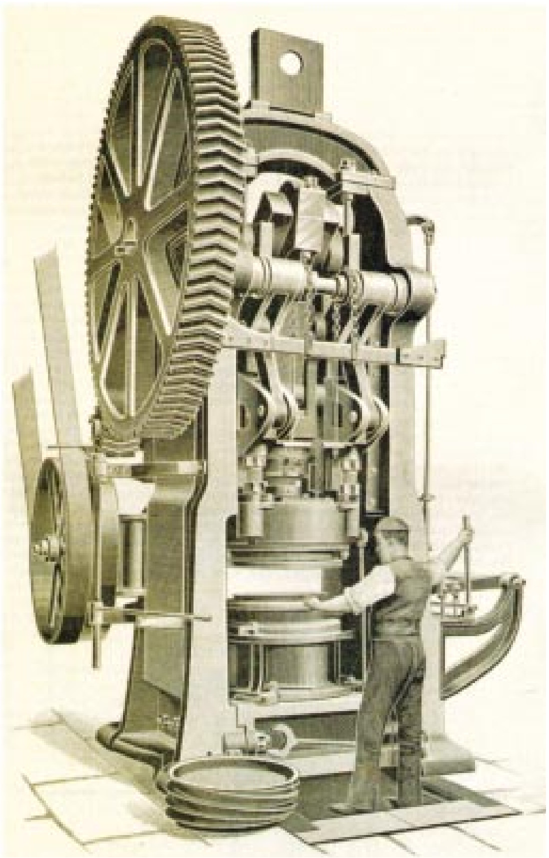
APRIL 1896

The 776th Olympiad began on April 6, and, for the first time since they were abolished, fifteen centuries ago, the famous games were revived—games, however, in which our modern cosmopolitan spirit is apparent by the lists being thrown open to the athletes of the world. The games were not held at the old Olympia, a small plain in Elis, but in the Stadium of Athens."

"Thomas Alva Edison has succeeded in devising a simple apparatus by means of which the skeleton of the limbs may be observed directly instead of photographically. The importance of the 'fluoroscope' to the surgeon cannot be over-estimated. It will give him an instant diagnosis of his case. The photographic method involves long exposure, in itself an evil, followed by the slow development and drying of the plate, and, worst of all, the uncertainty of getting any result whatever."

"The overground power plant at Niagara Falls is already regarded as one of the local attractions of Niagara. But the casual visitor fails to see the best of the work. Out of his sight below the solid floor, and directly beneath the dynamos, a great rectangular pit descends nearly two hundred feet through the solid rock. Near the bottom, the power company has installed great turbine water wheels, from each of which a vertical shaft rises to ground level to directly drive the rotating fields of the 5,000 H.P. alternators. The station now appears as a purveyor of electric energy, while originally it was intended rather to sell hydraulic power."

"One of the most recent examples of the ingenuity of the modern bicycle maker is the production of a jointless rim for wheels. A flat circular sheet of metal, the product of the Siemens furnace, is taken to a big power press, which we illustrate. These presses, each weighing about 35 tons, have been designed specially for the work, and supplied by Messrs. Taylor & Challen, of Birmingham, England." *Also in April, the editors note:* "Count Leo Tolstoi, the Russian novelist, now rides the wheel, much to the astonishment of the peasants on his estate."



Power press for making steel bicycle rims

APRIL 1846

Professor Faraday discovered, last January or February, a new magnetic principle, which he calls 'diamagnetism,' because bodies influenced by it or containing it (as bismuth, phosphorus, water, &c.) place themselves at right angles to those (iron, nickle, &c.) which contain the magnetic principle. A curious property of the diamagnetics is that they possess no polarity."

"The attention of the King of Prussia, and his ministers, has lately been called to an improvement in the art of glyptography—transferring engravings, etc., to plates of zinc. An inhabitant of Berlin is represented as having discovered a method of producing, in the most perfect, easy and rapid manner, exact fac-similes of documents and writings of every kind, and bank notes. One of the functionaries of the government gave the inventor an old document to copy, which seemed, from its age and worn condition, incapable of being imitated. The artist took it to his *atelier,* and in a few minutes returned with fifty copies of it. The imitation was so perfect, that it filled the monarch and his counsel with astonishment, amounting to stupefaction and even fright! The government are negotiating with the inventor for his secret."

NEWS AND ANALYSIS

IN FOCUS

REMI BENALI *Gamma Liaison*

***CRYOPRESERVATION TANKS WORLDWIDE,* including these at New York Hospital–Cornell University Medical Center, are holding hundreds of frozen embryos.**

EMBRYO OVERPOPULATION

Born into controversy, cryopreservation again stirs debate as thousands of frozen embryos grow old

Ever since physician Carl Wood and his Australian research team demonstrated in 1984 that human embryos generated in the laboratory could spend time in the deep freeze and go on to develop normally in the womb, in vitro fertilization (IVF) clinics around the world have been busily filling their squat, aluminum cryopreservation tanks. Plucked out of petri dishes, legions of embryos—technically termed pre-embryos at this two- to eight-cell stage—have been placed in ampoules of protective fluid and cooled to liquid air temperatures, remaining in suspended animation until needed by couples for subsequent IVF attempts.

Cryopreservation has proved a boon to women, sparing them multiple egg extractions. But as the number of frozen embryos grows, it has become obvious that a sizable fraction of them will never be required, and no one knows what to do with them. Arthur Caplan, director of the Center for Bioethics at the University of Pennsylvania, asks, "Is it more respectful to destroy embryos that aren't wanted or freeze them forever—is that dignified treatment?"

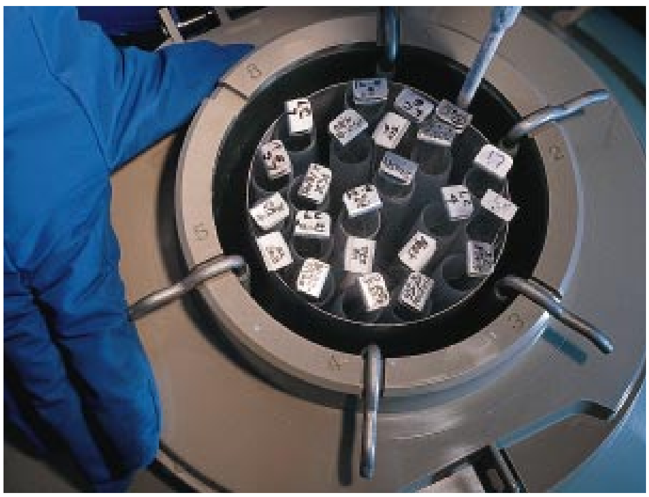
Although a few IVF programs work assiduously to minimize the number of embryos stored for longer than five years and have succeeded in keeping turnover high, many people connected with reproductive medicine expect the ranks in the tanks to keep expanding. Alan Trounson of the Monash University Institute of Reproduction and Development near Melbourne, who pioneered embryo-freezing technology, has voiced his concern over the buildup, as have ethicists and mental health professionals who counsel infertile couples.

Laboratory directors say the "Asch fiasco" has underscored the issue. In May last year the University of California at Irvine shut down the program run by infertility specialist Ricardo H. Asch on suspicion that it had mishandled frozen embryos, including giving them to other clinicians. The attendant press coverage—including a segment on the *Oprah*

Winfrey Show accusing the Irvine team of "high-tech baby kidnapping"—has caused patients to be extremely concerned about their embryos. This wariness has further alerted reproductive specialists to the medicolegal nightmares that can result from holding life on ice.

Asked how many embryos are currently stored internationally, Michael Tucker, scientific director at Reproductive Biology Associates in Atlanta, does a back-of-the-envelope calculation and hazards a high guess: close to a million, with some 100,000 in the U.S. But no one, not even the Society for Assisted Reproductive Technologies (SART), which maintains statistics on 250 or so IVF programs, knows for sure. The largest American programs, including, for example, those at the Jones Institute of the Eastern Virginia Medical School and New York Hospital–Cornell University Medical Center, tend to have several thousand pre-embryos warehoused in liquid nitrogen at –196 degrees Celsius (–320.8 degrees Fahrenheit); smaller, newer programs have several hundred.

Tucker arrived at his total by assuming each SART program has 300 embryos on store—and then throwing in a few extra. One can reach a similar figure by looking at the percentage of embryos consigned to cryopreservation: at Tucker's clinic, for instance, about 33 percent are preserved. That percentage may be higher at other programs, but using it, one can conservatively estimate that embryos were frozen in at least 9,000 IVF cycles initiated by the clinics reporting to SART in 1993; if the average of three embryos were frozen for each couple, that makes 27,000 embryos a year. If statistics compiled at the Jones Institute by Jake Mayer, director of the embryology lab there, can be taken as representative, the bulk of embryos are held for two or three years before being thawed for use in IVF attempts. So Tucker's tally looks about right.


REMI BENALI *Gamma Liaison*

TUBES ON ICE
contain one embryo apiece; a tank, in turn, holds 250 tubes.

Clinics already spend a good deal of time and effort ensuring that frozen embryos suffer no damage. Ethical and legal considerations have driven most programs to install backup liquid-nitrogen and power systems and to hone procedures for wheeling embryos to safety in case of fire or natural disasters. In addition, some clinics keep close track of the whereabouts and wishes of the embryos' "owners" (a precedent-setting 1989 federal district court decision held that labs are merely custodians of patients' "property"). Profit-driven clinics thus view with some disquiet the steady increase in the pre-embryo population; indeed, among colleagues at a conclave last summer, one prominent embryologist spoke of "harassing" patients to make them decide what they wanted to do with embryos that had languished for too long (some have been around since 1984).

Couples are often extremely reluctant to okay disposal. Some have strong feelings about the embryos' sanctity; some view them as "children" or "family," an attitude that appears rather odd but makes sense, infertility counselors say, given that these couples may already be raising one or more children conceived from stored embryos. Even patients who regard embryos as potential beings, rather than fully human, may hold on for long periods, regardless of whether or not they intend to continue with IVF. Clinics have begun to use a mild form of financial coercion: after a grace period of, say, six months, many now charge storage fees, which can amount to more than $300 annually.

Dorothy Greenfeld, Yale University psychotherapist and former president of the American Society for Reproductive Medicine's Mental Health Professional Group, points out that patients are not the only ones who become emotionally invested. "Embryologists and physicians have their own complicated issues with the technology," she says. "It seems that the staff in clinics may become more attached to these embryos than the couples do." At least one lab director admits—and several others intimate—that they would not oust embryos whose storage fees had not been paid, even though couples are warned on consent forms that this will be done.

"If these were animal embryos, no one would hesitate," one embryologist explains. "But they're of human origin, so one can be sympathetic with lab directors who are reluctant to thaw them." Apparently, some workers delay or refuse to thaw embryos even when given explicit consent to do so.

Caplan argues that labs, having created an overabundance of embryos, can solve the problem easily by setting a strict time limit on cryopreservation and hewing to it. But some experts maintain this would be unfair to patients. Jean Benward, a private practitioner in San Ramon, Calif., says that "patients are given consent forms as they come through the door, but there is a way in which this isn't informed consent." When they undertake IVF, Benward explains, couples cannot reasonably be expected to know how they will feel about their embryos down the line.

Benward contends that clinics should establish permanent patient advisory committees to provide feedback and to aid in formulating policy. Another tack, which is expensive but which is employed by the Cornell program, is to have physicians counsel patients as they make a decision to have their embryos thawed or donated to other couples or to researchers. (Few programs are genuinely able to offer patients all three choices: donated embryos are not in high demand, and so little research is done on embryos that ticking off a box assigning extra embryos to science is a fairly meaningless exercise.)

Some researchers have suggested that the problem will go away of its own accord with the advent of egg freezing, which is fraught with fewer ethical and philosophical complications. Egg freezing is still highly experimental, however, and may never pass muster. It appears that if the throngs in the cryotanks are to be kept in check, clinicians must work harder to involve couples in the decision-making process—and then abide by their dictates. —*Gina Maranto*

PALEOANTHROPOLOGY

OUT OF FOOD?

Hominids, and cannibalistic ones at that, may have reached Europe almost a million years ago

The story of our earliest ancestors has long seemed to be one about Africa. Virtually all the fossil hominids that are much more than a million years old have come from that continent. And until recently, researchers believed that only in the past half million years or so did our forebears rove as far as Europe. But finds made in the past couple of years have steadily been building a strong case that early members of the hominid clan ranged much farther abroad—and much earlier—than had been thought.

In 1994 Carl Swisher and Garnis Curtis, then at the Institute of Human Origins in Berkeley, Calif., first cast serious doubt on the chronology of the conventional theory when they reported that the remains of *Homo erectus* specimens found earlier in Java, Indonesia, were about 1.8 million years old. Because that is 600,000 years older than any other dated hominid fossils from the area, and more ancient than comparable African *H. erectus* remains, Swisher and Curtis took their find to support the idea that this upright-walking hominid evolved in Asia rather than in Africa.

Lingering questions about Swisher and Curtis's dating techniques still had not been settled when paleontologists received another surprise. Until last year, western Europe had not yielded evidence of habitation by hominids before a mere 500,000 years ago. But in August a team directed by Eudald Carbonell of the University Rovira i Virgili in Tarragona announced the discovery of hominid fossils and primitive tools that are at least 780,000 years old at Atapuerca in northern Spain. Moreover, Carbonell, Yolanda Fernández-Jalvo and their colleagues recently reported finding cut marks on the bones that make them easily the most disturbing remnants found so far.

The Spanish researchers believe the Atapuerca hominids practiced cannibalism. Scanning electron microscopy reveals V-shaped gouges in the bones—in exactly the locations that might be expected if someone had used a stone tool to remove meat from a corpse. Striations inside the cuts, together with their characteristic shape, rule out the teeth of scavengers as an explanation, Fernández-Jalvo maintains. Although Neanderthals carved up corpses some 200,000 years ago—whether for food or ritualistic purposes is not known—the signs of butchery in the Spanish bones seem to indicate a gruesome early record of cannibalism.

The Atapuerca finds are not the only

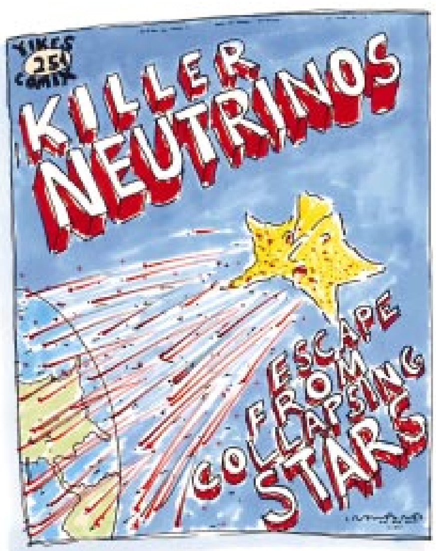
ANTI GRAVITY

Attack of the Killer Neutrinos

Incoming asteroids, nuclear war, deadly viruses—how many ways are there to destroy life on Earth? Thanks to physics, obsessive apocalyptists now have another possibility: lethal neutrinos. Neutrinos are those ghostly little rascals that appeared in experiments in the 1930s but were invisible, that might have some mass but then again might not, that can shift from one form to another but might not, and that hardly react with anything but—guess what?—sometimes do.

That last feature is why physicists must resort to unusual detection methods such as filling up tanks with nearly half a million liters of dry-cleaning fluid. Not that neutrinos leave unsightly stains; rather a huge target is necessary for that rare occasion when a neutrino bangs into a dry-cleaning-fluid atom and thus reveals its elusive presence. And if you think that some neutrinos might be killers, as does Juan I. Collar of the University of Paris, you need to know how frequently they interact with other kinds of matter.

Here's Collar's argument. The vast numbers of neutrinos produced by the sun and other celestial bodies generally pass through Earth each day without a peep. Yet once every 100 million years, a massive star collapses "silently" within a couple dozen light-years of Earth. (It just so happens that everything in space happens silently, but Collar is referring to a stellar collapse that does not produce any visible supernova.)



The silent ones may be the deadly ones. As the star collapses, it releases prodigious quantities of hyperactive neutrinos. These energetic neutrinos could ricochet off atoms in organic tissue, causing the atoms to tear through cells, rip apart DNA, and thereby induce cancer and cellular mutations severe enough to wipe out many species of animals.

Collar even derives specific figures. He calculates that for every kilogram of tissue, the neutrinos would send 19,000 atoms flying, leading to 12 tumors. That's about six cancer sites for the average turtle, 350 for the typical dog, 800 for the adult human—in short, enough to wipe out many species. To bolster his case, Collar also deduced that the 100-million-year period of these stellar collapses is consistent with the known extinctions in Earth's historical record.

Paleontologists do not take Collar's theory too seriously, because there are plenty of other, more likely killing mechanisms (including some that actually leave evidence). But neutrino bombardment does provide another source of consternation. Other apocalyptic scenarios at least leave hope for salvation. Asteroids could be diverted; nuclear war could be avoided; viruses could be contained. But with neutrinos, even the dry cleaners won't be spared. *—Philip Yam*

MICHAEL CRAWFORD

ones pointing to an early date for hominids in Europe. Soon after Carbonell's team revealed their discovery, Josep Gibert of the Sabadell Paleontology Institute announced the unearthing of a 1.8-million-year-old tooth fragment at Orce in southern Spain. Gibert's truly ancient remnant—together with a jawbone of roughly the same age that was found at Dmanisi in the Republic of Georgia in 1991—lends credence to the notion that a million and a half years before modern humans evolved, creatures that walked on two legs had moved out of Africa into Asia, where they had turned both left, toward Europe, and right, toward China.

Swisher and Curtis's dates for Asian hominids gained powerful support last November, when Huang Wanpo and his colleagues from the Institute of Vertebrate Paleontology and Paleoanthropology in Beijing reported unearthing in Longgupo Cave in Sichuan Province a jaw fragment, three teeth and stone tools some 1.9 million years old. The investigators suggest that the teeth are from a hominid possibly more primitive than *H. erectus*. Accurate dating of such meager fragments is a challenge, but a technique called electron spin resonance has confirmed the age that the researchers originally inferred from magnetic traces in surrounding rocks left by changes in the earth's magnetic field.

Roy Larick of the University of Massachusetts at Amherst, who collaborated with the Chinese team, says the recent finds suggest hominids came out of Africa in several distinct waves—the first about two million years ago. An advanced *H. erectus* then seems to have left Africa between 500,000 and 600,000 years ago, whereas fully modern humans departed less than 200,000 years ago. Ian Tattersall of the American Museum of Natural History in New York City, though differing with Larick on the exact interpretation of the Chinese discovery, agrees that "the general trend of recent finds supports a relatively early departure from Africa." Whether cannibalism routinely sustained such migrations, or whether it was merely an occasional expedient, remains to be seen.

—Tim Beardsley in Washington, D.C.

POLICY

THE BERRY AND THE PARASITE

A 30-year struggle to control schistosomiasis has revealed much about patents and profits

In 1964 Aklilu Lemma of Addis Ababa University traveled to Adwa, Ethiopia, to study schistosomiasis. This debilitating disease of the liver or bladder affects some 300 million people in Africa, Asia and Latin America. The *Schistosoma* parasite multiplies within snails that infest rivers and ponds; when humans use the water, the organism enters their skin. At one brook, Lemma saw women washing clothes with the sudsy extract from the local endod berry. Downstream, the snails were dead.

Back in Addis Ababa, Lemma, who has a Ph.D. from Johns Hopkins University, instituted a program to study whether the endod berry could be safely used in controlling *Schistosoma*-bearing snails. Although endod also kills mosquito larvae and fish, he found that it is harmless to rats; in humans, it is an emetic. "People grow it around their houses," Lemma reports. "They have tested it for safety and adopted it as a useful plant."

The subsequent saga of the berry attests to the difficulties that developing countries experience in benefiting from their own biodiversity. Each observer attributes endod's travails to a different stumbling block, but one moral seems to be clear: it takes a determined, politically savvy proponent to ensure that the promise of a product is realized for its own local community.

Lemma's results attracted scientists from the National Research Development Corporation in London, who offered to collaborate. "They took sackfuls of berries," Lemma relates, and he says he heard no more from them. Returning to Adwa, he and his colleagues started a test to see if endod could halt schistosomiasis. If the disease was not transmitted for five years, they theorized, children between one to six years of age should be free from it.

In 1970 Lemma left for a sabbatical at the Stanford Research Institute (SRI), stopping in London to check on his "collaborators." The tests had been so encouraging, he was informed, that the scientists had patented rather than published. Lemma did not appear on the patent, which was for an extraction process for endod. At SRI, he worked with Robert M. Parkhurst, who isolated the

IN BRIEF

Quarks Have Parts?

So suspect some physicists from the 444-member team that found the top quark in March 1995. Their most recent results, submitted to *Physical Review Letters,* suggest that quarks—long held to be the smallest of all subatomic particles—may contain even tinier parts. When the group collided protons with antiprotons, they witnessed an unexpectedly high number of so-called hard hits—just what one would expect if quarks had an internal structure. Of course, such collisions might also reflect measurement errors or the influence of unknown heavy particles. For now, no one is placing any bets.

A Public Display of Plutonium

Hoping to persuade other nations—Russia, in particular—to divulge how much plutonium they possess, in February the U.S. Department of Energy released figures showing its own holdings. Among the documents that the DOE made public were records detailing the trade of plutonium during the past 50 years. These legal but secret swaps—which ended five years ago—supplied nearly a ton of plutonium to 39 countries, among them South Africa, India, Iran, Israel and Pakistan. Most apparently received samples far too small and too impure for making nuclear weapons.

COUNTRIES RECEIVING LARGEST AMOUNT (IN KILOGRAMS)	
WEST GERMANY	518.1
JAPAN	113.5
FRANCE	41.5
BRITAIN	33.9
BELGIUM	11.8
SWEDEN	9.3
AUSTRALIA	6.4
SWITZERLAND	4.3
CANADA	3.5
ITALY	2.3

COUNTRIES THAT RECEIVED LESS THAN ONE-TENTH OF A KILOGRAM
ARGENTINA
CZECHOSLOVAKIA
FINLAND
IRELAND
IRAQ
NORWAY
PHILIPPINES
PORTUGAL
SOUTH KOREA
SPAIN
VENEZUELA

Not a Potto

While studying skeletons of *Perodicticus potto* (a relative of the lemur) at the University of Zurich, Jeffrey H. Schwartz of the University of Pittsburgh came across two curious specimens. The bones were from neither pottos nor any other known primate. He christened them *Pseudopotto martini*. The genus name notes that the mammals resemble pottos, explaining the earlier confusion, and the species name honors R. D. Martin, director of the Anthropological Institute and Museum at the University of Zurich. The next trick will be spotting *Pseudopotto* in the wild. Schwartz notes: "It is very exciting to think that somewhere in the tropical forests of Cameroon, *Pseudopotto* lives."

Continued on page 24

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Tool Time

ROGER WILMHURST *Bruce Coleman, Inc.*

Humans, aside from the accident-prone comedian Tim Allen, are distinguished among animals for their ability to make and use tools. Even chimpanzees are no match for man. The apes do use handy objects but never create them. Crows, though, may well design the items they use. Gavin R. Hunt of Massey University in New Zealand has suggested that a species of crow in New Caledonia—an island off Australia—produces two highly standardized implements: a twig having a hooked end and a stiff leaf with a barbed edge. The crows plunge the objects into holes to snare worms. Although other birds poke at prey with twigs, none shape them according to some predetermined pattern.

Bacteria behind Clogged Arteries

A number of scientists have confirmed a link between *Chlamydia pneumoniae,* a common bacteria that causes respiratory infections, and atherosclerosis, a disease in which fatty plaques narrow the body's arteries. Patients with coronary artery disease typically harbor antibodies to *C. pneumoniae* in their blood. And J. Thomas Grayston of the University of Washington and his colleagues have found chlamydia DNA in plaques from both the coronary and carotid arteries. It is too soon to say how, but some suggest that the microbe helps to promote arterial plaques.

Lead and Delinquency

A four-year study involving 301 public school boys has shown that exposure to lead makes youths more aggressive. None of the children examined suffered from clinical lead poisoning, so the researchers measured the amount of metal accumulated in leg bones. Consistently, boys having higher lead levels were deemed more violent by parents and teachers. Even when the scientists took intelligence, socioeconomic status and medical history into account, the lead-delinquency link held, suggesting that lead pollution might elevate crime rates.

Re-creating a Dinoroar

Computer scientists at Sandia National Laboratories are helping paleontologists simulate the sounds of a *Parasaurolophus,* a native of New Mexico during the Cretaceous period. The giant vegetarian sported a trombonelike crest, filled with looping nasal passages that some presume served as a resonating chamber for the dinosaur's voice. Using x-rays of a nearly intact skull the paleontologists found last summer, the scientists are modeling the exact shape of its cavities on a computer. They hope to determine the sound *Parasaurolophus* made, much in the same way the dimensions of an instrument predict its pitch and tone.

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active ingredient in endod, naming it "lemmatoxin." Along with chemist Wilfred A. Skinner, the researchers obtained a patent on a different method.

But Lemma convinced his colleagues that because endod was "poor man's medicine for a poor man's disease," it was unseemly to profit from it. Accordingly, SRI donated its patent to a nonprofit foundation that Lemma hoped to establish in Ethiopia. "I felt we should get the farmers to grow it and use it locally," Lemma explains. He challenged the British scientists to donate theirs as well. The affair became diplomatically embarrassing; the scientists capitulated.

In 1974 the results from Adwa came out: among 3,500 children between one and six years in age, the prevalence of schistosomiasis had fallen from 50 to 7 percent. Yet to become widely adopted, endod needed the blessing of the World Health Organization. That was not forthcoming. Ken E. Mott, who heads the WHO's schistosomiasis project, says the problem was Lemma's patents: "It was uncertain how endod should be developed, because somebody had a personal [and financial] agenda in this."

The WHO instead recommended a chemical molluscicide marketed by Bayer at $27,000 a ton in hard currency. (Endod sells for about $1,000 a ton.) The WHO questioned the safety of the berry, requiring that it pass tests costing millions of dollars. But the WHO would not help fund such tests, and in 1987 Mott advised the Italian government not to provide research grants for endod.

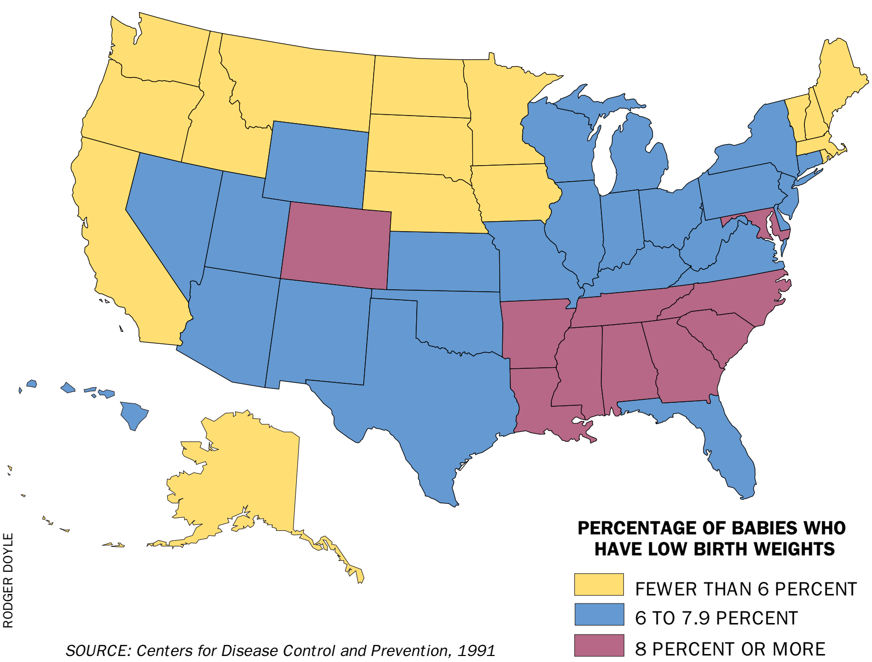
The endod patents then belonged to the Ethiopian Science Foundation, which was eventually subsumed by the Ethiopian government. Lemma attributes the WHO's animosity to a difficulty believing that good science can emanate from developing nations. "The things done in Africa did not hold any weight in the U.S. or Canada," Parkhurst agrees.

In 1976 Lemma joined the United Nations, serving on the Science and Technology Commission. He convened two endod conferences; funding started to trickle in from foreign-aid agencies and private organizations. The International Development Research Center (IDRC) in Ottawa offered to conduct the toxicity tests required by the WHO—provided the Ethiopian government renounced

BY THE NUMBERS

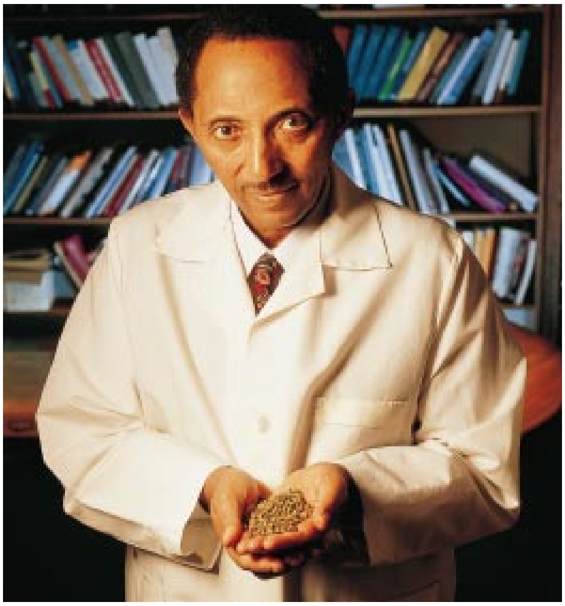
Low-Birth-Weight Babies

Low birth weight, which is defined as under 2,500 grams (or 5.5 pounds), is the chief contributor to infant illness and mortality. Of the more than 4.1 million babies born in the U.S. in 1991, almost 300,000 weighed less than 2,500 grams. Compared with those of normal weight, these infants are more likely to suffer



RODGER DOYLE

SOURCE: Centers for Disease Control and Prevention, 1991



KATHERINE LAMBERT

AKLILU LEMMA
holds the famous endod berry, which kills the snails that carry the schistosomiasis-causing parasite.

the endod patents. The test results, published in 1990, surprised no one. "It's as harmless as soap," states the IDRC's Don de Savigny.

Along with a colleague, Lemma received the Right Livelihood Award from the Swedish parliament in 1989 and was finally able to establish the nonprofit Endod Foundation. In 1990 the University of Toledo in Ohio granted Lemma an honorary degree. After Lemma's acceptance speech, his host, Harold Lee, asked if endod might be effective against zebra mussels. These mussels choke submerged pipes in the Great Lakes, racking up billions of dollars in damage. Lemma demonstrated how to apply the berries: the mussels died. In 1993 and 1994 the university obtained patents on this use of endod, with Lemma as an investigator. The university agreed to donate 10 percent of its earnings to the Endod Foundation.

Last year Lemma requested that the University of Toledo donate the patents to the foundation, which would make them freely available to African ven-

physical and emotional disabilities, including cerebral palsy, mental retardation, speech impairment, problems with vision and hearing, attention-deficit disorder, poor social skills, and behavioral difficulties. Recent research has even suggested that low birth weight can increase the chances of coronary heart disease, hypertension and diabetes later in life. Particularly at risk are the very low birth weight infants—those weighing less than 1,500 grams (3.3 pounds)—who numbered about 53,000 in 1991. Five-year mortality in this group is greater than 20 percent, and those who do survive are more prone to complications than are the moderately underweight.

Low birth weight is caused by diverse factors, among them low socioeconomic status, poor maternal nutrition, lack of prenatal care, cocaine use, and cigarette smoking, including passive smoking. Teenagers are more likely to have low-birth-weight babies than are women in their twenties and thirties, and indeed, teenagers account for almost a quarter of low-birth-weight babies. Women weighing under 100 pounds are at higher risk than heavier women. Other variables, such as water pollution, economic insecurity, and employment as a manual worker in the electronics, metal and leather goods industries, may also contribute to low birth weight.

The strong concentration of low-birth-weight babies in the Southeast reflects in part the large number of blacks living there. Black women account for 17 percent of births but have 32 percent of the low-birth-weight babies and 38 percent of the very low birth weight babies. Part of the difference between black and white rates is attributed to less access to prenatal care among blacks and to the fact that a larger proportion of black women give birth as teenagers.

But even when comparing black and white women of similar age, education and prenatal care, the rates of low-birth-weight babies for black women are twice as high as for whites. There is, however, recent, tentative evidence that after several generations of middle-class status, black women are no more at risk than are their white counterparts.

There is great potential for improvement by reducing the rate of teenage pregnancy and by making prenatal care universal (more than 20 percent of all women receive no prenatal care). Because unwanted babies are less likely to have received adequate prenatal care, the number of low-birth-weight babies could be reduced substantially through more widespread availability of family-planning services, including abortion. *—Rodger Doyle*

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Continued from page 24

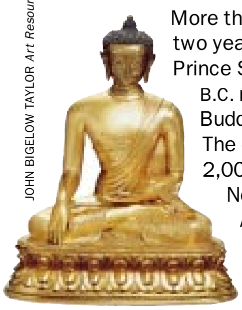
The Monsoon Method

During the first millennium A.D., southern Asians produced vast amounts of highly valued steel. Now archaeologists have described how. They guess that the ancients took advantage of monsoons: in summer, strong winds swept up the hills in the dry, southwestern part of Sri Lanka, reaching great speeds at the top. There the metal makers placed their furnaces. The current would pass over the front wall of a furnace, creating a low-pressure zone above it. This zone ensured that the furnace sucked in a steady, oxygen-rich stream of air, which stoked the flames separating the iron from its ore.

E-Epidemic

The number of known computer viruses rose 23 percent last year to a total of 7,400, according to a recent survey by S&S Software International. The firm, which makes antivirus software, now encounters 150 to 200 new viruses every month.

At Home with Buddha



JOHN BIGELOW TAYLOR *Art Resource*

More than 200 archaeologists spent two years excavating a site where Prince Siddhartha—a sixth-century B.C. monk better known as Buddha—was very likely born. The chambers rest underneath a 2,000-year-old temple in Lumbini, Nepal, near the Indian border. Ancient inscriptions in the temple claim that the structure marks the Enlightened One's birthplace.

FOLLOW-UP

New Drugs to Combat HIV

A new class of drugs, called protease inhibitors, may slow the course of HIV infection when used in conjunction with the approved medications AZT and 3TC. In one study the three drugs reduced the amount of HIV in 24 of 26 patients to levels that could not be detected using standard blood tests. Because protease inhibitors stall the rate at which HIV reproduces, the workers hope the virus will have less chance to become resistant to the drugs. (See August 1995, page 58.)

Second Breast Cancer Gene Found

Scientists at the Institute of Cancer Research (ICR) in England and at Duke University have located a second gene, called *BRCA2,* that when damaged confers risk for acquiring breast cancer. Women having mutations in *BRCA2* or *BRCA1*—the first such gene found—face an 80 to 90 percent chance of getting the disease. Both genes are large and subject to myriad cancer-causing mutations—so screening for individual defects could prove difficult. Yet a patent battle over *BRCA2* is brewing between CRC Technology, the company that funded the ICR's work, and Myriad Genetics, which co-holds the patent for *BRCA1.* (See December 1994, page 26.)

—Kristin Leutwyler

tures. The university responded with an offer to either sell the patents for $125,000 or license them for a $50,000 fee, plus 2.5 percent royalties and $10,000 in legal expenses, reserving the right to withdraw the license if net sales were less than $10 million in five years. Such terms, Lemma says, are impossible. "It is not university policy to give things away," Lee retorts. "Lemma can develop endod for another use and get [his own] patent." But no one is benefiting from these patents: lemmatoxin is too costly to synthesize, and no African country will sell endod to the Toledo group.

Meanwhile work on schistosomiasis goes on. The IDRC is conducting a field test to ensure that endod is efficacious in checking the disease. The Agronomic Institute in Florence is encouraging farmers to grow endod on wastelands. The University of Oslo is working with Addis Ababa University to check whether simply using endod as a soap can control the disease.

"Endod," Mott says, "has ended up not benefiting anybody except a few personalities who have extended their careers by presenting themselves as advocates for the Third World." Diverse reasons are offered for endod's tortuous history. Parkhurst opines that "bureaucracy is what killed it more than anything," along with a distrust of Third World science. De Savigny points out that endod is not an expensive cure backed by the biomedical industry: "Something you pick off a bush doesn't have that kind of support." Lee charges that Lemma does not work hard enough: "Why do you think I spent two years and got a patent, and he spent 30 years and got nothing?" Lemma counters that endod may yet end up benefiting rural Africans: "That is my wish and my dream." *—Madhusree Mukerjee*

This is the first of a two-part series on the legal and ethical issues that arise when patenting biodiversity.

PHYSICS

A SMATTERING OF ANTIMATTER

Physicists hope to get antihydrogen to live longer than 40 nanoseconds

The stuff of science fiction has finally become science fact: physicists at CERN, the European laboratory for particle physics near Geneva, have made the first atoms of antimatter. Although there were only about nine of them, all moving close to the speed of light and surviving just 40 billionths of a second, the results prove that antiatoms can exist. Researchers are now trying to trap and probe them.

Antimatter is identical to ordinary matter except that the electrical charges are reversed. An electron is negative, whereas an antielectron, or positron, is positive. With particle accelerators, physicists have had an easy time cooking up the constituents of antiatoms—namely, antiprotons and positrons.

Only now, however, have they managed to combine the two types of particles to create an antiatom. Using the antiprotons from the Low Energy Antiproton Ring (LEAR) at CERN, Walter Oelert of the Institute for Nuclear Physics Research in Jülich, Germany, and his collaborators have succeeded in making the antimatter version of hydrogen, the simplest and most common element in the universe. They directed a beam of antiprotons, moving near the speed of light, through a jet of xenon atoms. Most of the antiprotons passed through the jet, but on occasion one interacted with a xenon atom.

The energy of the interaction gave birth to pairs of electrons and positrons. Sometimes a newly created positron moved close to the velocity of an antiproton, enabling the antiproton to capture it and forming antihydrogen. The antiatoms lived for 40 nanoseconds before colliding with a target and vanishing in a telltale burst of energy. Fermi National Accelerator Laboratory in Batavia, Ill., is planning to duplicate the feat this summer.

Moving nearly at the speed of light and surviving only fleetingly, the antihydrogens are impossible to study. "Our method is not the right way to go," Oelert remarks. "We just did it for fun. To really do high-precision physics, you probably have to have a different method." That technique involves trapping the antihydrogen for seconds, even days, at a time. Gerald Gabrielse of Harvard University, Michael Holzscheiter of Los Alamos National Laboratory and Theodor W. Hänsch of the Max Planck Institute for Quantum Optics in Garching, Germany, lead the main research groups trying to do just that. Electrical and magnetic fields can in theory hold extremely cold antiprotons and positrons closely together so that the antiparticles bond. But Gabrielse feels that such antimatter creation and trapping is still a few years away.

The purpose of containing antihydrogen is to check fundamental theories and to help explain why matter predominates in the universe. Of course, there are other ways to probe the symmetry between matter and antimatter. Physicists have compared protons with antiprotons, finding that in terms of their charge-to-mass ratios, they are the same to about one part in 10 billion.

Other kinds of tests, though, have proved impossible with antiprotons. For instance, antimatter might free-fall at a rate different from that of ordinary matter, an outcome that would upset conventional physics wisdom. But exploring the effects of gravity on antiprotons has so far proved impossible. The antiproton's electrical charge reacts sensitively to other charges, a process that overwhelms the effects of gravity. Antihydrogen could sidestep the problem because, being neutral, it would not act on external electrical impulses. Such antiatom research might complement studies at the so-called B factory being built at the Stanford Linear Accelerator Center because it would check different aspects of symmetry in physical laws, Gabrielse says.

Given that matter and antimatter annihilate themselves in a burst of energy, could the combination power future space vehicles, as *Star Trek* and other science-fiction venues have it? Oelert cites calculations proving that production methods would consume all the fossil fuel on the earth to make just enough antihydrogen to run one average-size automobile for a year. The warp drive will have to stay off-line. *—Philip Yam*

FIELD NOTES

Interview with a Parrot

For months, I have been waiting to meet Alex, the celebrity African gray parrot who has given new meaning to the epithet "birdbrain." Trained by Irene M. Pepperberg of the University of Arizona, Alex may be the only nonhuman who speaks English and means what he says. The 20-year-old bird is said to count up to six and to recognize and name some 100 different objects, along with their color, texture and shape; his ability to categorize rivals that of chimpanzees.

Walking into Pepperberg's small laboratory with a friend, I am stopped short by a furious barrage of wolf whistles. Flustered, I locate the source as a medium-size gray bird with a knowing eye, standing on a table littered with fruit and paper fragments. "Alex likes tall men," explains Pepperberg, indicating my companion. Within minutes Alex is perched on his shoulder, shivering, fluttering and hopping from foot to foot with excitement. "If he really likes you," a student warns, "he'll throw up into your ear"—referring to a parrot's instinct for regurgitating food and stuffing it into a mate. "You wanna grape?" Alex suddenly asks his new consort in a nasal but perfectly clear voice. I am transfixed with awe—until Pepperberg explains that Alex occasionally uses phrases without meaning them.

Sometimes he does mean them. Ill at ease on my hand, Alex squawks, "Wanna go back," and climbs onto the back of a chair. Watching the transactions are two other African grays—Kyaaro, a nervous bird that Pepperberg likens to a child with attention-deficit disorder, and Griffin, a fluffy, wide-eyed six-month-old. It is mealtime, and while Kyaaro sips his coffee—which, I am told, helps to calm him down—Griffin is being coaxed with bits of banana. "Bread," announces Alex, and, being handed a piece of muffin, proceeds to eat carefully around the blueberries.

My friend leaves so that Alex can concentrate, and we get to work. "How many?" asks a student, displaying a tray with four corks. But Alex is in an ornery mood and will not look. "Two," he says quickly; then, "Cork nut"—his designation for an almond, his reward.

"That's wrong, Alex. No cork nut. How many?"

"Four," Alex replies. "Four," echoes Kyaaro melodically from across the room. Griffin, on my shoulder, pulls out my hairpins while I try to take notes. "You weren't looking," the student sighs and fetches a metal key and a green plastic one. "What toy?"

"Key."

"How many?"

"Two."

"What's different?"

"Color."

This time Alex gets his cork nut. While he nibbles, Griffin hops off to steal the rest of Alex's food, and I take out my camera. Instantly, Alex puffs out his feathers—or what is left of them, given that he has pulled out most of his tail—and straightens up. I have to put the device away before he can get back to work. Alex goes on to identify a stone as "rock," a square as "four corner," the letters "O" and "R" placed together as "OR" and eventually to request in a small, sad voice, "Cork nut."

Pepperberg teaches her parrots by using a threesome—herself, the bird and a student. One person holds up an object; the other names and then receives it. Listening, watching and practicing, the bird learns the word that will get him the new toy. These days Alex often substitutes for a human in teaching the younger birds. He rarely makes mistakes when in this role, and Kyaaro and Griffin learn faster from him than from humans.

For a long time, scientists believed that birds, with their small brains, were capable of no more than mindless mimicry or simple association. But Pepperberg has shown that Alex, at least, can use language creatively—and also reason with a complexity comparable to that demonstrated in nonhuman primates or cetaceans. Next, Pepperberg hopes to teach Alex that symbols such as "3" refer to a particular number of objects.

My friend returns, and Alex is distracted again. "I'm sorry," he says after a particularly poor session. "Wanna go back." It is time to leave. The parting is eased by the arrival of a tall male student. My last glimpse of the astonishing Alex reveals a scruffy gray bird dancing in ecstasy on a man's shoulder. *—Madhusree Mukerjee*

TIMOTHY ARCHIBALD

MATHEMATICS

THE NOT SO ENORMOUS THEOREM

Mathematicians are attempting to make the world's longest proof shorter

It is called, perhaps with understatement, the Enormous Theorem. More than 100 mathematicians toiled for 30 years to produce the proof known formally as the classification of finite, simple groups. Completed in the early 1980s, it consists of some 500 published papers totaling 15,000 pages.

Now two participants in that enterprise are leading an effort to whittle the Enormous Theorem down to a paltry 3,000 or so pages. Even at that size, the proof will still be too large and complex for most mathematicians to grasp, acknowledges Ronald M. Solomon of Ohio State University, a co-leader of the so-called revision project. "Our hope is that people will be inspired with new ideas to make more improvements" that shrink the proof further, Solomon says. Ideally, even the shorter proof "will be out of date in the not so distant future."

A finite group consists of a limited number of elements linked by a logical operation such as addition, multiplication or, in the case of geometric objects, rotation around an axis. Since groups were invented by Évariste Galois in the early 1830s, they have become vital not only to mathematics but also to particle physics and other highly mathematical fields of science.

The Enormous Theorem established that all finite simple groups can fall into 17 infinite families or 26 so-called "sporadic" forms. The groups are often compared with the elementary particles, which combine to form more complex forms of matter. The largest of the sporadic groups, called "the Monster," has 10^{54} elements.

One of the few people thought to understand the entire proof, Daniel Gorenstein, who served as the general contractor for the proof's construction, died in 1992. Before he passed away, Gorenstein and two of his lieutenants vowed to construct a second-generation proof that would be much simpler and shorter. The American Mathematical Society recently published the second volume of what is expected to be a 15-tome set, to be completed in a decade or so.

Even disregarding its length, the original proof contained numerous weaknesses. One major section, on the so-called quasi-thin group, was never published. Several components also relied on computer calculations, a practice on which many mathematical purists still frown.

Most of these weaknesses have already been addressed, says Michael Aschbacher of the California Institute of Technology. He rules out the possibility that the proof could be dramatically compressed by showing that some groups are different aspects of the same underlying group, just as particle physicists showed that many subatomic particles were manifestations of simpler particles called quarks. By definition, the simple groups "can't be decomposed even further," he says.

The proof could be condensed by some other development that reveals connections between groups or casts them in a clearer light, adds Aschbacher, who helped to reconstruct the original proof and remains active in the revision. "I don't think that's going to happen, but anything is possible."

The first three volumes of the revised theorem should be accessible and interesting to anyone with a background in group theory. Beyond that, "it's not for the fainthearted," says Richard N. Lyons of Rutgers University, co-leader with Solomon of the revision project.

Solomon notes that researchers in graph theory, combinatorics and logic and in group theory have now begun to accept the Enormous Theorem and to build on it. "Everybody—well, I hope everybody—does this with a little bit of trepidation," he says. "Mathematics is an evolving subject." *—John Horgan*

GEOLOGY

ROCKING ROCKS

Well-balanced boulders may mark earthquake-free locales

What adolescent hiker has not been tempted to knock over a boulder that is perched insecurely by the side of the trail? With one quick shove, over goes a rock that may have maintained itself in an upright but vulnerable position for centuries—perhaps thousands of years. It seems that good reason now exists to resist the impulse. Researchers have started to use such "precarious rocks" to help them determine whether a particular area may be prone to earthquakes.

The basic premise of the technique is straightforward: seismic shaking can easily topple delicately poised rocks; hence, finding such rocks undisturbed indicates that no earthquakes have occurred close by. The reasoning is elementary; however, until now, few geologists have ever attempted to quantify the relation between unstable rock formations and earthquake ground motion.

Recently James N. Brune and John W. Bell of the University of Nevada at Reno, along with several colleagues, have started to examine various sites in the American Southwest with an eye to gauging what the existence of precariously balanced boulders might indicate about the likelihood of earthquakes.

JOHN W. BELL

PRECARIOUS ROCKS* *mark areas free from seismic shaking.

Brune makes no claims about being the first to recognize that suitably balanced rocks can act as natural seismometers: "I'm sure many people have notices them and said, 'By gosh, an earthquake could knock those over.'" But he and his co-workers have lately invested considerable effort to make the method more exact. For instance, they looked closely at the problem of estimating just how much earthquake-induced motion a particular rock could withstand before it toppled over. They also employed several strategies to determine the length of time a given top-heavy rock might have remained in place since it eroded from the surrounding bedrock.

One method of determining how long a boulder has rested undisturbed is to examine its surface. In dry climates, one commonly finds that rocks are encrusted with a microscopic layer of "varnish," a clay-rich coating that slowly accumulates through exposure to the atmosphere. Because rock varnish contains organic substances, scientists can determine its age with carbon 14 dating.

Another method for finding the time a boulder has stood in the open uses cosmic rays—swiftly moving particles that rain down from the sky in a steady stream. Because cosmic rays create distinctive kinds of atoms when they irradiate common minerals, measurements of "cosmogenic isotopes" can serve to determine how long a certain rock surface has been exposed.

With these tools at the ready, Brune crisscrossed much of southern California and Nevada, looking for sites with precariously balanced rocks. Some teetering boulders, such as those he found in California near Victorville and Jacumba, would totter with a modest sideways push (about 20 percent of the force of gravity), yet careful measurements indicate that those rocks have not moved from their positions for more than 10,000 years—good markers for earthquake-free zones.

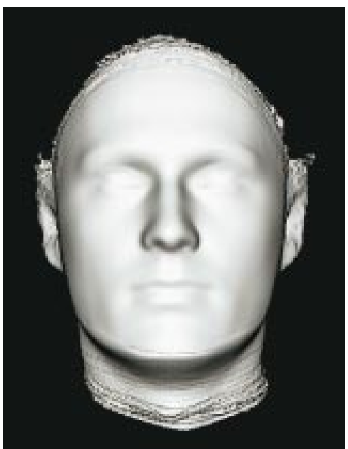
Brune and his colleagues have also applied their technique near Yucca Mountain in Nevada, where the nation's first high-level nuclear-waste repository may be built. Their studies provided a comforting result. Brune concludes, "There has not been strong shaking at Yucca Mountain for thousands of years."

As convincing as this technique would appear, some researchers are reserving judgment about its ultimate usefulness. Klaus H. Jacob, a seismologist at Columbia University's Lamont-Doherty Earth Observatory, is concerned about the problems involved in estimating the amount of seismic shaking a site may have endured from the position and shape of the rocks. He explains the difficulties he encountered once when he tried to calculate the motions of an earthquake that had overturned several railroad cars: "The math I had to do to get at this problem was so much more sophisticated than I expected, I almost gave up."

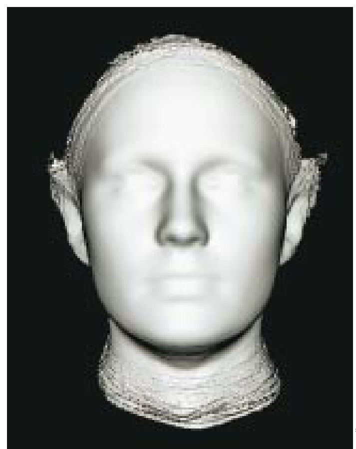
So Jacob remains unsure whether the "precarious rocks" method yet provides reliable estimates of ground motion and cautions that the technique needs to be fully tested in places where earthquakes have recently occurred. Still, he applauds the efforts of Brune and his colleagues to grapple with the question of what these curious rocks can say about earthquake hazards, and he regards their investigation as "brilliant, basic and just the right thing to ask." —*David Schneider*

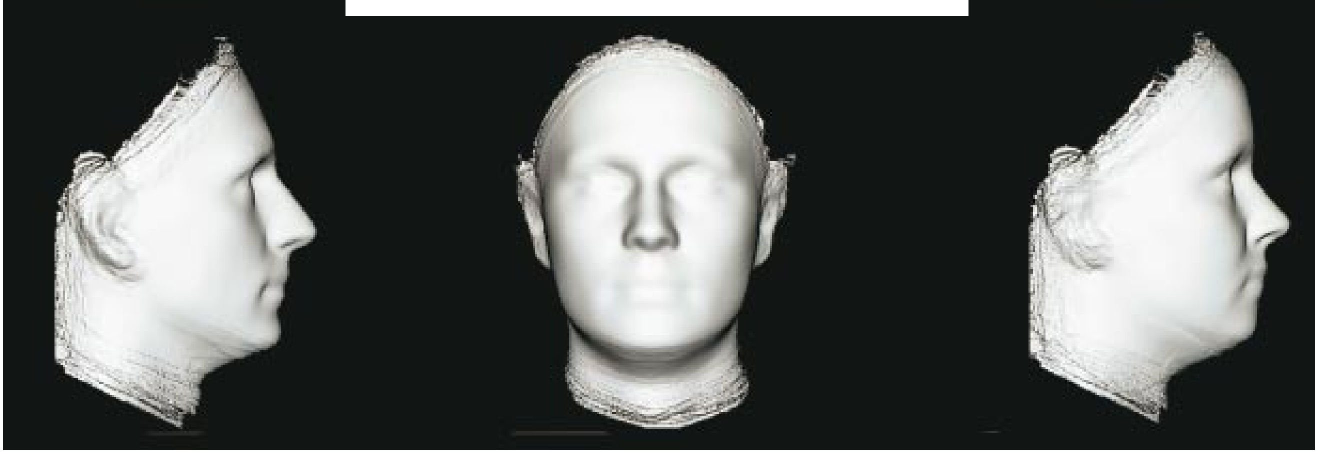
IMAGING

Engendering Faces



The difference between male and female faces can largely be captured by a single variable, state Alice J. O'Toole of the University of Texas at Dallas and Thomas Vetter of the Max Planck Institute for Biological Cybernetics in Tübingen, Germany. They analyzed heads of 65 men and 65 women, finding an average head (*bottom center*) and a set of corrections to it, called eigenheads (see December 1995, page 14). The first eigenhead, when added to the average head, yielded a male face (*top left*); when subtracted, a female face (*top right*). Subtle variations were coded for by a different eigenhead (*bottom left* and *bottom right*). —*Madhusree Mukerjee*





ALICE J. O'TOOLE, THOMAS VETTER, NIKOLAUS TROJE AND HEINRICH H. BÜLTHOFF

The Perils of an Irregular Deregulation

President Bill Clinton signed the Telecommunications Act of 1996 twice, once with a fountain pen and once with an electronic one. The bill regulates cyberspace, so some political flak must have thought it would be a cute idea to sign it there. Few in cyberspace appreciated the gesture. On the Internet, the day of the signing, February 8, 1996, is referred to as Black Thursday. But the double signing is in fact more appropriate than intended. For the bill is two pieces of legislation in one—one social and the other economic, one repressive and the other just cowardly.

The Telecommunications Act is the U.S. leadership's response to the 21st century. In a digital age, there is no longer any reason to try to regulate media into separate boxes: local versus long-distance telephone, broadcast, cable, computer data and so on. On the contrary, the most exciting and innovative new forms of communication can come only from allowing all to commingle and compete. The bill's achievement is that it breaks down the barriers between markets to permit just such competition.

But the bill ducks the tricky economic issues about how competition will happen and how to manage the transition. The only aspect of the future that it does address directly is the way in which the new media will free people to express themselves: basically, the U.S. government wants the power to stop them.

Section 502 of the bill, also known as the Communications Decency Act of 1996, makes it a criminal offense to send any "communication which is obscene, lewd, lascivious, filthy, or indecent, with intent to annoy, abuse, threaten, or harass another person." It also outlaws anyone who "knowingly" communicates, "in a manner available to a person under 18 years of age," any message that "describes, in terms patently offensive as measured by contemporary community standards, sexual or excretory activities or organs." Whether Congress intended it or not—and there is much reason to believe that Senator J. James Exon of Nebraska and the other creators of the decency amendment did intend it—the restrictions threaten to stop far more than those who would make obscene suggestions to kids. Representative Henry Hyde of Illinois demonstrated just how much speech might be censored when he—unwittingly, he claims—added an amendment to the bill that theoretically outlaws discussion of abortion on the Net.

On the Internet, the fear is that the bill will unleash a flood of lawsuits by those who feel annoyed or harassed—not to mention those who find their community standards offended—by some message traveling across the networks. There is so much uncertainty concerning words such as "knowingly," "community standards" and "annoy" that fear of prosecution already threatens a chilling effect on the exuberant growth of the Net. And the mere fact that America regulates speech on the Internet throws away the moral leverage it might exert over other countries, however repressive they might be. The American Civil Liberties Union promptly brought suit to declare the law unconstitutional.

KATHERINE LAMBERT

***FUTURE OF TELECOMS** will have to be unraveled by the FCC.*

Clinton, Speaker of the House Newt Gingrich and many of the others involved in telecommunications reform argue that the risks of censorship are worth the economic momentum to be gained. If they turn out to be right, though, it will be despite themselves. In practice, the politicians have ducked responsibility for the tough economic decisions that will determine whether competition flourishes or is buried under new waves of red tape. For, ironically, they have handed the hard and meaningful work over to the very bureaucrats whom these self-proclaimed deregulators most love to criticize: the Federal Communications Commission.

Take universal service. Today "essential" telecoms services, mostly telephones for residential customers, are made affordable by subsidies from profits made on long-distance and business services. Competition makes nonsense of such cross-subsidies. Any attempt to revive them gives bureaucrats great power to influence the shape of technological development at the expense of consumer choice. Privately, many legislators despair of reconciling universal service and competition.

But rather than take any tough decision that might offend the vested interests affected by universal service, the reform bill passes the buck. It creates a federal-state commission that will decide which services are essential and how to provide them at "just, affordable" prices. Then it gives the FCC a further six months to create "specific, predictable and sufficient federal and state mechanisms" to preserve universal service.

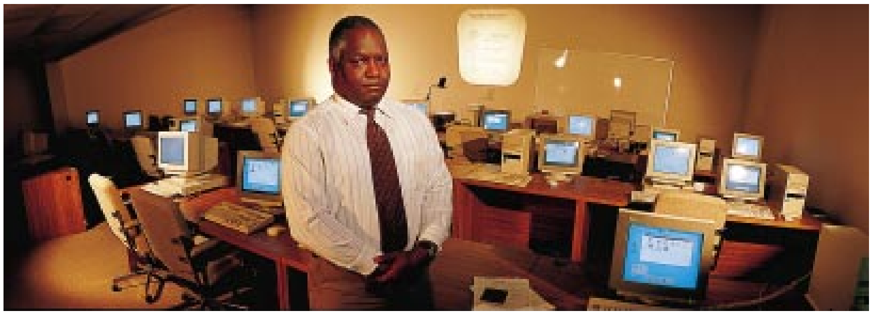
Similarly, the bill acknowledges that it is essential that even rivals offer free and equal interconnections between networks. So who is going to decide what, if any, regulation is needed to ensure these interconnections? You guessed it: the FCC has six months. And who is going to determine what technical capabilities local telecoms companies—who have a de facto monopoly on connections to homes and offices—will have to offer their new rivals? You guessed it again. In all, the FCC will have to make nearly 100 rulings in the next year or so to work out the crucial provisions that will determine the success or failure of telecommunications reform. And before that process is over, the same Congress that passed the buck threatens to begin hearings to decide whether to eliminate the FCC as surplus bureaucracy.

The Telecoms bill offers little real leadership in bringing America into the world of the future, but it has nonetheless shattered the status quo. There is no turning back. Americans must now either build the media world they want—dragging their leaders kicking and screaming behind them if necessary—or simply sit back and accept whatever regime is thrust on them. The new media offer everyone an opportunity to speak and listen freely. Grasping that freedom is worth a long, steady fight. It starts here.—*John Browning in London*

INFORMATION TECHNOLOGY

BATTLING THE ENEMY WITHIN

A billion-dollar fiasco is just the tip of the military's software problems



KATHERINE LAMBERT

WHISTLE-BLOWER
Russell D. Varnado is taking on IBM, Loral and the U.S. Army.

A major U.S. Army initiative to modernize thousands of aging computer systems has hit the skids, careening far beyond schedule and well over budget. The 10-year project, known as the Sustaining Base Information Services (SBIS) program, is supposed to replace some 3,700 automated applications by the year 2002. The current systems automate virtually every business function—from payroll and personnel management to budgeting and health care—at more than 380 installations worldwide. But after investing almost three years and about $158 million, the army has yet to receive a single replacement system.

The failure is significant not only because it strands the army with outdated software but also because SBIS is just one casualty among many. In January top Pentagon officials reportedly killed the larger Corporate Information Management (CIM) initiative, which for six years had tried to consolidate and modernize thousands of the armed services' old and redundant computer systems.

The Pentagon has not been tracking either costs or savings of CIM. But the Department of Defense projected in 1992 that CIM would help it cut $36 billion by 1997. The General Accounting Office (GAO), in contrast, concluded last July that "Defense continues to spend about $3 billion annually to develop and modernize automated information systems with little demonstrable benefit. Few redundant systems have been eliminated, and significant savings have not yet materialized."

Why is one of the most technologically advanced organizations so consistently humbled in its attempts to master business software? A close look at the troubles of SBIS reveals that inadequate software technology, industry incompetence, a flawed procurement process and naive expectations all play a role.

The army conceived SBIS in 1992 to solve a long-festering problem: most of the computer systems that the armed services rely on to raise, organize, train, equip, deploy and sustain their forces are growing obsolete. Designed 20 or more years ago to run on equally ancient mainframes, the systems are becoming prohibitively expensive to maintain. The antiquated programs typically cannot share information with one another, and many force the army to work in ways that no longer make sense.

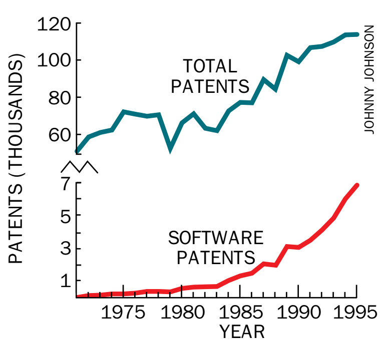
SBIS was to replace 3,700 largely incompatible systems with about 1,500 new applications. The new systems would all run on the same kinds of computers and networks and would store data in compatible ways. By eliminating duplication, shutting down mainframes and allowing information to flow smoothly, billions would be saved. And best of all, the systems would be based on the industry standards and

PATENTS

When Novelty Is Not New

From 1994 to 1996, more than 17,000 software patents will be issued, implying that thousands of novel and "unobvious" software ideas arose in the 1990s. As recent controversies involving such patents show, the good ones can be quite valuable (for instance, the $100-million settlement won from Microsoft by Stac), but other questionable patents can threaten the health of software companies in general until they are invalidated or obviated.

The problem is that the U.S. Patent and Trademark Office does not have the funds to provide patent examiners with the time and resources needed to investigate how novel and unobvious a software patent application truly is. Searching the history of computing is a difficult undertaking: there are more than 200 relevant journals, some dating back to the 1950s, but few places in the country maintain a large enough subset of these references—or the additional, but necessary, technical reports from university, government and corporate research facilities and the product manuals from the software industry.



Given the hundreds of millions of dollars government agencies spend on basic computing research, allocating a few million dollars yearly over several years to archive this country's computing history does not seem like such an insupportable burden. But Congress and leading technology agencies show little interest. But until an effective solution is achieved, the software industry should expect a growing number of lawsuits in proportion to the number of software patents. —*Gregory* so would be cheap and easy to upgrade.

The army wisely decided to split its ambitious program into phases. The first contract called only for the common infrastructure and 89 applications, which would take three years to develop. In June 1993 a team of companies led by IBM Federal Systems (which was sold to Loral six months later) beat out several competitors for the contract with a bid of $474 million.

IBM's winning proposal included techniques touted in the industry for their ability to make software development faster, less costly and less risky. Automated tools would boost programmer productivity. Designers would enlist users to help craft prototypes of the applications, so as to avoid expensive design changes later. Computer code already written for other systems would be reused.

Parts of the proposal should have raised questions, however. To back up claims that it could reuse more than 70 percent of existing code (about three times the industry average), IBM cited its work for the Federal Aviation Administration and Westpac Bank of Australia. But the FAA was forced to abandon much of IBM's work, at a loss of nearly $1 billion. Westpac was likewise left with little to show for its nearly $150-million investment and dropped IBM, with some critics accusing IBM of promising technology it could not deliver.

IBM and its successor Loral again face that charge, this time made by a former army official. "IBM had a conflict of interest from the beginning" because it has lucrative contracts to keep the old mainframes running, says Russell D. Varnado, who managed information technology acquisition for the Army Material Command until 1992.

Last December Varnado and a small software firm called Pentagen Technologies filed a federal whistle-blower suit against IBM, Loral and the army officials who manage SBIS. The action accuses IBM and Loral of contracting to perform tasks that they knew were beyond their abilities; it also accuses army officials of failing to enforce the contract. IBM and Loral are fighting the suit.

The charges are based in part on a report filed by Charlotte J. Lakey, who managed the SBIS program from its inception until April 1994. The report describes how the project slipped behind schedule from the outset. "[Loral] missed most of their deliverables," Lakey recalled in an interview, including "their system design plan, software development plan, communications plans—basic things like that."

Annoyed by the delays and alarmed when Loral proposed a software price that was "a lot higher" than expected, Lakey decided that the army should threaten to terminate the contract. But her superior overruled her, and several months later Lakey was removed from her post. In her final report, she suggested that "there needs to be a better contract mechanism...than hoping you get an honorable contractor."

Although Colonel Charles Mudd, the current SBIS program manager, says Loral is using the promised state-of-the-art techniques and limiting systems' designs to fit the budget, the estimated expense has skyrocketed. About $114 million of the $165 million set aside for software and services in the contract has already been obligated, even though no systems have been delivered (four are in testing). The latest estimate released by the army puts the life-cycle costs of SBIS's first phase at $1.4 billion.

For its extra billion, the DOD now expects considerably less: the army has cut back the number of applications to be built from 89 to just 19 and the number of installation sites from 128 to 43. So rather than replacing 985 of the army's 3,700 systems, this phase will apparently upgrade only about 180. Mudd attributes the reductions to budget cuts. But according to House Appropriations Committee staff, the SBIS budget increased 56 percent last year, from $62 million to $97 million. Mudd responds that he has been handed a "major budget cut" for next year. Paradoxically, cutting losses now could raise the price for SBIS, by prolonging the time until expensive old systems are replaced.

One lesson the DOD should learn from this experience—as it casts about for a strategy to replace CIM—is the virtue of patience, says Sanford F. Reigle, who has been investigating the initiative for the GAO. "It took them 30 years to get this screwed up," he says. "We got there slowly, and we'll get out of it slowly."

Indeed, in 1993, four days after William Perry, then deputy secretary of defense, ordered CIM to be accelerated so that all systems would be complete in three years, former director of defense information Paul Strassman objected in a memorandum to Perry. The DOD maintains some 11,000 major applications and perhaps 50,000 databases, he wrote: "The CIM goal to reverse engineer this inventory is 20 to 50 times bigger and twice as fast than anything ever attempted in the commercial sector. The DOD record to date in delivering on time even one million lines of code on schedule and on budget shows a 100% failure rate." Strassman's warning might have had more impact had he not resigned eight months earlier.

—*W. Wayt Gibbs in San Francisco*

Alarmed that 11 federal agencies now face computer projects headed for disaster, Congress opted for a radical solution. In January it fundamentally reformed the way the government acquires systems. Next month, an analysis of the new law's chance of reducing costly software meltdowns.

PUBLIC HEALTH

AUGMENTING DISCORD

The real science of silicone breast implants is hard to see

Last October a jury in Reno, Nev., ordered Dow Chemical Company to pay Charlotte and Marvin Mahlum $14.1 million to compensate the couple for Charlotte Mahlum's illnesses—allegedly caused by the silicone in her breast implants. Yet only a few days before, jurors in Texas voted to exonerate Baxter Health Care, another company facing implant liability lawsuits: the panel decided that silicone had not caused immune disorders. And despite the magnitude of the Mahlum settlement, all the subsequent jury rulings on breast implants have rejected the plaintiffs' arguments of a health hazard—reversing a nearly 15-year tendency to penalize the makers of silicone.

This legal trend suggests that a scientific consensus has emerged on the overall safety of implants. Indeed, studies have not found evidence for a link between silicone implants and autoimmune disorders such as lupus, scleroderma and rheumatoid arthritis. But researchers remain uncertain about other side effects implants may have. If history is any measure, legal, financial and emotional factors may outweigh scientific ones in determining the future of implants—and not only those for breasts.

Silicone breast implants have been available since the early 1960s, but questions regarding their safety were raised only recently. In 1992 the Food and Drug Administration removed implants from the market until they could be reviewed further, citing concern about the potential hazards of ruptured implants, hardening of the breasts, and women's increased risk for contracting autoimmune disorders. The agency restricted their use to reconstructive surgery for mastectomy patients participating in clinical trials. At the time, FDA commissioner David A. Kessler explained the agency's decision in the *New England Journal of Medicine:* "Even after 30 years of use involving one million women, adequate data to demonstrate the safety and effectiveness of these devices do not exist."

Investigators at Harvard Medical School and the Mayo Clinic have come to a different conclusion—at least about implants and autoimmune conditions. Last summer Matthew H. Liang and his colleagues from Brigham and Women's Hospital at Harvard Medical School released a study of more than 87,000 women—with and without autoimmune diseases—1,183 of whom had implants. According to Liang, the findings "should reassure women with breast implants." In the

CZARINA GERMANN

***BREAST IMPLANTS** remain controversial, although requests for surgery have increased. Most women receive saline implants since the FDA is still evaluating the safety of silicone.*

Mayo Clinic study, published in 1994, Sherine E. Gabriel and her colleagues surveyed more than 2,000 women, including 749 with breast implants. These researchers also found no link between implants and autoimmune diseases.

Despite such results, implants remain under FDA scrutiny. Kessler testified before the U.S. House of Representatives last year, saying that "neither of these studies...rules out a small but significant increase in risk for rare connective tissue disease." Critics of the two studies point out that autoimmune diseases affect only a small percentage of the population anyway, so a noticeable increase in the number of cases would be apparent only in studies that consider a much larger number of women. Currently the FDA is conducting clinical trials to assess the short-term risks of implants, such as rupture or hardening of the breasts.

Although implants still have not been approved for widespread use, the height of the panic over their safety appears to have subsided. Roxanne J. Guy, a plastic and reconstructive surgeon in Melbourne, Fla., states that the first stories about a possible link between implants and autoimmune disorders created among her patients a period of "almost hysteria." Now she finds they tend to take the more circumspect attitude that nothing is completely safe. Yet the scare has left some of her patients unsure about where the truth lies, and this uncertainty may be putting them at needless risk. Doctors worry that women may be requesting unnecessary operations to have safe implants removed.

For their part, chemical companies appear to be feeling more confident about proving their cases in court. Nevertheless, the cost of defending themselves has been steep. To sidestep future losses, some businesses have stopped making silicone and other materials used in medical implant devices, ranging from pacemakers to hormone-releasing implants for postmenopausal women.

According to Stephanie Burns of Dow Corning, mounting lawsuits also present the possibility of a "biomaterials crisis in the U.S. as companies withdraw raw materials for certain devices from the market." Dow Corning, one of the leading producers of silicone used in medical devices, has stopped supplying implant companies with the material. According to the FDA, there has not been a scarcity of critical products, but the agency has expressed concern about the potential for shortages.

At the heart of both the scientific and legal debate about the safety of breast implants lies a fundamental tension over whether the benefits of breast augmentation outweigh the risks. Although proponents can recount a list of benefits resulting from the procedure—improved body image, more self-confidence—these advantages may seem frivolous to others.

Even so, says Roberta Gartside, a plastic surgeon in the Washington, D.C., area, "doctors must be careful about putting their own value system on patients" and must provide them with the safest treatment possible. But the legacy of the controversy might make that goal medically impossible. On that issue, the jury is still out. —*Sasha Nemecek*

OPTICS

A Discerning Eye

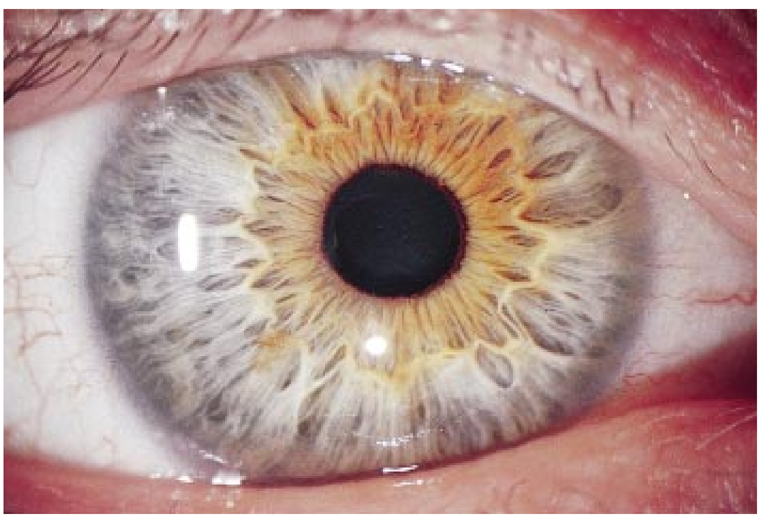
In the James Bond movie *Never Say Never Again,* a camera zooms up to a character to identify him by the unique appearance of his eye. At that time, there was no device that could accomplish such a thing. But now Sensar, a subsidiary of the David Sarnoff Research Center, has announced a $25.8-million agreement with OKI Electric Industry Ltd. in Tokyo, one of the world's leading suppliers of automated teller machines (ATMs). This means iris recognition could be coming to an ATM near you.

Unlike signature verification, voice recognition or fingerprinting, iris recognition requires little cooperation. A person simply walks up to the machine and inserts his or her bankcard. Meanwhile an ordinary video camera captures an image of the customer's right or left eye. This image is converted into a digital code, which is compared with one already stored for that individual. If the system perceives a match, the customer can proceed. The process takes about five seconds.

Although color is the first thing we notice about someone's eyes, recognition is based only on immutable structures of the iris. These include the trabecular meshwork of connective tissue, collagenous stromal fibers, ciliary processes, contraction furrows, crypts, vasculature, rings, corona, coloration and freckles. As with fingerprints, most of these characteristics are established by random processes before birth, says John G. Daugman of the Computer Laboratory at the University of Cambridge, who developed the algorithm behind the process. The iris's pattern—which is different in each eye—appears to persist virtually unchanged throughout life. Even identical twins have unique iris morphology. What is more, no prosthesis can defeat the system because it detects the minute pulsations and pupil changes that indicate living tissue, contends Sensar's Kevin B. McQuade.

Experts in high security have shown a keen interest in iris-based identification: McQuade speaks in hushed tones about inquiries from the Central Intelligence Agency. Frank Bouchier of the Security Systems and Technology Center at Sandia National Laboratories tested an early version on 199 eyes and found zero false accepts and less than 5 percent false rejects.

The first ATMs equipped with iris recognition are expected by the end of this year. And if the technology catches on, it could protect users of "smart" cards. The customer's iris code could be stored on the card, and the merchant would be unable to access the data unless the customer—or more precisely, the customer's eye—were present. —*Karla Harby*



JOSEPH McNALLY

PROFILE: Margie Profet

Evolutionary Theories for Everyday Life

On this morning, Seattle's sky and surrounding waters are gray, and even the blue eyes and sweater of Margie Profet seem gray. The evolutionary biologist is explaining that she loves the rain and its flat tones because they make the world look more three-dimensional, and she points to her panoramic view of Portage Bay and the University of Washington to demonstrate: "That glass one over there is my building, the astronomy building."

It is true that a planet that may support life has just been found, but it seems a little premature for an evolutionary biologist to be turning to astronomy. Profet, however, says she is just doing what she has always done: trying to come at a subject that she doesn't know so she can get excited and perhaps find a different perspective—"I just wanted a new adventure in life, and I wanted back that math part of my brain that had died."

Profet is also, at least for now, removing herself from a discipline that she helped to popularize—and from a storm of criticism over her recent book, *Protecting Your Baby-to-Be.* Renowned for three evolutionary theories, Profet appears to have crossed a line in the eyes of some of her colleagues in the field of Darwinian medicine, and of many in the medical establishment, when she recommended that pregnant women follow her advice: don't eat pungent vegetables.

In pared-down form, her pregnancy theory posits that the nausea or food aversions many women experience in the first trimester are adaptations designed to protect embryos. Profet argues that some toxins in plants—including, for instance, allyl isothiocyanate, a carcinogen found in cabbage, cauliflower and brussels sprouts—evolved to ward off herbivores and that some of these compounds could, even in tiny amounts, cause defects during the critical stage when organs are forming. In general, the Pleistocene plants that constituted the diet of our hunter-gatherer ancestors—and, hence, those that would have been the force behind the adaptation—were even more likely to contain toxins, Profet explains, because agriculturists had not yet selectively bred for crops that were less bitter (that is, less poisonous).

Therefore, her theory contends, we evolved mechanisms to deal with these dietary threats. Hormonal changes make the olfactory systems of pregnant women hypersensitive, able to detect spoilage or teratogens in a single whiff. A woman can thus avoid dangerous foods, relying instead on nutrients that her body stored up before conception. Once the embryonic organs are more or less formed, hormones allow nausea to subside, and women can eat less discriminatingly. Profet correlates the period of pregnancy sickness (from about the third week after conception, when the placenta forms, to 14 weeks after conception) with the period of organ creation. And although there are no direct studies on the topic, Profet extensively reviews the literature on plant toxins as well as on birth defects.

"I think it is good to try to jump into something new every once in a while."

So, according to Profet, a pregnant woman fleeing the scene of boiling broccoli or brewing coffee is protecting her embryo and should pay attention to her instincts. Which is why Profet says she took her message out of the realm of theoretical biology and academic papers to the realm of the masses and national book tours. But her dietary proscriptions have brought her into often rancorous conflict with obstetricians and nutritionists, as well as with the March of Dimes. Her critics contend that she herself may very well cause birth defects by warning women to stay away from greens.

Others embrace her theory—if not her approach. "I was critical of the stance that she has taken. But I was also very supportive of the idea, because I think it is fascinating," says Cassandra E. Henderson of the Montefiore Medical Center, who intends to study plant toxins and to determine whether the compounds cause birth defects in animals. "But I cannot go to the next step and say, 'Don't eat this because it may cause birth defects.' I have no evidence."

For her part, Profet believes there is ample reason for concern. Even if there are no direct data, she says that no one has come up with a criticism that her theory cannot handle. She maintains that her goal was to get women to "err on the side of caution until we have better information" and to stimulate scientific study. "I like looking for solutions to things. And for that you need good theory, and you need good experiments," Profet explains, adding that doing these experiments is not where her talents lie. But she is adamant to the point of self-righteousness about speaking out. "We are talking about life and death. This is not some kind of intellectual fun, you know," Profet states. "People are getting birth defects."

She pauses and rolls her hands up inside her sweater, taking in the room, its wall of windows and wide vista, the binoculars on the table. A view of the water is very important, Profet says, because she did her best thinking in the mid-1980s in San Francisco, in a house with such a view. She had just completed her second bachelor's degree—this time in physics at the University of California at Berkeley; she had studied political philosophy at Harvard University for the first one—and "I just wanted some time to think about whatever I wanted to think about."

That happened to be evolutionary biology. "I mean, the first month out of physics I went and got a standard biology book. I knew some people in evolutionary biology, and I would have some conversations with them, and I would read everything, and I just started thinking about things. I had this wonderful view and my animals," recalls Profet in her fast and breathless voice, holding out pictures of wild foxes and the raccoon she befriended while living there. "And it was really productive. It was the most productive time of my life, the next three or four years."

Her pregnancy theory, which she first began to research in 1986, was followed in quick succession by two others that are essentially variations on the same theme: ejection. The second one came to her one night when her allergies had suddenly brought on a fit of scratching, and she began to think about people who had fits of coughing and sneezing. "I thought: What do you need these things for? It is almost like you are trying to expel something immediately.

EVOLUTIONARY BIOLOGIST Margie Profet has turned to the study of stars.

And, well, maybe you are trying to expel it immediately, and if so, what would cause that?" Out of this came her idea that certain forms of allergies evolved as a means of expelling nasty things such as plant toxins and insect venom.

"Every mechanism out there was designed by natural selection to solve a problem, so you have to identify the problem," Profet declares. You have to ask, "During the Pleistocene, would this really have been adaptive?" This reasoning led her next to an explanation of menstruation. She recalls that when she first heard about pregnancy sickness and menstruation as a kid, neither made sense: "I was miffed. No, not miffed. Just puzzled." Then one night in 1988, she dreamed of black triangles embedded in a red background (other aspects of the dream resembled an educational cartoon about menstruation that Profet had seen in high school); her cat woke her up in the middle of the vision, so she was able to remember it. It became clear to Profet that menstruation is more than merely a monthly waste of blood and energy: the process allows the reproductive tract to rid itself of pathogens that attach themselves to sperm.

According to her argument, the myriad bacteria that are found in and around the genitals of men and women hitch rides on sperm, thereby gaining access to the uterus and fallopian tubes. The uterine wall sheds each month so it can cleanse the system, washing away the contaminants that could cause infection or infertility. As with the theory of pregnancy sickness, the menstruation idea awaits further study—but Profet specifically urges that gynecologists check women with particularly heavy flows to see if they have active infections. She is again outspoken about being proactive: "You get bad theories that people adhere to, and it is killing people or causing them a lot of harm." In the scientific community, debate continues.

In an upcoming issue of the *Quarterly Review of Biology* Beverly I. Strassmann of the University of Michigan argues, among other things, that there is no evidence that there are more pathogens in the uterus before menstruation than there are immediately after. Strassmann offers instead another explanation for such bleeding: the uterine lining sloughs off when implantation does not occur, because keeping the womb in a constant state of readiness requires more energy than do the cycles of menstruation and renewal.

Despite her rich intellectual life between 1985 and 1988, when she worked out her theoretical trinity, Profet says her poor economic situation drove her to consider getting a doctorate in anthropology at Harvard—she figured that with a stipend and a student's schedule she could do the coursework and keep researching evolutionary biology. "But it was just not like that at all," she says. Graduate school was too stifling for Profet's taste and, she maintains almost wistfully, the wrong place for people who need freedom and who want to use the energy of their twenties and thirties to ask naive questions: "You may be using up a time in life that will just never come again."

She left the program, returning to California and to a part-time job that she had held in the Berkeley laboratory of Bruce Ames, a toxicologist famous for his work on plant toxins and natural carcinogens. (She still maintains an affiliation with the lab.) Over time, her ideas—two of them published in the *Quarterly Review of Biology* and one as a chapter in the 1992 book *The Adapted Mind*—earned Profet a reputation as a maverick. And in 1993 she won one of the "genius" awards from the MacArthur Foundation.

But Profet seems tired of evolutionary biology for now. "I love the field as I think the field should be," she says in a nearly questioning voice. "But as the field currently is, I don't." Profet says too few of her colleagues make a distinction between a hypothesis and a theory, rushing to publish ideas that are not rigorously worked out but that may have implications for public health. And so she says it suits her just fine to be a visiting scholar in astronomy. "I am here to explore," Profet says. "I think it is good to try to jump into something new every once in a while." As long as her room has a view. —*Marguerite Holloway*

Ten Years of the Chornobyl Era

The environmental and health effects of nuclear power's greatest calamity will last for generations

by Yuri M. Shcherbak

GROCHOWIAK/KEPLICZ *Sygma*

"It seemed as if the world was coming to an end....I could not believe my eyes; I saw the reactor ruined by the explosion. I was the first man in the world to see this. As a nuclear engineer I realized all the consequences of what had happened. It was a nuclear hell. I was gripped by fear."

These words were written to me in 1986 by the head of the shift operating the reactor that exploded at the Chornobyl nuclear power plant in northern Ukraine. The explosion and a resulting fire showered radioactive debris over much of eastern Europe. The author of the words above, along with several others, was later jailed for his role in the disaster, although he never admitted guilt.

Subsequent official investigations have shown, however, that responsibility for this extraordinary tragedy reaches far beyond just those on duty at the plant on the night of April 25 and early morning of April 26, 1986. The consequences, likewise, have spread far beyond the nuclear energy industry and raise fundamental questions for a technological civilization. Before the explosion, Chornobyl was a small city hardly known to the outside world. Since then, the name—often known by its Russian spelling, Chernobyl—has entered the chronicle of the 20th century as the worst technogenic environmental disaster in history. It is an internationally known metaphor for catastrophe as potent as "Stalingrad" or "Bhopal." Indeed, it is now clear that the political repercussions from Chornobyl accelerated the collapse of the Soviet empire.

Because of the importance of this calamity for all of humanity, it is vital that the world understands both the reasons it happened and the consequences. The events that led up to the explosion are well known. Reactor number four, a 1,000-megawatt RBMK-1000 design, produced steam that drove generators to make electricity. On the night of the accident, operators were conducting a test to see how long the generators would run without power. For this purpose, they greatly reduced the power being produced in the reactor and blocked the flow of steam to the generators.

Unfortunately, the RBMK-1000 has a design flaw that makes its operation at low power unstable. In this mode of operation, any spurious increase in the production of steam can boost the rate of energy production in the reactor. If that extra energy generates still more steam, the result can be a runaway power surge. In addition, the operators had disabled safety systems that could have averted the reactor's destruction, because the systems might have interfered with the results of the test.

At 1:23 and 40 seconds on the morning of April 26, realizing belatedly that the situation had become hazardous, an operator pressed a button to activate the automatic protection system. The action was intended to shut the reactor down, but by this time it was too late. What actually happened can be likened to a driver who presses the brake pedal to slow down a car but finds instead that it accelerates tremendously.

Within three seconds, power production in the reactor's core surged to 100 times the normal maximum level, and there was a drastic increase in temperature. The result was two explosions that blew off the 2,000-metric-ton metal plate that sealed the top of the reactor, destroying the building housing it. The nuclear genie had been liberated.

Despite heroic attempts to quell the ensuing fire, hundreds of tons of graphite that had served as a moderator in the reactor burned for 10 days. Rising hot gases carried into the environment aerosolized fuel as well as fission products, isotopes that are created when uranium atoms split apart. The fuel consisted principally of uranium; mixed in with it was some plutonium created as a byproduct of normal operation. Plutonium is the most toxic element known, and some of the fission products were far more radioactive than uranium or plutonium. Among the most dangerous were iodine 131, strontium 90 and cesium 137.

A plume containing these radioisotopes moved with prevailing winds to the north and west, raining radioactive particles on areas thousands of miles

IGOR KOSTIN/IMAGO *Sygma*

FORBIDDEN ZONE: militiaman controls access to a town in the district of Narodichi, a region evacuated after the explosion and fire at the nearby Chornobyl plant caused a shower of dangerously radioactive fallout across eastern Europe.

away. Regions affected included not only Ukraine itself but also Belarus, Russia, Georgia, Poland, Sweden, Germany, Turkey and others. Even such distant lands as the U.S. and Japan received measurable amounts of radiation. In Poland, Germany, Austria and Hungary as well as Ukraine, crops and milk were so contaminated they had to be destroyed. In Finland, Sweden and Norway, carcasses of reindeer that had grazed on contaminated vegetation had to be dumped.

Widespread Effects

The total amount of radioactivity released will never be known, but the official Soviet figure of 90 million curies represents a minimum. Other estimates suggest that the total might have been several times higher. It is fair to say that in terms of the amount of radioactive fallout—though not, of course, the heat and blast effects—the accident was comparable to a medium-size nuclear strike. In the immediate aftermath of the explosion and fire, 187 people fell ill from acute radiation sickness; 31 of these died. Most of these early casualties were firefighters who combated the blaze.

The destroyed reactor liberated hundreds of times more radiation than was produced by the atomic bombings of Hiroshima and Nagasaki. The intensity of gamma radiation on the site of the power plant reached more than 100 roentgens an hour. This level produces in an hour doses hundreds of times the maximum dose the International Commission on Radiological Protection recommends for members of the public a *year.* On the roof of the destroyed reactor building, radiation levels reached a frightening 100,000 roentgens an hour.

The human dimensions of the tragedy are vast and heartbreaking. At the time of the accident, I was working as a medical researcher at the Institute of Epidemiology and Infectious Diseases in Kiev, some 60 miles from the Chornobyl plant. Sometime on April 26 a friend told me that people had been arriving at hospitals for treatment of burns sustained in an accident at the plant, but we had no idea of its seriousness. There was little official news during the next few days, and what there was suggested the danger was not great. The authorities jammed most foreign broadcasts, although we could listen as Swedish radio reported the detection of high levels of radioactivity in that country and elsewhere. I and some other physicians decided to drive toward the accident site to investigate and help as we could.

We set off cheerfully enough, but as we got closer we started to see signs of mass panic. People with connections to officialdom had used their influence to send children away by air and rail. Others without special connections were waiting in long lines for tickets or occasionally storming trains to try to escape. Families had become split up. The only comparable social upheaval I had seen was during a cholera epidemic. Already many workers from the plant had been hospitalized.

The distribution of the fallout was extremely patchy. One corner of a field might be highly dangerous, while just a few yards away levels seemed low. Nevertheless, huge areas were affected. Although iodine 131 has a half-life of only

VLADIMIR SYOMIN

AWAITING A THYROID EXAMINATION, a young patient and her mother sit anxiously at the Kiev Institute of Endocrinology. In the days and weeks following the 1986 accident at Chornobyl, an estimated 13,000 children inhaled aerosols containing high levels of iodine 131, which collects in the thyroid. Among Ukrainian children, thyroid cancer rates have increased roughly 10-fold.

eight days, it caused large radiation exposures during the weeks immediately following the accident. Strontium 90 and cesium 137, on the other hand, are more persistent. Scientists believe it is the cesium that will account for the largest radiation doses in the long run.

All told, well over 260,000 square kilometers of territory in Ukraine, Russia and Belarus still have more than one curie per square kilometer of contamination with cesium 137. At this level, annual health checks for radiation effects are advised for residents. In my own country of Ukraine, the total area with this level of contamination exceeds 35,000 square kilometers—more than 5 percent of the nation's total area. Most of this, 26,000 square kilometers, is arable land. In the worst affected areas there are restrictions on the use of crops, but less contaminated districts are still under cultivation.

The heavily contaminated parts of Ukraine constitute 13 administrative regions (oblasts). In these oblasts are 1,300 towns and villages with a total population of 2.6 million, including 700,000 children. Within about 10 days of the accident, 135,000 people living in the worst-affected areas had left their homes; by now the total has reached 167,000.

Yet it is clear that the authorities' attempts to keep the scale of the disaster quiet actually made things worse than they need have been. If more inhabitants in the region had been evacuated promptly during those crucial first few days, radiation doses for many people might have been lower.

The region within 30 kilometers of the Chornobyl plant is now largely uninhabited; 60 settlements outside this zone have also been moved. Formerly busy communities are ghost towns. The government has responded to this unprecedented disruption by enacting laws giving special legal status to contaminated areas and granting protections to those who suffered the most. Yet the repercussions will last for generations.

Multiple Illnesses

The medical consequences are, of course, the most serious. Some 30,000 people have fallen ill among the 400,000 workers who toiled as "liquidators," burying the most dangerous wastes and constructing a special building around the ruined reactor that is universally referred to as "the sarcophagus." Of these sick people, about 5,000 are now too ill to work.

It is hard to know, even approximately, how many people have already died as a result of the accident. Populations have been greatly disrupted, and children have been sent away from some areas. By comparing mortality rates before and after the accident, the environmental organization Greenpeace Ukraine has estimated a total of 32,000 deaths. There are other estimates that are higher, and some that are lower, but I believe a figure in this range is defensible. Some, perhaps many, of these deaths may be the result of the immense psychological stress experienced by those living in the contaminated region.

One medical survey of a large group of liquidators, carried out by researchers in Kiev led by Sergei Komissarenko, has found that most of the sample were suffering from a constellation of symptoms that together seem to define a new medical syndrome. The symptoms include fatigue, apathy and a decreased number of "natural killer" cells in the blood.

Natural killer cells, a type of white blood cell, can kill the cells of tumors and virus-infected cells. A reduction in their number, therefore, suppresses the immune system. Some have dubbed this syndrome "Chornobyl AIDS." Besides having increased rates of leukemia and malignant tumors, people with this syndrome are susceptible to more severe forms of cardiac conditions as well as common infections such as bronchitis, tonsillitis and pneumonia.

As a consequence of inhaling aerosols containing iodine 131 immediately after the accident, 13,000 children in the region experienced radiation doses to the thyroid of more than 200 roentgen equivalents. (This means they received at least twice the maximum recommended dose for nuclear industry workers for an entire year.) Up to 4,000 of these children had doses as high as 2,000 roentgen equivalents. Because iodine collects in the thyroid gland, these children have developed chronic inflammation of the thyroid. Although the inflammation itself produces no symptoms, it has started to give rise to a wave of cases of thyroid cancer.

The numbers speak for themselves. Data gathered by the Kiev researcher Mykola D. Tronko and his colleagues indicate that between 1981 and 1985—before the accident—the number of thyroid cancer cases in Ukraine was about five a year. Within five years of the disaster the number had grown to 22 cases a year, and from 1992 to 1995 it reached an average of 43 cases a year. From 1986 to the end of 1995, 589 cases of thyroid cancer were recorded in children and adolescents. (In Belarus the number is even higher.) Ukraine's overall rate of thyroid cancer among children has increased about 10-fold from preaccident levels and is now more than four cases per million. Cancer of the thyroid metastasizes readily, although if caught early enough it can be treated by removing the thyroid gland. Patients must then receive lifelong treatment with supplemental thyroid hormones.

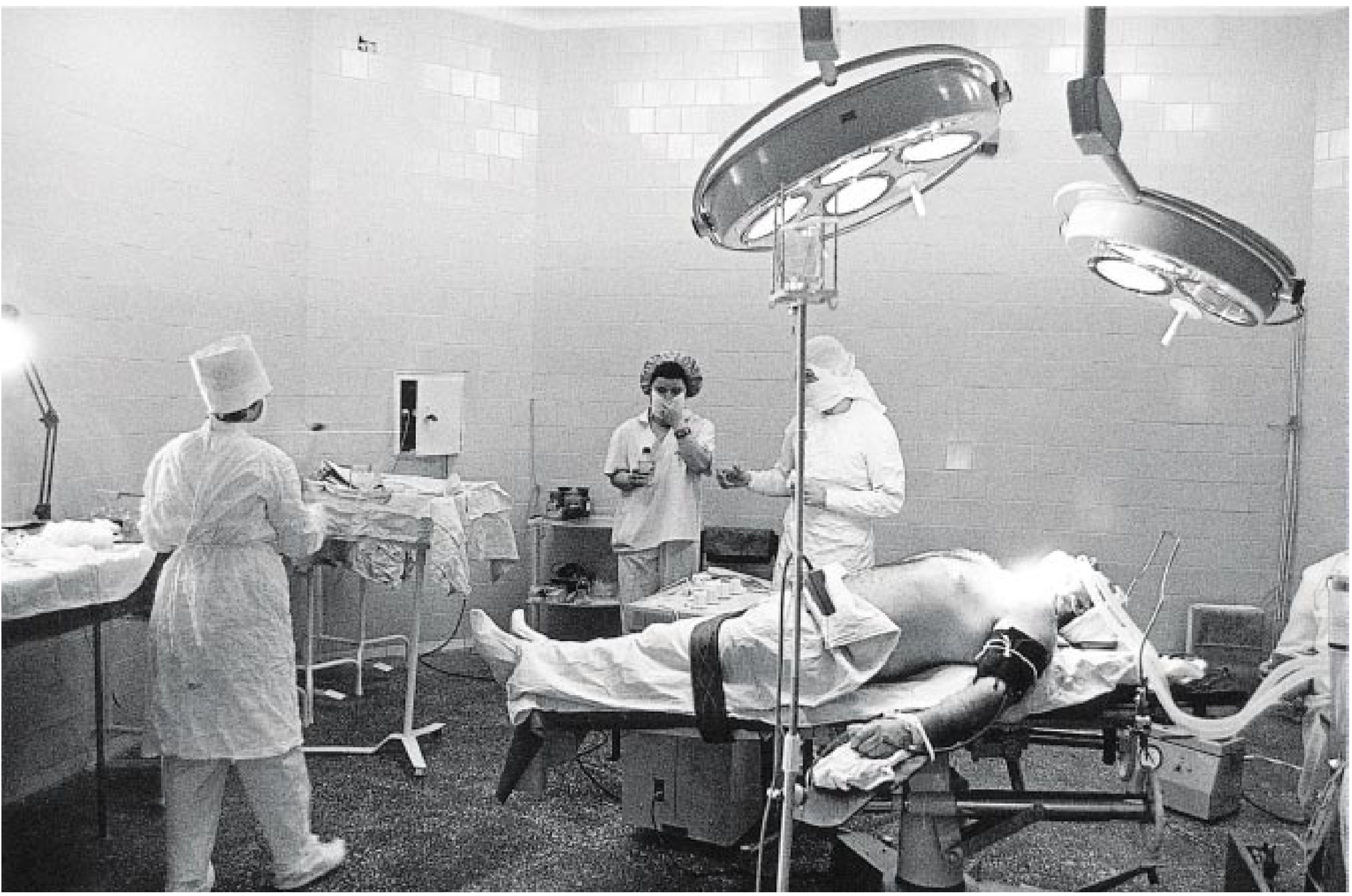
Other research by Ukrainian and Israeli scientists has found that one in every three liquidators—primarily men in their thirties—has been plagued by sexual or reproductive disorders. The problems include impotence and sperm abnormalities. Reductions in the fertilizing capacity of the sperm have also been noted. The number of pregnancies with complications has been growing among women living in the affected areas, and many youngsters fall prey to a debilitating fear of radiation.

The optimists who predicted no long-term medical consequences from the explosion have thus been proved egregiously wrong. These authorities were principally medical officials of the former Soviet Union who were following a script written by the political bureau of the Communist Party's Central Committee. They also include some Western nuclear energy specialists and military experts.

It is also true that the forecasts of "catastrophists"—some of whom predicted well over 100,000 cancer cases—have not come to pass. Still, previous experience with the long-term effects of radiation—much of it derived from studies at Hiroshima and Nagasaki—suggests that the toll will continue to rise. Cancers caused by radiation can take many years before they become detectable, so the prospects for the long-term health of children in the high-radiation regions are, sadly, poor.

The hushing up of the danger from radiation in Soviet propaganda has produced quite the opposite effects from those intended. People live under constant stress, fearful about their health and, especially, that of their children. This mental trauma has given rise to a psychological syndrome comparable to that suffered by veterans of wars in Vietnam and Afghanistan. Among children evacuated from the reactor zone, there has been a 10- to 15-fold increase in the incidence of neuropsychiatric disorders.

The catastrophe and the resulting resettlement of large populations have also caused irreparable harm to the rich ethnic diversity of the contaminated areas, particularly to the so-called *drevly-*



VLADIMIR SYOMIN

THYROID OPERATION will remove the cancerous gland from a patient in an attempt to prevent the spread of the disease. The operation, carried out at the Kiev Institute of Endocrinology's cancer clinic, is the only treatment for cancer of the thyroid. The patient will then have to take thyroid hormones for the rest of his life to replace those no longer produced in his body.

BURNED-OUT REACTOR was photographed from the air not long after the disaster (*left*). A concrete-and-steel sarcophagus was hastily built (*right*) to contain dangerous radioisotopes; it is now decaying at an alarming rate. An international consortium proposes to surround it with a stronger structure, but construction would cost about $300 million and take five years.

any, woodland people, and *polishchuks,* inhabitants of the Polissya region. Unique architectural features and other artifacts of their spiritual and material culture have been effectively lost as abandoned towns and villages have fallen into disrepair. Much of the beautiful landscape is now unsafe for humans.

The Ukrainian government, which is in a severe economic crisis, is today obliged to spend more than 5 percent of its budget dealing with the aftermath of Chornobyl. The money provides benefits such as free housing to about three million people who have been officially recognized as having suffered from the catastrophe, including 356,000 liquidators and 870,000 children. Ukraine has introduced a special income tax corresponding to 12 percent of earnings to raise the necessary revenue, but it is unclear how long the government can maintain benefits at current levels.

Today the Chornobyl zone is one of the most dangerously radioactive places in the world. In the debris of the ruined reactor are tens of thousands of metric tons of nuclear fuel with a total radioactivity level of some 20 million curies. The radiation level in the reactor itself, at several thousand roentgens per hour, is lethal for any form of life. But the danger is spread far and wide. In the 30-kilometer zone surrounding the reactor are about 800 hastily created burial sites where highly radioactive waste, including trees that absorbed radioisotopes from the atmosphere, has been simply dumped into clay-lined pits.

These dumps may account for the substantial contamination of the sediments of the Dnieper River and its tributary the Pripyat, which supply water for 30 million people. Sediments of the Pripyat adjacent to Chornobyl contain an estimated 10,000 curies of strontium 90, 12,000 curies of cesium 137 and 2,000 curies of plutonium. In order to prevent soluble compounds from further contaminating water sources, the wastes must be removed to properly designed and equipped storage facilities—facilities that do not yet exist.

Cost of Cleanup

The two reactors that are still in operation at the Chornobyl plant also pose a major problem (a fire put a third out of action in 1992). These generate up to 5 percent of Ukraine's power; the nuclear energy sector altogether produces 40 percent of the country's electricity. Even so, Ukraine and the Group of Seven industrial nations last December signed a formal agreement on a cooperative plan to shut down the whole Chornobyl plant by the year 2000. The agreement establishes that the European Union and the U.S. will help Ukraine devise plans to mitigate the effects of the shutdown on local populations. It also sets up mechanisms to allow donor countries to expedite safety improvements at one of the reactors still in use. In addition, the agreement provides for international cooperation on decommissioning the plant, as well as on the biggest problem of all: an ecologically sound, long-term replacement for the sarcophagus that was built around the ruin of reactor number four.

The 10-story sarcophagus, which is built largely of concrete and large slabs of metal and has walls over six meters thick, was designed for a lifetime of 30 years. But it was constructed in a great hurry under conditions of high radiation. As a result, the quality of the work was poor, and today the structure is in need of immediate repair. Metal used in the edifice has rusted, and more than 1,000 square meters of concrete have become seriously cracked. Rain and snow can get inside. If the sarcophagus were to collapse—which could happen if there were an earthquake—the rubble would very likely release large amounts of radioactive dust.

In 1993 an international competition was held to find the best long-term solution. Six prospective projects were chosen for further evaluation (out of 94 proposals), and the next year a winner was selected—Alliance, a consortium led by Campenon Bernard of France. The consortium's proposal, which entails the construction of a "supersarcophagus" around the existing one, unites firms from France, Germany, Britain, Russia and Ukraine. The group has already conducted feasibility studies. If the project goes forward, design work will cost $20 million to $30 million, and construction—which would take five years—upwards of $300 million. Final disposal of the waste from the accident will take

30 years. One possibility being explored is that the waste might be encased in a special glass.

Chornobyl was not simply another disaster of the sort that humankind has experienced throughout history, like a fire or an earthquake or a flood. It is a global environmental event of a new kind. It is characterized by the presence of thousands of environmental refugees; long-term contamination of land, water and air; and possibly irreparable damage to ecosystems. Chornobyl demonstrates the ever growing threat of technology run amok.

The designers of the plant, which did not conform to international safety requirements, are surely culpable at least as much as the operators. The RBMK-1000 is an adaptation of a military reactor originally designed to produce material for nuclear weapons. There was no reinforced containment structure around the reactor to limit the effects of an accident. That RBMK reactors are still in operation in Ukraine, Lithuania and Russia should be cause for alarm.

The disaster illustrates the great responsibility that falls on the shoulders of scientific and other experts who give advice to politicians on technical matters. Moreover, I would argue that the former Soviet Union's communist leadership must share the blame. Despite then President Mikhail S. Gorbachev's professed support for glasnost, or openness, the regime hypocritically closed ranks in the aftermath of the tragedy in a futile and ultimately harmful attempt to gloss over the enormity of what had occurred.

The event offers a vivid demonstration of the failures of the monopolistic Soviet political and scientific system. The emphasis under that regime was on secrecy and on simplifying safety features in order to make construction as cheap as possible. International experience with reactor safety was simply disregarded. The calamity underscores, further, the danger that nuclear power plants could pose in regions where wars are being fought. Of course, all such plants are potentially vulnerable to terrorist attack.

Chornobyl has taught the nations of the world a dreadful lesson about the necessity for preparedness if we are to rely on nuclear technology. Humankind lost a sort of innocence on April 26, 1986. We have embarked on a new, post-Chornobyl era, and we have yet to comprehend all the consequences. SA

SIPA

GHOST TOWN: Pripyat, a once vibrant city of 45,000, was home to many of the workers from the Chornobyl plant. It was evacuated after the accident and remains deserted.

The Author

YURI M. SHCHERBAK is ambassador of Ukraine to the U.S. He graduated from Kiev Medical College in 1958 and has advanced degrees in epidemiology. Besides having published extensively in epidemiology and virology, he is the author of 20 books of poetry, plays and essays. In 1988 Shcherbak founded and became leader of the Ukrainian Green Movement, now the Green Party. In 1989 he won a seat in the Supreme Soviet of the U.S.S.R., where as an opposition leader he initiated the first parliamentary investigation of the Chornobyl accident.

Further Reading

CHERNOBYL: A DOCUMENTARY STORY. Iurii Shcherbak. Translated by Ian Press. St. Martin's Press, 1989.

CHORNOBYL: LIVING WITH THE MONSTER. Mike Edwards in *National Geographic,* Vol. 186, No. 2, pages 100–115; August 1994.

RADIATION AND HUMAN IMMUNITY [in Russian]. Sergei Komissarenko. Naukova Dumka, Kiev, 1994.

CARING FOR SURVIVORS OF THE CHERNOBYL DISASTER: WHAT THE CLINICIAN SHOULD KNOW. Armin D. Weinberg et al. in *Journal of the American Medical Association,* Vol. 274, No. 5, pages 408–412; August 2, 1995.

The Birth of Complex Cells

Humans, together with all other animals, plants and fungi, owe their existence to the momentous transformation of tiny, primitive bacteria into large, intricately organized cells

by Christian de Duve

About 3.7 billion years ago the first living organisms appeared on the earth. They were small, single-celled microbes not very different from some present-day bacteria. Cells of this kind are classified as prokaryotes because they lack a nucleus (*karyon* in Greek), a distinct compartment for their genetic machinery. Prokaryotes turned out to be enormously successful. Thanks to their remarkable ability to evolve and adapt, they spawned a wide variety of species and invaded every habitat the world had to offer.

The living mantle of our planet would still be made exclusively of prokaryotes but for an extraordinary development that gave rise to a very different kind of cell, called a eukaryote because it possesses a true nucleus. (The prefix *eu* is derived from the Greek word meaning "good.") The consequences of this event were truly epoch-making. Today all multicellular organisms consist of eukaryotic cells, which are vastly more complex than prokaryotes. Without the emergence of eukaryotic cells, the whole variegated pageantry of plant and animal life would not exist, and no human would be around to enjoy that diversity and to penetrate its secrets.

Eukaryotic cells most likely evolved from prokaryotic ancestors. But how? That question has been difficult to address because no intermediates of this momentous transition have survived or left fossils to provide direct clues. One can view only the final eukaryotic product, something strikingly different from any prokaryotic cell. Yet the problem is no longer insoluble. With the tools of modern biology, researchers have uncovered revealing kinships among a number of eukaryotic and prokaryotic features, thus throwing light on the manner in which the former may have been derived from the latter.

Appreciation of this astonishing evolutionary journey requires a basic understanding of how the two fundamental cell types differ. Eukaryotic cells are much larger than prokaryotes (typically some 10,000 times in volume), and their repository of genetic information is far more organized. In prokaryotes the entire genetic archive consists of a single chromosome made of a circular string of DNA that is in direct contact with the rest of the cell. In eukaryotes, most DNA is contained in more highly structured chromosomes that are grouped within a well-defined central enclosure, the nucleus. The region surrounding the nucleus (the cytoplasm) is partitioned by membranes into an elaborate network of compartments that fulfill a host of functions. Skeletal elements within the cytoplasm provide eukaryotic cells with internal structural support. With the help of tiny molecular motors, these elements also enable the cells to shuffle their contents and to propel themselves from place to place.

Most eukaryotic cells further distinguish themselves from prokaryotes by having in their cytoplasm up to several thousand specialized structures, or organelles, about the size of a prokaryotic cell. The most important of such organelles are peroxisomes (which serve assorted metabolic functions), mitochondria (the power factories of cells) and, in algae and plant cells, plastids (the sites of photosynthesis). Indeed, with their many organelles and intricate internal structures, even single-celled eukaryotes, such as yeasts or amoebas, prove to be immensely complex organisms.

The organization of prokaryotic cells is much more rudimentary. Yet prokaryotes and eukaryotes are undeniably related. That much is clear from their many genetic similarities. It has even been possible to establish the approximate time when the eukaryotic branch of life's evolutionary tree began to detach from the prokaryotic trunk. This divergence started in the remote past, probably before three billion years ago. Subsequent events in the development of eukaryotes, which may have taken as long as one billion years or more, would still be shrouded in mystery were it not

PROKARYOTIC AND EUKARYOTIC CELLS differ in size and complexity. Prokaryotic cells (*right*) are normally about one micron across, whereas eukaryotic cells typically range from 10 to 30 microns. The latter, here represented by a hypothetical green alga (*far right*), house a wide array of specialized structures—including an encapsulated nucleus containing the cell's main genetic stores.

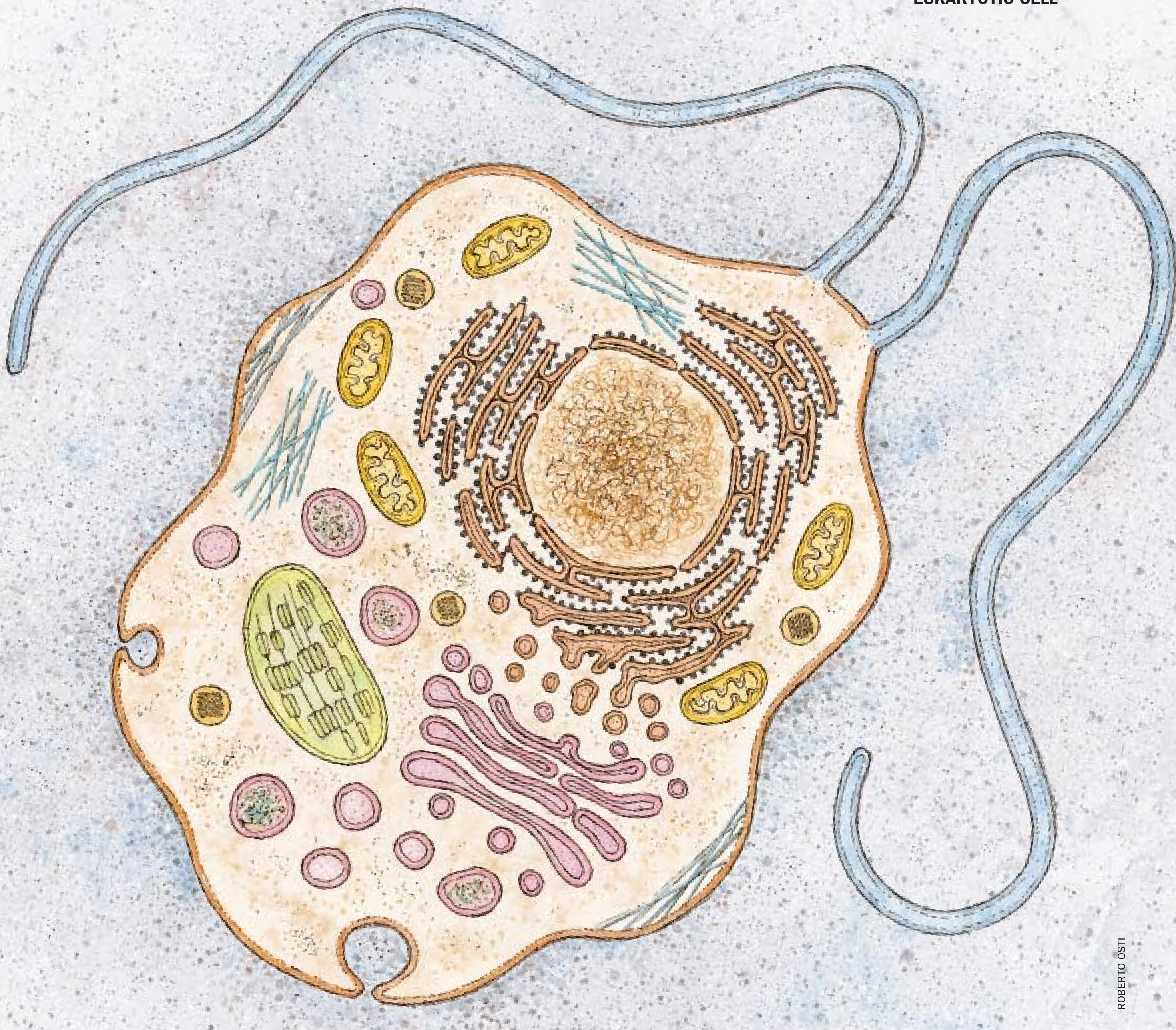
for an illuminating clue that has come from the analysis of the numerous organelles that reside in the cytoplasm.

A Fateful Meal

Biologists have long suspected that mitochondria and plastids descend from bacteria that were adopted by some ancestral host cell as endosymbionts (a word derived from Greek roots that means "living together inside"). This theory goes back more than a century. But the notion enjoyed little favor among mainstream biologists until it was revived in 1967 by Lynn Margulis, then at Boston University, who has since tirelessly championed it, at first against strong opposition. Her persuasiveness is no longer needed. Proofs of the bacterial origin of mitochondria and plastids are overwhelming.

The most convincing evidence is the presence within these organelles of a vestigial—but still functional—genetic system. That system includes DNA-based genes, the means to replicate this DNA, and all the molecular tools needed to construct protein molecules from their DNA-encoded blueprints. A number of properties clearly characterize this genetic apparatus as prokaryotelike and distinguish it from the main eukaryotic genetic system.

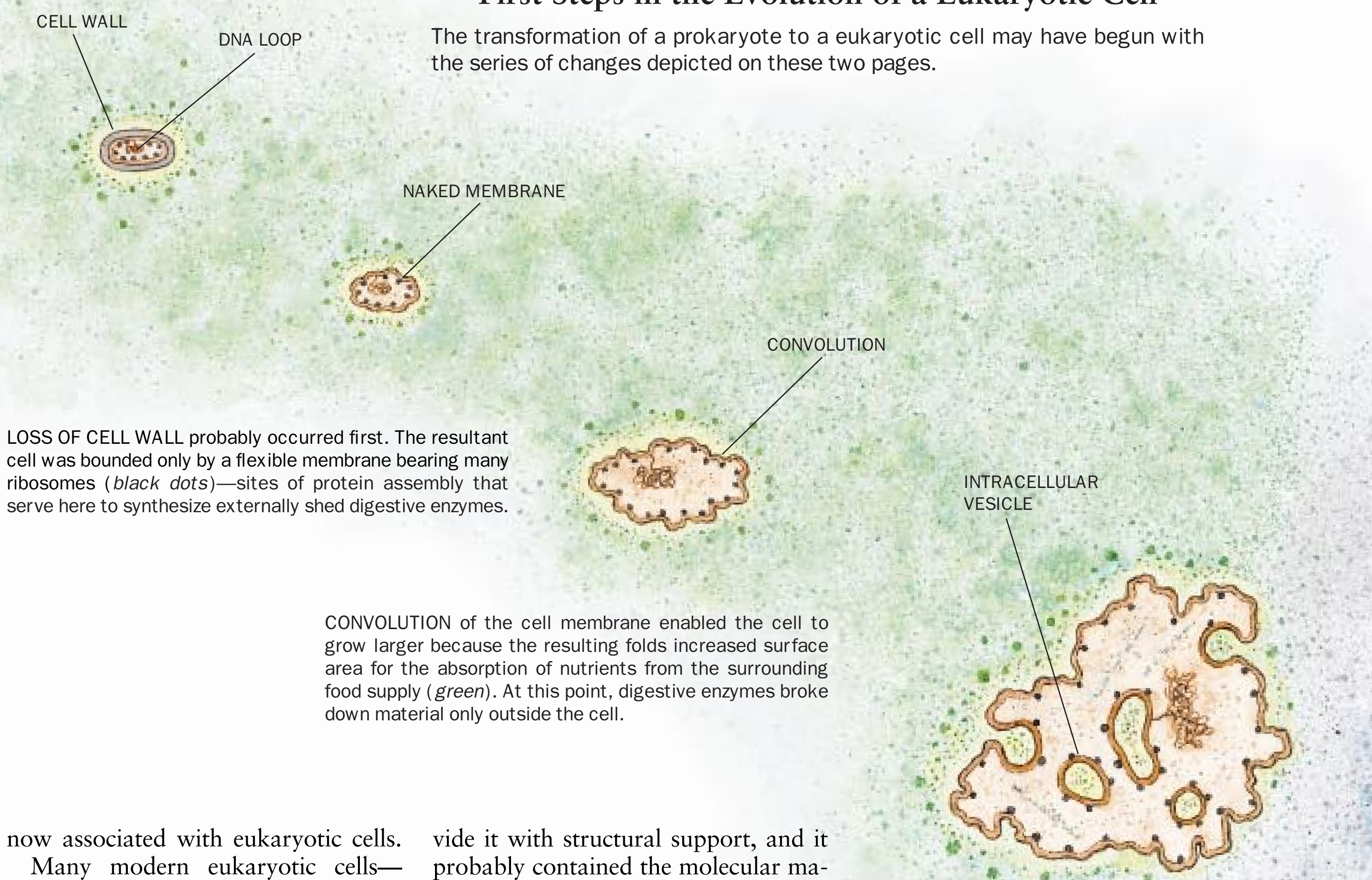
Endosymbiont adoption is often presented as resulting from some kind of encounter—aggressive predation, peaceful invasion, mutually beneficial association or merger—between two typical prokaryotes. But these descriptions are troubling because modern bacteria do not exhibit such behavior. Moreover, the joining of simple prokaryotes would leave many other characteristics of eukaryotic cells unaccounted for. There is a more straightforward explanation, which is directly suggested by nature itself—namely, that endosymbionts were originally taken up in the course of feeding by an unusually large host cell that had already acquired many properties



ROBERTO OSTI

First Steps in the Evolution of a Eukaryotic Cell

The transformation of a prokaryote to a eukaryotic cell may have begun with the series of changes depicted on these two pages.



LOSS OF CELL WALL probably occurred first. The resultant cell was bounded only by a flexible membrane bearing many ribosomes (*black dots*)—sites of protein assembly that serve here to synthesize externally shed digestive enzymes.

CONVOLUTION of the cell membrane enabled the cell to grow larger because the resulting folds increased surface area for the absorption of nutrients from the surrounding food supply (*green*). At this point, digestive enzymes broke down material only outside the cell.

INWARD FOLDING of the membrane allowed pockets to pinch off, forming isolated interior compartments. Digestion then occurred both outside and inside the cell. Internalization of the patch of membrane to which DNA was anchored created a sac with DNA attached—a precursor of the cell nucleus.

now associated with eukaryotic cells.

Many modern eukaryotic cells—white blood cells, for example—entrap prokaryotes. As a rule, the ingested microorganisms are killed and broken down. Sometimes they escape destruction and go on to maim or kill their captors. On a rare occasion, both captor and victim survive in a state of mutual tolerance that can later turn into mutual assistance and, eventually, dependency. Mitochondria and plastids thus may have been a host cell's permanent guests.

If this surmise is true, it reveals a great deal about the earlier evolution of the host. The adoption of endosymbionts must have followed after some prokaryotic ancestor to eukaryotes evolved into a primitive phagocyte (from the Greek for "eating cell"), a cell capable of engulfing voluminous bodies, such as bacteria. And if this ancient cell was anything like modern phagocytes, it must have been much larger than its prey and surrounded by a flexible membrane able to envelop bulky extracellular objects. The pioneering phagocyte must also have had an internal network of compartments connected with the outer membrane and specialized in the processing of ingested materials. It would also have had an internal skeleton of sorts to provide it with structural support, and it probably contained the molecular machinery to flex the outer membrane and to move internal contents about.

The development of such cellular structures represents the essence of the prokaryote-eukaryote transition. The chief problem, then, is to devise a plausible explanation for the progressive construction of these features in a manner that can be accounted for by the operation of natural selection. Each small change in the cell must have improved its chance of surviving and reproducing (offered a selective advantage) so that the new trait would become increasingly widespread in the population.

Genesis of an Eating Cell

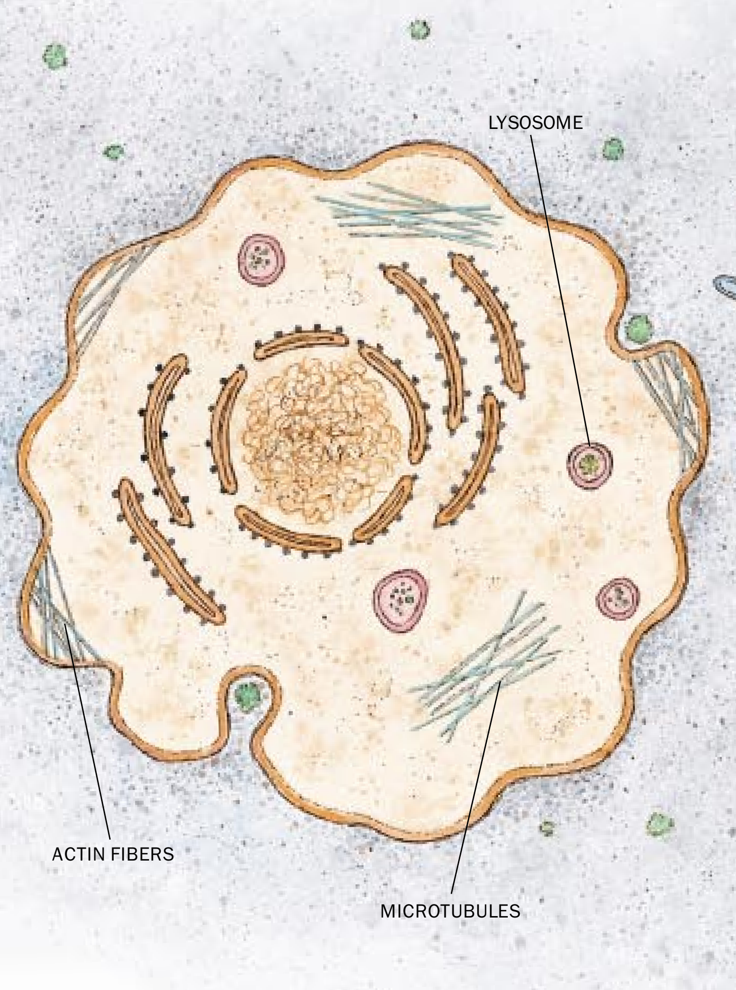
What forces might drive a primitive prokaryote to evolve in the direction of a modern eukaryotic cell? To address this question, I will make a few assumptions. First, I shall take it that the ancestral cell fed on the debris and discharges of other organisms; it was what biologists label a heterotroph. It therefore lived in surroundings that provided it with food. An interesting possibility is that it resided in mixed prokaryotic colonies of the kind that have fossilized into layered rocks called stromatolites. Living stromatolite colonies still exist; they are formed of layers of heterotrophs topped by photosynthetic organisms that multiply with the help of sunlight and supply the lower layers with food. The fossil record indicates that such colonies already existed more than 3.5 billion years ago.

A second hypothesis, a corollary of the first, is that the ancestral organism had to digest its food. I shall assume that it did so (like most modern heterotrophic prokaryotes) by means of secreted enzymes that degraded food outside the cell. That is, digestion occurred before ingestion.

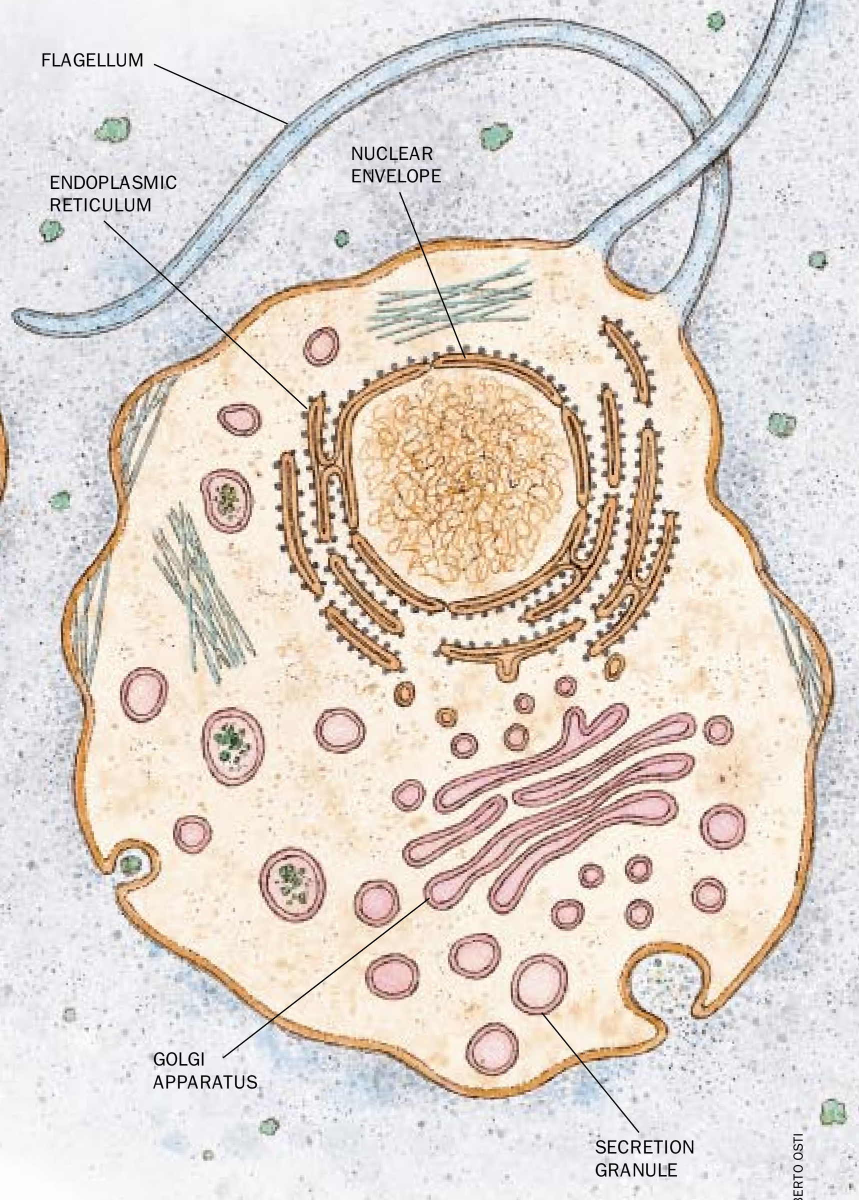
A final supposition is that the organism had lost the ability to manufacture a cell wall, the rigid shell that surrounds most prokaryotes and provides them with structural support and protection against injury. Notwithstanding their fragility, free-living naked forms of this kind exist today, even in unfavorable surroundings. In the case under consideration, the stromatolite colony would have provided the ancient organism with excellent shelter.

Accepting these three assumptions, one can now visualize the ancestral organism as a flattened, flexible blob—almost protean in its ability to change shape—in intimate contact with its food. Such a cell would thrive and grow faster than its walled-in relatives. It need not, however, automatically respond to growth by dividing, as do most cells. An alternative behavior would be expansion and folding of the surrounding membrane, thus increasing the surface available for the intake of nutrients and the excretion of waste—limiting factors on the growth of any cell. The ability to create an extensively folded surface would allow the organism to expand far beyond the size of ordinary prokaryotes. Indeed, giant prokaryotes living today have a highly convoluted outer membrane, probably a prerequisite of their enormous girth. Thus, one eukaryotic property—large size—can be accounted for simply enough.

Natural selection is likely to favor expansion over division because deep folds would increase the cell's ability to obtain food by creating partially confined areas—narrow inlets along the rugged



EMERGENCE OF SKELETAL ELEMENTS made up of fibers and microtubules lent internal support to the growing cell and enabled it to flex the outer membrane and move material about. The cell, newly freed from its food supply, became proficient at enveloping large particles and digesting them internally. It eventually absorbed all its food in this fashion, using enzymes that were delivered to digestive sacs by way of an expanding network of interior compartments. Some of these compartments flattened and surrounded the increasing quantity of DNA.



PRIMITIVE PHAGOCYTE, an "eating cell," ultimately developed from the sequence of incremental evolutionary advances. This cell used flagella, seen as whiplike projections, for propulsion. The phagocyte also acquired a true nucleus (as the compartments surrounding the DNA fused together), along with an increasingly complex family of cellular structures that evolved from internalized parts of the cell membrane.

cellular coast—within which high concentrations of digestive enzymes would break down food more efficiently. Here is where a crucial development could have taken place: given the self-sealing propensity of biological membranes (which are like soap bubbles in this respect), no great leap of imagination is required to see how folds could split off to form intracellular sacs. Once such a process was initiated, as a more or less random side effect of membrane expansion, any genetic change that would promote its further development would be greatly favored by natural selection. The inlets would have turned into confined inland ponds, within which food would now be trapped together with the enzymes that digest it. From being extracellular, digestion would have become intracellular.

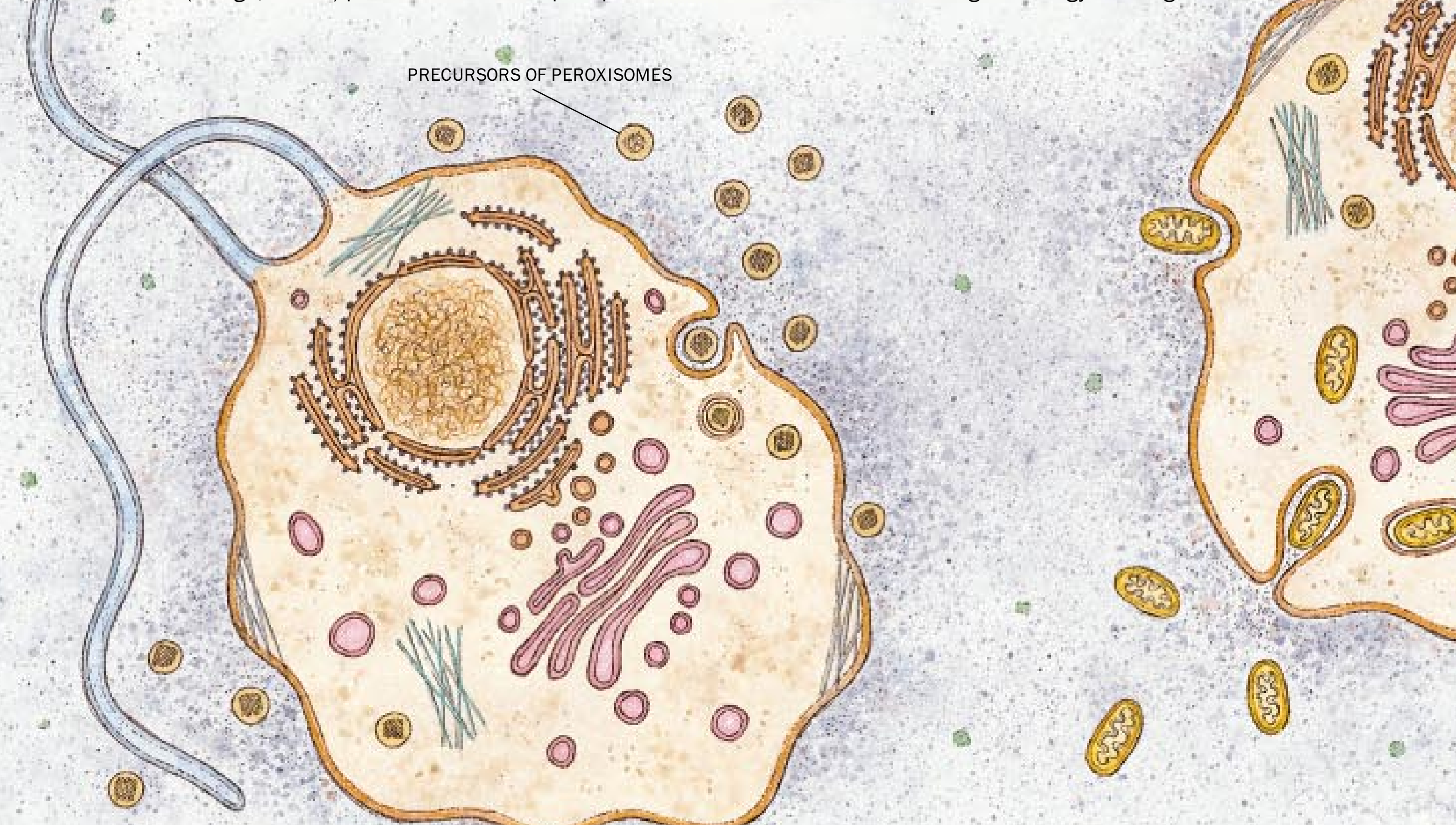
Cells capable of catching and processing food in this way would have gained enormously in their ability to exploit their environment, and the resulting boost to survival and reproductive potential would have been gigantic. Such cells would have acquired the fundamental features of phagocytosis: engulfment of extracellular objects by infoldings of the cell membrane (endocytosis), followed by the breakdown of the captured materials within intracellular digestive pockets (lysosomes). All that came after may be seen as evolutionary trimmings, important and useful but not essential. The primitive intracellular pockets gradually gave rise to many specialized subsections, forming what is known as the cytomembrane system, characteristic of all modern eukaryotic cells. Strong support for this model comes from the observation that many systems present in the cell membrane of prokaryotes are found in various parts of the eukaryotic cytomembrane system.

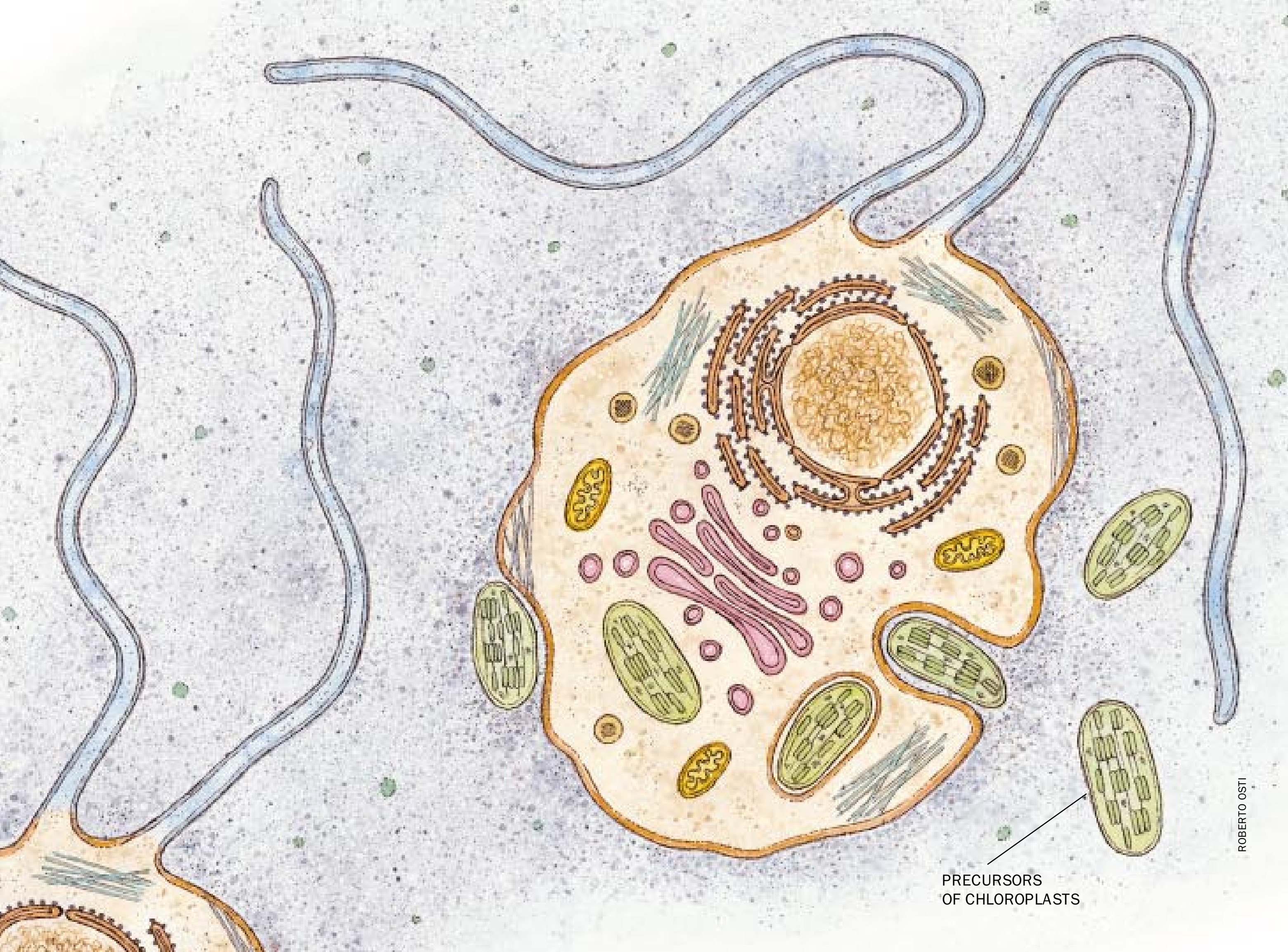
Interestingly, the genesis of the nucleus—the hallmark of eukaryotic cells—can also be accounted for, at least schematically, as resulting from the internalization of some of the cell's outer membrane. In prokaryotes the circular DNA chromosome is attached to the cell membrane. Infolding of this particular patch of cell membrane could create an intracellular sac bearing the chromosome on its surface. That structure could have been the seed of the eukaryotic nucleus, which is surrounded by a double membrane formed from flattened parts of the intracellular membrane system that fuse into a spherical envelope.

The proposed scenario explains how a small prokaryote could have evolved into a giant cell displaying some of the main properties of eukaryotic cells, in-

Final Steps in the Evolution of a Eukaryotic Cell

Adoption of prokaryotes as permanent guests within larger phagocytes marked the final phase in the evolution of eukaryotic cells. The precursors to peroxisomes (*beige, left*) may have been the first prokaryotes to develop into eukaryotic organelles. They detoxified destructive compounds created by rising oxygen levels in the atmosphere. The precursors of mitochondria (*orange, middle*) proved even more adept at protecting the host cells against oxygen and offered the further ability to generate the energy-rich molecule adenosine triphosphate (ATP). The development of peroxisomes and mitochondria then allowed the adoption of the precursors of plastids, such as chloroplasts (*green, right*), oxygen-producing centers of photosynthesis. This final step benefited the host cells by supplying the means to manufacture materials using the energy of sunlight.



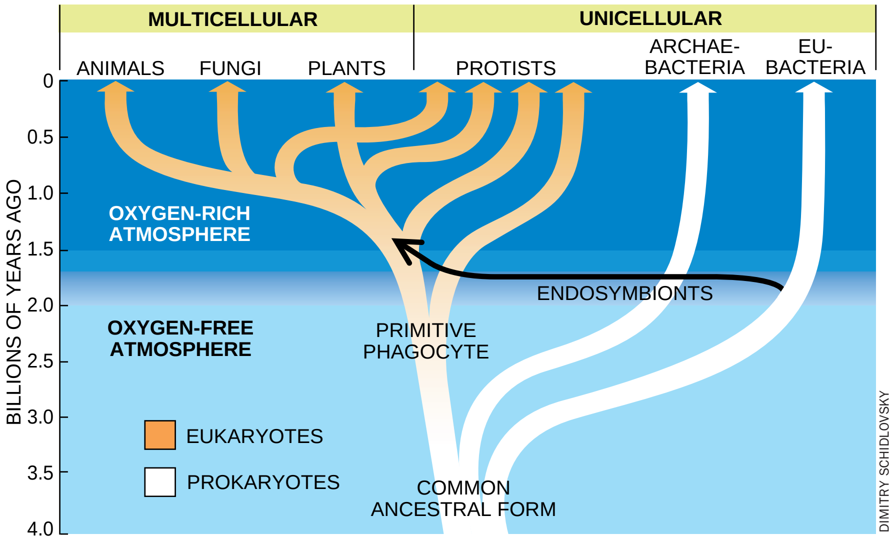


cluding a fenced-off nucleus, a vast network of internal membranes and the ability to catch food and digest it internally. Such progress could have taken place by a very large number of almost imperceptible steps, each of which enhanced the cell's autonomy and provided a selective advantage. But there was a condition. Having lost the support of a rigid outer wall, the cell needed inner props for its enlarging bulk.

Modern eukaryotic cells are reinforced by fibrous and tubular structures, often associated with tiny motor systems, that allow the cells to move around and power their internal traffic. No counterpart of the many proteins that make up these systems is found in prokaryotes. Thus, the development of the cytoskeletal system must have required a large number of authentic innovations. Nothing is known about these key evolutionary events, except that they most likely went together with cell enlargement and membrane expansion, often in pacesetting fashion.

At the end of this long road lay the primitive phagocyte: a cell efficiently organized to feed on bacteria, a mighty hunter no longer condemned to reside inside its food supply but free to roam the world and pursue its prey actively, a cell ready, when the time came, to become the host of endosymbionts.

Such cells, which still lacked mitochondria and some other key organelles characteristic of modern eukaryotes, would be expected to have invaded many niches and filled them with variously adapted progeny. Yet few if any descendants of such evolutionary lines have survived to the present day. A few unicellular eukaryotes devoid of mitochondria exist, but the possibility that their forebears once possessed mitochondria and lost them cannot be excluded. Thus, all eukaryotes may well have evolved from primitive phagocytes that incorporated the precursors to mitochondria. Whether more than one such adoption took place is still being debated, but the majority opinion is that mitochondria sprang from a single stock. It would appear that the acquisi-



EVOLUTIONARY TREE depicts major events in the history of life. This well-accepted chronology has newly been challenged by Russell F. Doolittle of the University of California at San Diego and his co-workers, who argue that the last common ancestor of all living beings existed a little more than two billion years ago.

tion of mitochondria either saved one eukaryotic lineage from elimination or conferred such a tremendous selective advantage on its beneficiaries as to drive almost all other eukaryotes to extinction. Why then were mitochondria so overwhelmingly important?

The Oxygen Holocaust

The primary function of mitochondria in cells today is the combustion of foodstuffs with oxygen to assemble the energy-rich molecule adenosine triphosphate (ATP). Life is vitally dependent on this process, which is the main purveyor of energy in the vast majority of oxygen-dependent (aerobic) organisms. Yet when the first cells appeared on the earth, there was no oxygen in the atmosphere. Free molecular oxygen is a product of life; it began to be generated when certain photosynthetic microorganisms, called cyanobacteria, appeared. These cells exploit the energy of sunlight to extract the hydrogen they need for self-construction from water molecules, leaving molecular oxygen as a by-product. Oxygen first entered the atmosphere in appreciable quantity some two billion years ago, progressively rising to reach a stable level about 1.5 billion years ago.

Before the appearance of atmospheric oxygen, all forms of life must have been adapted to an oxygen-free (anaerobic) environment. Presumably, like the obligatory anaerobes of today, they were extremely sensitive to oxygen. Within cells, oxygen readily generates several toxic chemical groups. These cellular poisons include the superoxide ion, the hydroxyl radical and hydrogen peroxide. As oxygen concentration rose two billion years ago, many early organisms probably fell victim to the "oxygen holocaust." Survivors included those cells that found refuge in some oxygen-free location or had developed other protection against oxygen toxicity.

These facts point to an attractive hypothesis. Perhaps the phagocytic forerunner of eukaryotes was anaerobic and was rescued from the oxygen crisis by the aerobic ancestors of mitochondria: cells that not only destroyed the dangerous oxygen (by converting it to innocuous water) but even turned it into a tremendously useful ally. This theory would neatly account for the apparent lifesaving effect of mitochondrial adoption and has enjoyed considerable favor.

Yet there is a problem with this idea. Adaptation to oxygen very likely took place gradually, starting with primitive systems of oxygen detoxification. A considerable amount of time must have been needed to reach the ultimate sophistication of modern mitochondria. How did anaerobic phagocytes survive during all the time it took for the ancestors of mitochondria to evolve?

A solution to this puzzle is suggested by the fact that eukaryotic cells contain other oxygen-utilizing organelles, as widely distributed throughout the plant and animal world as mitochondria but much more primitive in structure and composition. These are the peroxisomes [see "Microbodies in the Living Cell," by Christian de Duve; SCIENTIFIC AMERICAN, May 1983]. Peroxisomes, like mitochondria, carry out a number of oxidizing metabolic reactions. Unlike mitochondria, however, they do not use the energy released by these reactions to assemble ATP but squander it as heat. In the process, they convert oxygen to hydrogen peroxide, but then they destroy this dangerous compound with an enzyme called catalase. Peroxisomes also contain an enzyme that removes the superoxide ion. They therefore qualify eminently as primary rescuers from oxygen toxicity.

I first made this argument in 1969, when peroxisomes were believed to be specialized parts of the cytomembrane system. I thus included peroxisomes within the general membrane expansion model I had proposed for the development of the primitive phagocyte. Afterward, experiments by the late Brian H. Poole and by Paul B. Lazarow, my associates at the Rockefeller University, conclusively demonstrated that peroxisomes are entirely unrelated to the cytomembrane system. Instead they acquire their proteins much as mitochondria and plastids do (by a process I will explain shortly). Hence, it seemed reasonable that all three organelles began as endosymbionts. So, in 1982, I revised my original proposal and suggested that peroxisomes might stem from primitive aerobic bacteria that were adopted before mitochondria. These early oxygen detoxifiers could have protected their host cells during all the time it took for the ancestors of mitochondria to reach the high efficiency they possessed when they were adopted.

So far researchers have obtained no solid evidence to support this hypothesis or, for that matter, to disprove it. Unlike mitochondria and plastids, peroxisomes do not contain the remnants of an independent genetic system. This observation nonetheless remains compatible with the theory that peroxisomes developed from an endosymbiont. Mitochondria and plastids have lost most of their original genes to the nucleus, and the older peroxisomes could have lost all their DNA by now.

Whichever way they were acquired, peroxisomes may well have allowed early eukaryotes to weather the oxygen crisis. Their ubiquitous distribution would thereby be explained. The tremendous gain in energy retrieval provided with the coupling of the formation of ATP to oxygen utilization would account for the subsequent adoption of mitochondria, organelles that have the additional advantage of keeping the oxygen in their surroundings at a much lower level than peroxisomes can maintain.

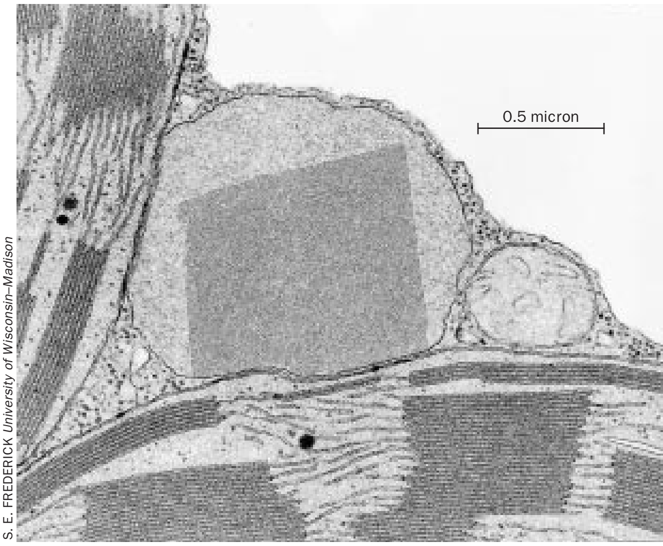
Why then did peroxisomes not disappear after mitochondria were in place? By the time eukaryotic cells acquired mitochondria, some peroxisomal activities (for instance, the metabolism of certain fatty acids) must have become so vital that these primitive organelles could not be eliminated by natural selection. Hence, peroxisomes and mitochondria are found together in most modern eukaryotic cells.

The other major organelles of endosymbiont origin are the plastids, whose main representatives are the chloroplasts, the green photosynthetic organelles of unicellular algae and multicellular plants. Plastids are derived from cyanobacteria, the prokaryotes responsible for the oxygen crisis. Their adoption as endosymbionts quite likely followed that of mitochondria. The selective advantages that favored the adoption of photosynthetic endosymbionts are obvious. Cells that had once needed a constant food supply henceforth thrived on nothing more than air, water, a few dissolved minerals and light. In fact, there is evidence that eukaryotic cells acquired plastids at least three separate times, giving rise to green, red and brown algae. Members of the first of these groups were later to form multicellular plants.

From Prisoner to Slave

What started as an uneasy truce soon turned into the progressive enslavement of the captured endosymbiont prisoners by their phagocytic hosts. This subjugation was achieved by the piecemeal transfer of most of the endosymbionts' genes to the host cell's nucleus. In itself, the uptake of genes by the nucleus is not particularly extraordinary. When foreign genes are introduced into the cytoplasm of a cell (as in some bioengineering experiments), they can readily home to the nucleus and function there. That is, they replicate during cell division and can serve as the master templates for the production of proteins. But the migration of genes from endosymbionts to the nucleus is remarkable because it seems to have raised more difficulties than it solved. Once this transfer occurred, the proteins encoded by these genes began to be manufactured in the cytoplasm of the host cell (where the products of all nuclear genes are constructed). These molecules had then to migrate into the endosymbiont to be of use. Somehow this seemingly unpromising scheme not only withstood the hazards of evolution but also proved so successful that all endosymbionts retaining copies of transferred genes eventually disappeared.

Today mitochondria, plastids and peroxisomes acquire proteins from the surrounding cytoplasm with the aid of complex transport structures in their bounding membranes. These structures recognize parts of newly made protein molecules as "address tags" specific to each organelle. The transport apparatus then allows the appropriate molecules to travel through the membrane with the help of energy and of specialized proteins (aptly called chaperones). These systems for bringing externally made proteins into the organelles could conceivably have evolved from similar systems for protein secretion that existed in the original membranes of the endosymbionts. In their new function, however, those systems would have to operate from outside to inside.



S. E. FREDERICK *University of Wisconsin–Madison*

FOUR ORGANELLES appear in a tobacco leaf cell. The two chloroplasts (*left* and *bottom*) and the mitochondrion (*middle right*) evolved from prokaryotic endosymbionts. The peroxisome (*center*)—containing a prominent crystalline inclusion, most probably made up of the enzyme catalase—may have derived from an endosymbiont as well.

The adoption of endosymbionts undoubtedly played a critical role in the birth of eukaryotes. But this was not the key event. More significant (and requiring a much larger number of evolutionary innovations) was the long, mysterious process that made such acquisition possible: the slow conversion, over as long as one billion years or more, of a prokaryotic ancestor into a large phagocytic microbe possessing most attributes of modern eukaryotic cells. Science is beginning to lift the veil that shrouds this momentous transformation, without which much of the living world, including humans, would not exist. SA

The Author

CHRISTIAN DE DUVE shared the 1974 Nobel Prize in Physiology or Medicine with Albert Claude and George E. Palade "for their discoveries concerning the structural and functional organization of the cell." He divides his time between the University of Louvain in Belgium, where he is professor emeritus of biochemistry, and the Rockefeller University in New York City, where he is Andrew W. Mellon Professor Emeritus. In Belgium, de Duve founded the International Institute of Cellular and Molecular Pathology. He is the author of *A Guided Tour of the Living Cell; Blueprint for a Cell: The Nature and Origin of Life;* and *Vital Dust: Life as a Cosmic Imperative.*

Further Reading

THE ORIGIN OF EUKARYOTE AND ARCHAEBACTERIAL CELLS. T. Cavalier-Smith in *Annals of the New York Academy of Sciences,* Vol. 503, pages 17–54; July 1987.

BLUEPRINT FOR A CELL: THE NATURE AND ORIGIN OF LIFE. Christian de Duve. Neil Patterson Publishers/Carolina Biological Supply Company, 1991.

TRACING THE HISTORY OF EUKARYOTIC CELLS: THE ENIGMATIC SMILE. Betsy D. Dyer and Robert A. Obar. Columbia University Press, 1994.

VITAL DUST: LIFE AS A COSMIC IMPERATIVE. Christian de Duve. BasicBooks, 1995.

Searching for Life on Other Planets

Life remains a phenomenon we know only on Earth. But an innovative telescope in space could change that by detecting signs of life on distant planets

by J. Roger P. Angel and Neville J. Woolf

The possibility that we are not alone in the universe has fascinated people for centuries. In the 1600s Galileo Galilei peered into the night sky with his newly invented telescope, recognized mountains on the moon, and noted that other planets were spheres like Earth. About 60 years later other stargazers observed polar ice caps on Mars, as well as color variations on the planet's surface, which they believed to be vegetation changing with the seasons (the colors are now known to be the result of dust storms). During the latter part of this century, cameras on board unmanned spacecraft captured images from Mars of channels carved by long gone rivers, offering hope that life once may have existed there. But samples of Martian soil obtained in the 1970s by the *Viking* lander spacecraft lacked material evidence of any life. Indeed, the present conditions in the rest of our solar system seem to be generally incompatible with life like that found on Earth.

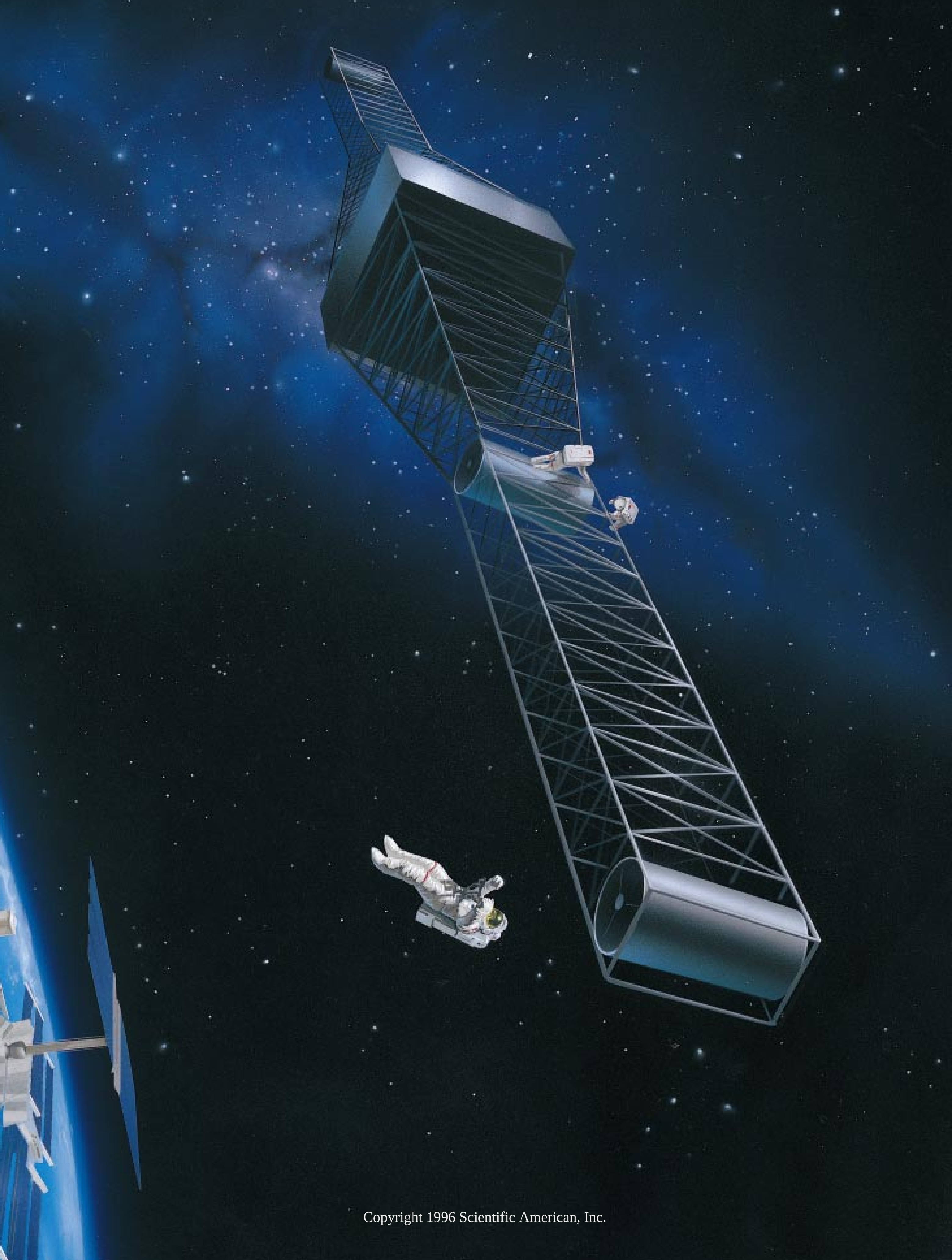
But our search for extraterrestrial life has recently been extended—we can now turn our attention to planets outside our own solar system. After years of looking, astronomers have turned up evidence of planets orbiting three distant stars similar to our sun [*see box on pages 62 and 63*]. Planets around these and other stars may have evolved living organisms. Finding extraterrestrial life may seem a Herculean task, but within the next decade, we could build the equipment needed to locate planets with life-forms like the primitive ones on Earth.

The largest and most powerful telescope now in space, the *Hubble Space Telescope,* can just make out mountains on Mars. Pictures sharp enough to display geologic features of planets around other stars would require an array of space telescopes the size of the U.S. Furthermore, as Carl Sagan of Cornell University has pointed out, pictures of Earth do not reveal the presence of life unless they are taken at very high resolution. Detailed images could be obtained with unmanned spacecraft sent to other solar systems, but the huge distance between Earth and any other planet is a distinct drawback to this approach—it would take millennia to travel to another solar system and send back useful images.

Taking photographs, however, is not the best way to start studying distant planets. Astronomers instead rely on the technique of spectroscopy to obtain most of their information. In spectroscopy, light originating from an object in space can be analyzed for unique markers that help researchers piece together characteristics such as the celestial body's tem-

ALFRED T. KAMAJIAN

SPACE-BASED TELESCOPE SYSTEM that can search for life-bearing planets has been proposed by the authors. The instrument, a type of interferometer, could be assembled at the proposed international space station (*lower left*). Subsequently, electric propulsion would send the 50- to 75-meter-long device into an orbit around the sun roughly the same as Jupiter's. Such a mission is at the focus of the National Aeronautics and Space Administration's plans to study neighboring planetary systems.



New Planets around Sunlike Stars

Until recently, astronomers had no direct evidence that planets of any kind orbited other stars resembling the sun. Then, last October, Michel Mayor and Didier Queloz of the Geneva Observatory announced the detection of a massive planet circling the sunlike star 51 Pegasi [see "Strange Places," by Corey S. Powell, "Science and the Citizen," SCIENTIFIC AMERICAN, January]. Geoffrey W. Marcy and R. Paul Butler of San Francisco State University and the University of California at Berkeley swiftly confirmed the finding and, just three months later, turned up two more bodies orbiting other, similar stars, proving the first discovery was no fluke.

Nobody has actually seen these alien worlds; all three were identified indirectly, by measuring the way they influenced the movement of their parent stars. As an object orbits a star, its gravitational pull causes the star to wobble back and forth. That motion creates a periodic displacement, known as a Doppler shift, in the spectrum of the star as seen from Earth. The pattern of the shift reveals the size and shape of the companion's orbit; the shift's magnitude indicates the companion's minimum possible mass. No other details (temperature or composition, for instance) can be discerned through the Doppler technique.

Even from that limited information, it is clear that the new planets are unlike anything seen before. The one around 51 Pegasi is the oddest of the bunch. Its mass is at least half that of Jupiter, and yet it orbits just seven million kilometers from the parent star—less than one eighth Mercury's distance from the sun. At such proximity, the planet's surface would be baked to a theoretical temperature of 1,300 degrees Celsius. The planet's orbital period, or year, is just 4.2 days.

One of the planets found by Marcy and Butler orbits the star 47 Ursae Majoris; this body has somewhat less extreme attributes. Its three-year orbit takes it on a circular course about 300 million kilometers from its star (corresponding to an orbit between Mars and Jupiter), and its mass is at minimum 2.3 times that of Jupiter; it would not seem terribly out of place in our own solar system.

The third new body, also identified by Marcy and Butler, circles the star 70 Virginis. This "planet" is rather different from the other two. It is the heftiest of the group, having at least 6.5 times the mass of Jupiter, and its 117-day orbit has a highly elliptical shape. Marcy has asserted that it lies in the "Goldilocks zone," the range of distances where a planet's temperature could be "just right" for water to exist in liquid form. Despite such optimistic talk, this giant planet probably has a deep, suffocating atmosphere that offers poor prospects for life. In fact, based on its great mass and elliptical orbit, many scientists argue that the 70 Virginis companion should be classified not as a planet at all but as a brown dwarf, a gaseous object that forms somewhat like a star but lacks enough mass to shine.

There is a reason why astronomers are finding only massive bodies in fairly short-period orbits: these are the kind that are easiest to discern using the Doppler technique. Uncovering a planet in a slow orbit akin to Jupiter's would require at least a decade of high-precision Doppler observations. One possible way to broaden the search is to look at gravitational lensing, a process whereby the gravity of an intervening star temporarily magnifies the light from a more distant one. If the lensing star has planets, they could produce additional, short-lived brightenings. Many stars can be monitored at once, so this approach could yield statistics on the abundance of planets. Unfortunately, it cannot be used to detect planets around nearby stars.

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perature, atmospheric pressure and chemical composition.

The vital signs easiest to spot with spectroscopy are radio signals designed by extraterrestrials for interstellar communication. Such transmissions would be totally unlike natural phenomena; such unexpected features are examples of the kind of beacons that we must look for to locate intelligent life elsewhere. Yet sensitive scans of faraway star systems have not come across any signals, indicating only that extraterrestrials bent on interstellar radio communication are uncommon.

But planets may be home to noncommunicating life-forms, so we need to be able to find evidence of even the simplest organisms. To expand our capacity to locate distant planets and determine whether these worlds are inhabited, we have proposed a powerful and novel successor to Galileo's telescope that will, we believe, enable us to detect life on other planets.

The simplest forms of life on our planet altered the conditions on Earth in ways that a distant observer could perceive. The fossil records indicate that within a billion years of Earth's formation, as soon as the heavy bombardment by asteroids ceased, primitive organisms such as bacteria and algae had spread around most of the globe. These organisms represented the totality of life here for the next two billion years; consequently, if life exists on other planets, it might well be in this highly uncommunicative form.

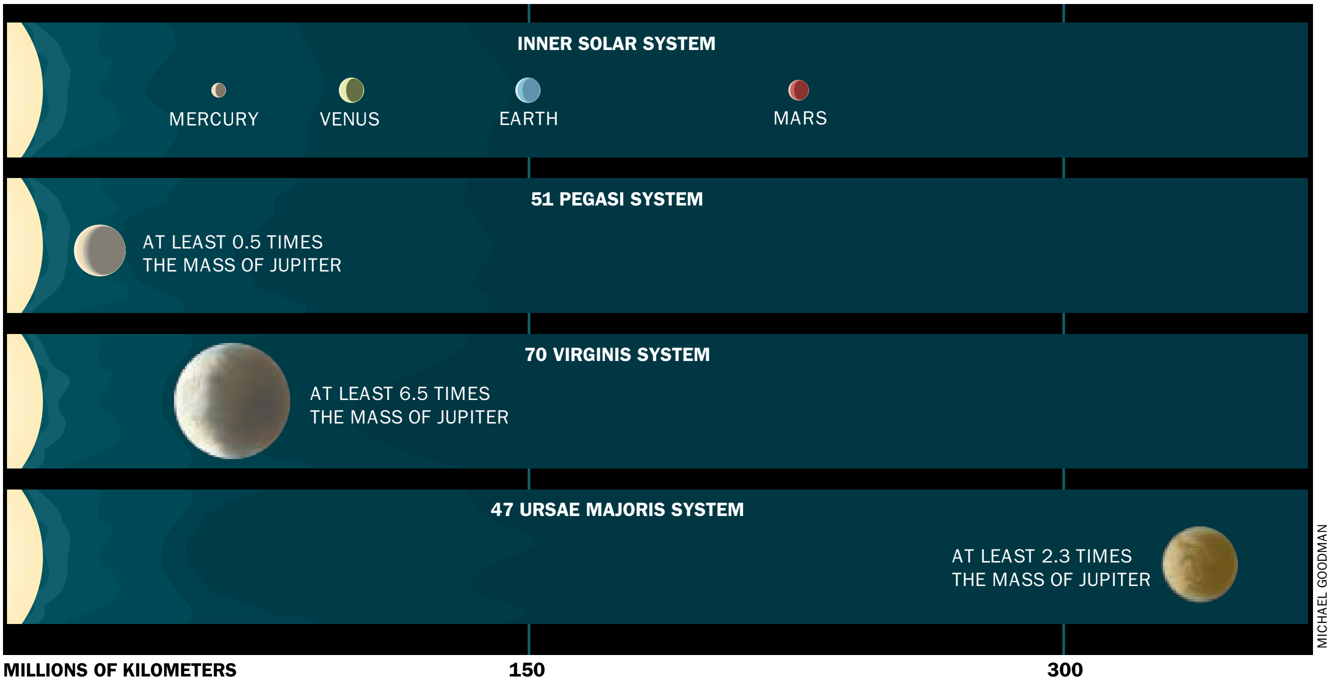
Algae and the Atmosphere

Earth's humble blue-green algae do not operate radio transmitters, but they are chemical engineers par excellence. As algae became more widespread, they began adding large quantities of oxygen to the atmosphere. The production of oxygen is fundamental to carbon-based life: the simplest organisms take in water, nitrogen and carbon dioxide as nutrients and then release oxygen into the atmosphere as waste. Oxygen is a chemically reactive gas; without continued replenishment by algae and, later in Earth's evolution, by plants, its concentration would fall. Thus, the presence of large amounts of oxygen in a planet's atmosphere is the first indicator that some form of carbon-based life may exist there.

Oxygen leaves an unmistakable mark on the radiation emitted by a planet. For example, some of the sunlight that reaches Earth's surface is reflected through the atmosphere back toward space. Oxygen in the atmosphere absorbs some of this radiation, and thus an observer of Earth using spectroscopy to study the reflected sunlight could pick out the distinctive signature associated with oxygen.

In 1980 Toby C. Owen, then at the State University of New York at Stony Brook, suggested looking for oxygen's signal in the visible red light reflected by planets, as a sign of life there. Closer to home, Sagan reported in 1993 that the *Galileo* space probe recorded the distinctive spectrum of oxygen in the red region of visible light coming from Earth. Indeed, this indication of life's existence has been radiating a recognizable signal into space for at least the past 500 million years.

Of course, there could be some nonbiological source of oxygen on a planet



Another possibility involves searching directly for the radiation reflected by large planets around other stars. Normally, Earth's atmosphere would hopelessly blur together star and planet. Adaptive optics—a means for canceling out atmospheric distortion—may offer a way to overcome this problem. In theory, an adaptive optics system conceived by J. Roger P. Angel and refined by David Sandler and Steve Stahl of Thermotrex Corporation in San Diego could capture an image of a large planet at Jupiter's orbital distance in a single night of observation.

The newfound planets represent only the tip of the iceberg. Continued observations, careful data analysis—and innovative technologies, such as a space-based interferometer—will soon yield many more such discoveries, giving us a better sense of the true variety of worlds out there. —*Corey S. Powell, staff writer*

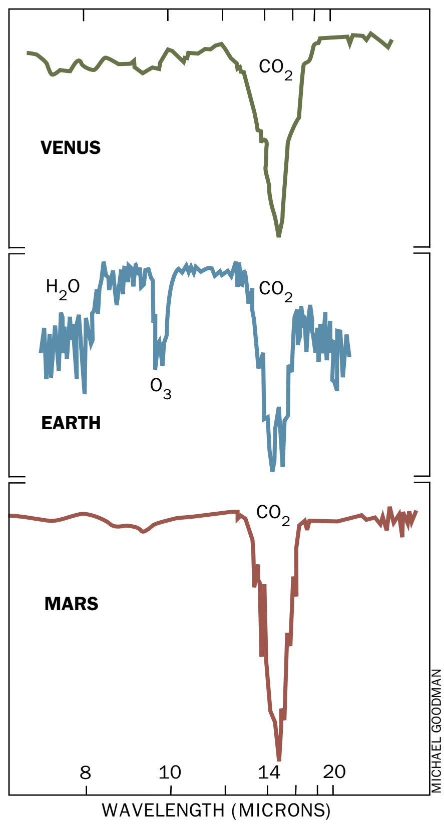
without life, so this possibility must always be explored. In addition, life could be based on some other brand of chemistry that does not produce oxygen as carbon-based life does. But compelling reasons lead us to expect that life on other planets would have a chemistry similar to our own. Carbon is particularly suitable as a building block of life: it is abundant in the universe, and no other known element can form the myriad of complex but stable molecules necessary for life as we know it.

Searching for Another Earth

Our water-rich planet is obviously favorable to life. Water provides a solvent for the biochemical reactions of life to take place and serves as a source of needed hydrogen for living matter. Planets similar to Earth in size and distance from their sun represent the most plausible homes for carbon-based life in other solar systems, primarily because liquid water could exist on these worlds. A planet's distance from its star determines its temperature—whether it will be too hot or too cold for liquid water.

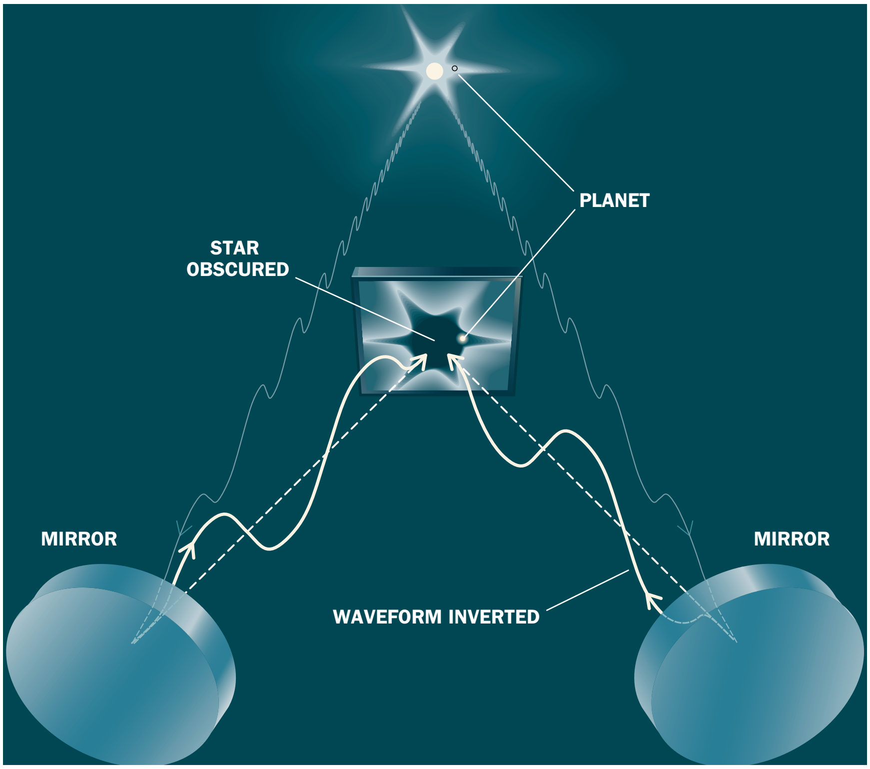
We can easily estimate the "Goldilocks orbit"—the distance at which conditions are "just right" to generate and sustain life as it exists on Earth. For a large, hot star, 25 times as bright as our sun, a hypothetical Earth-like planet would lie at about the distance that Jupiter circles the sun. For a small, cool star, one tenth as bright as the sun, the planet's orbit would resemble Mercury's course.

But proper location means little if a planet's pull of gravity cannot hold on to oceans and an atmosphere. If distance from a star were the only factor to consider, Earth's moon would have liquid



SOURCE: R. Hanel, Goddard Space Flight Center

INFRARED SIGNATURE OF LIFE can be seen only on Earth: although Venus, Earth and Mars all have atmospheres rich in carbon dioxide (CO_2), only Earth carries abundant water (H_2O) and ozone (O_3), a form of oxygen usually found high in the atmosphere. Water is a vital ingredient needed to sustain carbon-based life; oxygen is a sign of its presence. Infrared radiation emitted from planets in distant solar systems might reveal other worlds similar to our own.



CANCELING STARLIGHT enables astronomers to see dim planets typically obscured by stellar radiance. Two telescopes focused on the same star (*top*) can cancel out much of its light: one telescope inverts the light—making peaks into troughs and vice versa (*right*). When the inverted light is combined with the noninverted starlight from the second telescope (*left*), the light waves interfere with one another, and the image of the star vanishes (*center*).

water. But gravity depends on the size and density of the body: because the moon is smaller and less dense than Earth, its pull of gravity is much weaker. Any water or layers of atmosphere that might develop on or around such a body would quickly be lost to space.

Conversely, a very large planet, which has a strong pull of gravity, will attract gases from space. Scientists believe that Jupiter developed this way, gradually accumulating a huge outer shell of hydrogen and helium. Life as we know it seems unlikely to exist on massive gaseous planets like Jupiter.

Although we have a fairly specific description of the kind of planet that might be hospitable to life, finding *any* object orbiting distant stars has proved daunting. Currently the best methods for detecting such bodies actually involve looking not at the planets themselves but at their stars. Astronomers watch for slight variations in a star's orbit or light emission that can be explained only by the presence of planets. Unfortunately, indirect observation of planets tells us little about their characteristics. Indeed, all indirect techniques reveal only a body's mass and position; ascertaining whether it carries inhabitants remains impossible.

Seeing Infrared

Clearly, we need a different technique to reveal characteristics as specific as what chemicals can be found on a planet. Previously we mentioned that the visible radiation coming from a planet can confirm the presence of certain molecules, in particular oxygen, that we know support life. But distinguishing faint oxygen signals in light reflected by a small planet around even a star in our own sun's neighborhood would be extraordinarily difficult.

For example, the glow from a distant planet's sun would outshine the planet by a factor of 10 billion. So hunting for planets can be as challenging as trying to pick out a glowworm sitting next to a searchlight, both of which are thousands of kilometers away. Even if we could pick out the light reflected by a planet, any oxygen features in its visible spectrum would be weak and remarkably hard to spot.

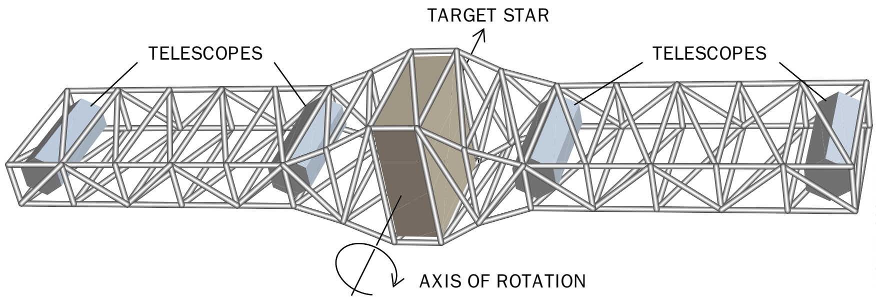
Faced with this quandary, in 1986 we proposed, along with Andrew Y. S. Cheng, now at the University of Hong Kong, that monitoring the mid-infrared wavelengths (longer than visible red wavelengths) emitted by a planet would be a better method for finding planets and looking for extraterrestrial life. This type of radiation—really the planet's radiated heat—has a wavelength 10 to 20 times longer than that of visible light. At these wavelengths, a planet emits about 40 times as many photons—particles of light—as it does at shorter wavelengths, and the nearby star would outshine the planet "only" 10 million times, a ratio 1,000 times more favorable than that which red light offers.

Moreover, three compounds that should appear together on inhabited planets—ozone (a form of oxygen usually located high in the atmosphere), carbon dioxide and water—are easily recognizable by examining the infrared spectrum. Once again, our solar system provides promising support for this technique: a survey of the infrared emissions of local planets reveals that only Earth displays the infrared signature of life [*see lower illustration on preceding page*]. Although Earth, Mars and Venus all have atmospheres with carbon dioxide, only Earth shows the signature of plentiful water and ozone.

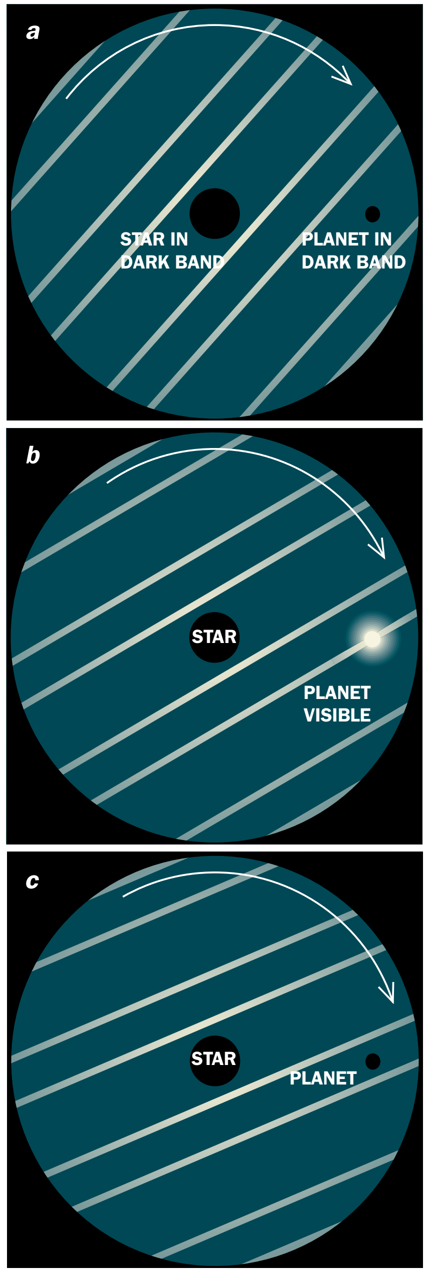
What kind of telescope do we need to locate Earth-like planets and pick up their infrared emissions? Some of today's ground-based telescopes can detect the strong infrared radiation emanating from stars. But the heat emitted by our atmosphere and by the telescope itself would completely swamp any sign of a planet. Even Antarctica is not nearly cold enough to enable us to pick out such a faint image: the telescope must be cooled to at least minus 225 degrees Celsius (about 50 kelvins). More troublesome, radiation passing through Earth's atmosphere is imprinted with exactly the features of ozone, carbon dioxide and water we hope to find on another planet. Obviously, we reasoned, we must move the telescope into space.

Even then, to distinguish a planet's radiation from that of its star, a traditional telescope would have to be much larger than any ground-based or orbiting telescope built to date. Because light cannot be focused to a spot smaller than its wavelength, light from a distant point in the sky can at best be focused to a fuzzy core surrounded by a faint halo; even a perfect telescope mirror cannot form perfect images. If the halo surrounding the star extends beyond the planet's orbit, then we cannot discern the much dimmer body of the planet inside it. By making a telescope mirror and the resulting image very large, we can, in principle, make the image of a star as sharp as desired, but the size of the equipment needed to achieve such resolution renders the project infeasible.

We can predict the performance of telescopes and thus know in advance what kind of image quality we can expect. For example, to monitor the infrared spectrum of an Earth-like planet circling, say, a star 30 light-years away, we would need an enormous space telescope, close to 60 meters in diameter. With current technology, the cost of such an instrument would rival the national debt. And even telescope enthusiasts such as ourselves regard the size of this device as daunting.



MICHAEL GOODMAN



MICHAEL GOODMAN

ROTATING INTERFEROMETER could reveal the existence of a planet around a distant star. The four telescopes arranged as shown above in the authors' proposed instrument would produce a composite view of the sky partially darkened by numerous bands; the star to be obscured would be hidden by one strip. As the instrument rotates about the line connecting the center of the device with the star, the dark bands will also rotate. A nearby planet would pass in and out of the bands (*panels a–c*). Scientists could then analyze the pattern of blinking to determine how far the planet is from its star.

Rethinking the Telescope

To develop a more reasonably sized telescope that would allow us to locate small, perhaps habitable, planets, we knew we would have to play some tricks with our instruments. One useful stratagem had been suggested 23 years ago by Ronald N. Bracewell of Stanford University. He showed how two small telescopes could be adapted to search for large, cool planets similar to Jupiter. The instrument he proposed consisted of two one-meter telescopes separated by 20 meters. Each telescope alone would have yielded blurred pictures that would never have enabled Bracewell to resolve the faint images of planets. But together the two devices could be arranged to observe distant worlds.

If he focused both telescopes on the same star, Bracewell envisaged that he would be able to invert the light waves from one telescope, flipping peaks into troughs and vice versa. Then he would combine the inverted light with light from the second telescope. Because the first image would be the reverse of the second, when Bracewell combined the two so that they overlapped precisely, the light from the star—both the core and the surrounding halo—would be canceled out. (The light would not disappear, of course; energy must be conserved. Instead the light from the star would be diverted to a separate part of the telescope.) Scientists refer to this type of device as an interferometer because it reveals details about the source of light by employing the interference of light waves.

The interferometer designed by Bracewell can obscure a star only if the star is perpendicular to the line joining the centers of each telescope. With such an arrangement, both telescopes receive exactly the same pattern of light waves from the star. If we sweep the instrument through the sky, stars will appear to blink as they move in and out of alignment.

A planet separated from its star by even a fairly small distance, however, will not be aligned with the device when its star is brought into alignment. The two telescopes will register the planet's signal at slightly different times, so the light waves from the planet will not cancel one another out. If light shines through the interferometer after we have canceled out the star's image, we know that some additional source of infrared radiation—perhaps a planet—exists near the star. We can analyze this signal by rotating the interferometer about the line joining the instrument and the star. The image will change intensity as the device rotates; planets should display a recognizable pattern of variation [*see illustration on this page*].

After working out the design for this interferometer, Bracewell realized that the main obstacle to locating a Jupiter-like planet would not be the overpowering light from a nearby star; it would instead be the heat radiated by dust particles in our solar system, referred to as zodiacal glow. The faint signal from a distant planet would be almost imperceptible against the background glare. Any hope of discovering a planet would require averaging data for at least one month to see through this glowing background.

In addition, we found that when we tried to adapt Bracewell's design to hunt for planets smaller than Jupiter that orbit closer to a sun, a problem arose. No interferometer can perfectly cancel out starlight—the area darkened is rather small, light from the star always leaks around the edges, and any excess light presents a significant obstacle when we try to see extremely dim, small planets such as Earth.

To tackle these restrictions, a number of researchers, including the two of us, have been working on alternative strategies. In 1990 one of us (Angel) suggested that arranging four mirrors in a diamond pattern allows better cancellation of starlight. But to suppress the background glare of zodiacal light, each telescope would have to be eight meters in diameter. Alain Léger and his collaborators at the University of Paris then suggested the first practical solution to this complication. They proposed placing the device in orbit around the sun, at about the distance of Jupiter's orbit, which would naturally cool the telescopes to an appropriate temperature and would minimize background glare from zodiacal light. Because of the decrease in background glare, the orbiting interferometer could be relatively small: a sensitive instrument could be built with four individual telescopes as small as one meter in diameter. The instrument has one significant drawback, however. Because it is so effective at canceling out a star's light, the device can sometimes conceal a nearby planet as well.

Here the matter rested until 1995, when the National Aeronautics and Space Administration solicited from researchers a road map for the exploration of other solar systems. NASA selected three teams to investigate various methods for discovering planets around other stars. We assembled a team that included Bracewell, Léger and his colleague Jean-Marie Mariotti of the Paris Observatory, as well as some 20 other scientists and engineers. In particular, the two of us at the University of Arizona have been studying the potential of a new approach. We have designed

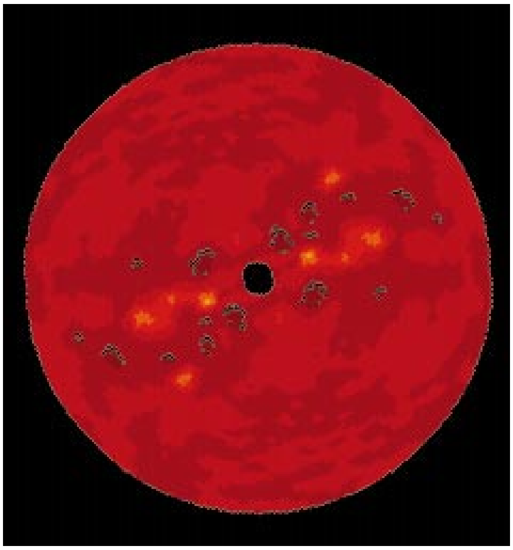


IMAGE OF DISTANT PLANETS, created from simulated interferometer signals, indicates what astronomers might reasonably expect to see with a space-based telescope. This study displays a system about 30 light-years away, with four planets roughly equivalent in luminosity to Earth. (Each planet appears twice, mirrored across the star.) With this sensitivity, the authors speculate that the instrument could easily examine the planet recently found orbiting 47 Ursae Majoris.

an interferometer with two pairs of mirrors all arranged in a straight line. Each pair of mirrors will darken the star's main image, but significantly, each pair will also cancel the starlight leak of the other pair.

It turns out that because this interferometer cancels starlight very effectively, it can be made rather long, roughly 50 to 75 meters in length. The size of the instrument offers an important advantage: with this arrangement, the signals from planets are complex and unique. With the proper analysis, we can use the data from the interferometer to reconstruct an image of a distant solar system [*see illustration on this page*]. As we envision the orbiting interferometer, it would point to a different star each day but could return to interesting systems for more extensive observations.

If pointed at our own solar system from a nearby star, the interferometer could pick out Venus, Earth, Mars, Jupiter and Saturn. And the data could be analyzed to determine the chemical composition of each planet's atmosphere. From our solar system, the device could easily study the newly discovered planet around 47 Ursae Majoris. More important, this interferometer could identify Earthlike planets elsewhere that would otherwise elude us, and the device can check all these planets for the presence of carbon dioxide, water and ozone.

Building such an instrument would be a substantial undertaking, perhaps an international project, and many of the details have yet to be completely worked out. We estimate that the proposed interferometer will cost less than $2 billion—about 10 percent of NASA's budget for space science research over the next decade. The discovery of life on another planet may arguably be the crowning achievement in the exploration of space. Finding life elsewhere, NASA administrator Daniel S. Goldin has said, "would change everything—no human endeavor or thought would be unchanged by that discovery."

Remarkably, the technology to assist in this discovery is at our fingertips. Soon we should be able to answer the centuries-old question, "Is life on Earth alone in the universe?" SA

The Authors

J. ROGER P. ANGEL and NEVILLE J. WOOLF have collaborated for the past 15 years on methods for making better telescopes. They are based at Steward Observatory at the University of Arizona. Angel is a fellow of the Royal Society and directs the Steward Observatory Mirror Laboratory. Woolf has pioneered techniques to minimize the distortion of images caused by the atmosphere. Angel and Woolf consider the quest for distant planets to be the ultimate test for telescope builders; they are meeting this challenge by pushing the limits of outer-space observation technology, such as adaptive optics and space telescopes.

Further Reading

A SPACE TELESCOPE FOR INFRARED SPECTROSCOPY OF EARTH-LIKE PLANETS. J.R.P. Angel, A.Y.S. Cheng and N. J. Woolf in *Nature,* Vol. 322, pages 341–343; July 24, 1986.

USE OF A 16 METER TELESCOPE TO DETECT EARTHLIKE PLANETS. J. Roger P. Angel in *The Next Generation Space Telescope*. Edited by P. Bely and C. J. Burrows. Space Telescope Science Institute, Baltimore, 1990.

LIFE IN THE UNIVERSE. Special issue of *Scientific American,* Vol. 271, No. 4; October 1994.

Smart Rooms

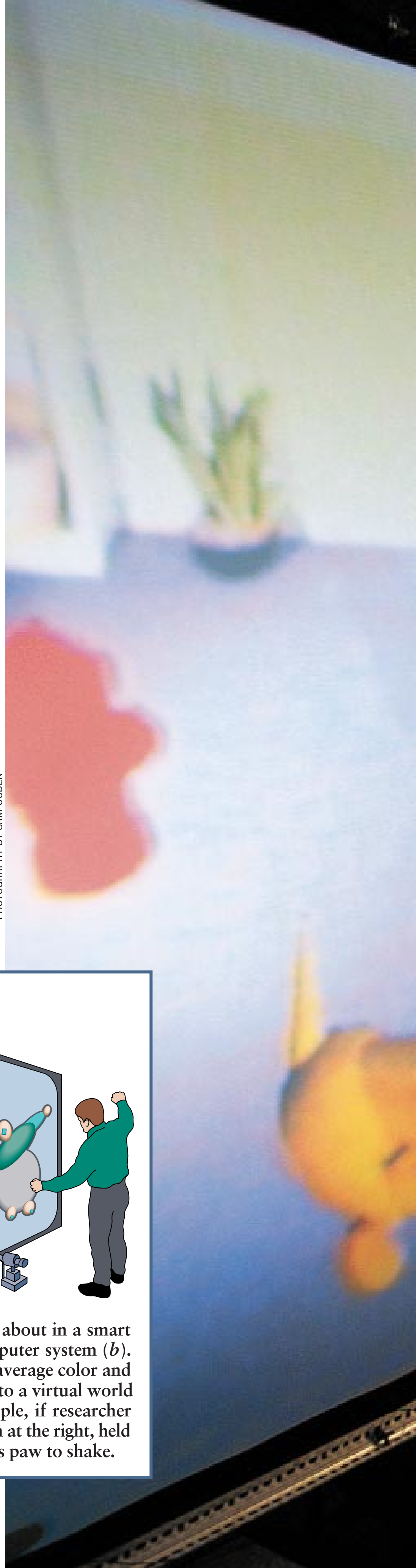
In creating computer systems that can identify people and interpret their actions, researchers have come one step closer to building helpful home and work environments

by Alex P. Pentland

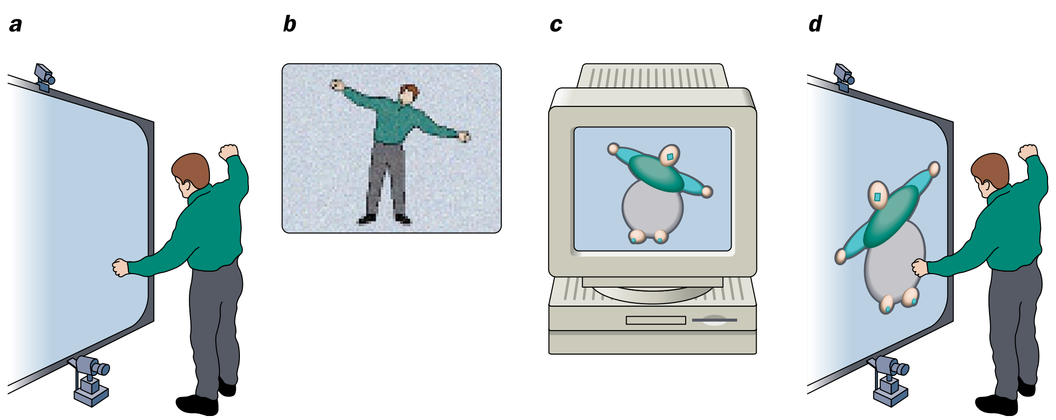
Imagine a house that always knows where your kids are and tells you if they are getting into trouble. Or an office that sees when you are having an important meeting and shields you from interruptions. Or a car that senses when you are tired and warns you to pull over. Scientists have long tried to design computer systems that could accomplish such feats. Despite their efforts, modern machines are still no match for baby-sitters or secretaries. But they could be.

The problem, in my opinion, is that our current computers are both deaf and blind: they experience the world only by way of a keyboard and a mouse. Even multimedia machines, those that handle audiovisual signals as well as text, simply transport strings of data. They do not understand the meaning behind the characters, sounds and pictures they convey. I believe computers must be able to see and hear what we do before they can prove truly helpful. What is more, they must be able to recognize who we are and, as much as another person or even a dog would, make sense of what we are thinking.

To that end, my group at the Media Laboratory at the Massachusetts Institute of Technology has recently developed a family of computer systems for recognizing faces, expressions and gestures. The technology has enabled us to build environments that behave somewhat like the house, office and car described above. These areas, which we call smart rooms, are furnished with cameras and microphones that relay their recordings to a nearby network of computers. The computers as-

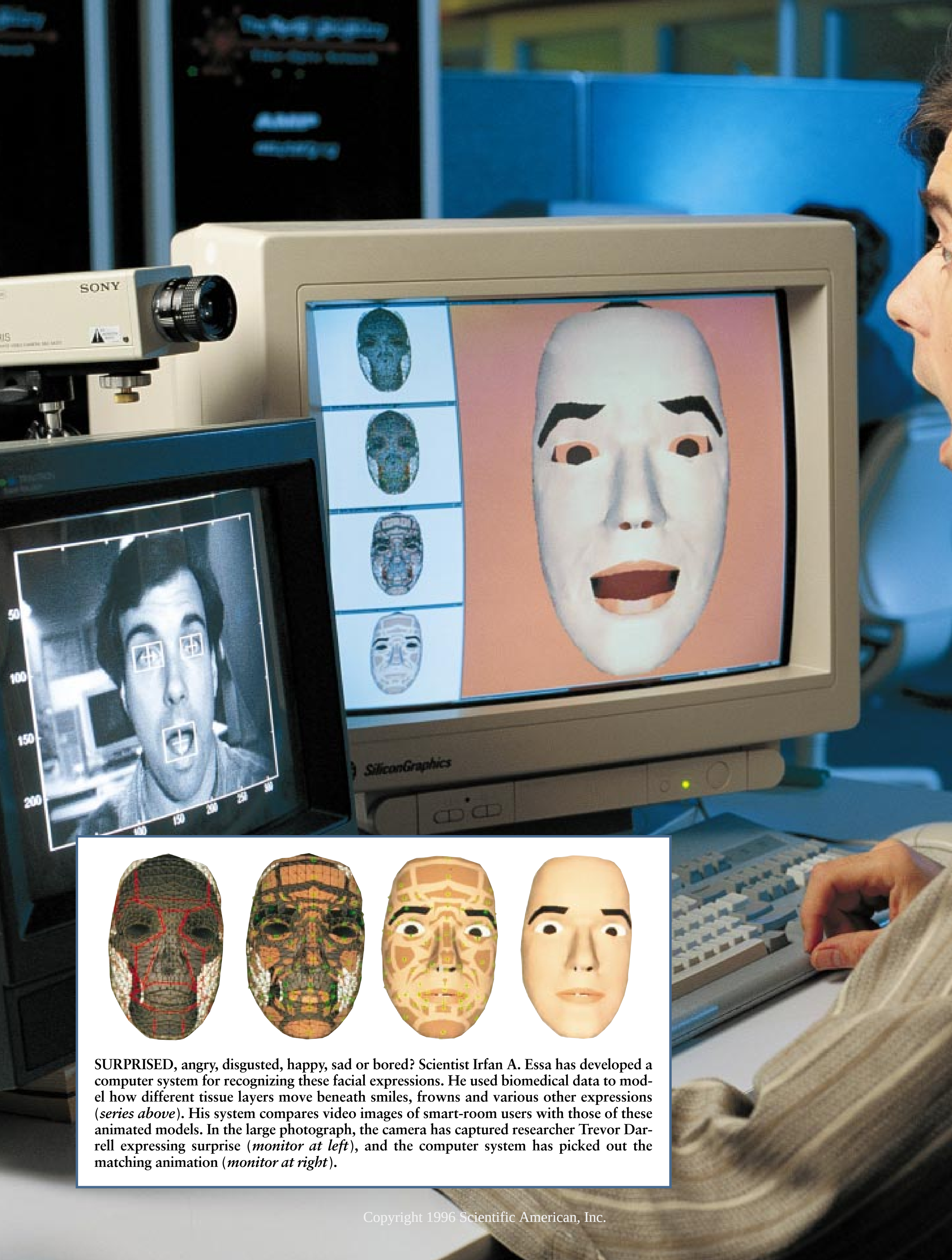


PHOTOGRAPHY BY SAM OGDEN



PERSON FINDER (Pfinder) is a program that can track an individual as he moves about in a smart room. A camera records his movements (*a*) and relays that information to the computer system (*b*). Pfinder then models the person as a collection of blobs (*c*). Each blob represents the average color and position of the head, shirt, pants, hands and feet. Next, Pfinder projects the model into a virtual world so that imaginary characters can interact with the smart-room user (*d*). For example, if researcher Christopher R. Wren of the Massachusetts Institute of Technology's Media Lab, shown at the right, held out his hand, his blob man would do the same. Silas the virtual dog would then lift his paw to shake.

JARED SCHNEIDMAN DESIGN



SURPRISED, angry, disgusted, happy, sad or bored? Scientist Irfan A. Essa has developed a computer system for recognizing these facial expressions. He used biomedical data to model how different tissue layers move beneath smiles, frowns and various other expressions (*series above*). His system compares video images of smart-room users with those of these animated models. In the large photograph, the camera has captured researcher Trevor Darrell expressing surprise (*monitor at left*), and the computer system has picked out the matching animation (*monitor at right*).

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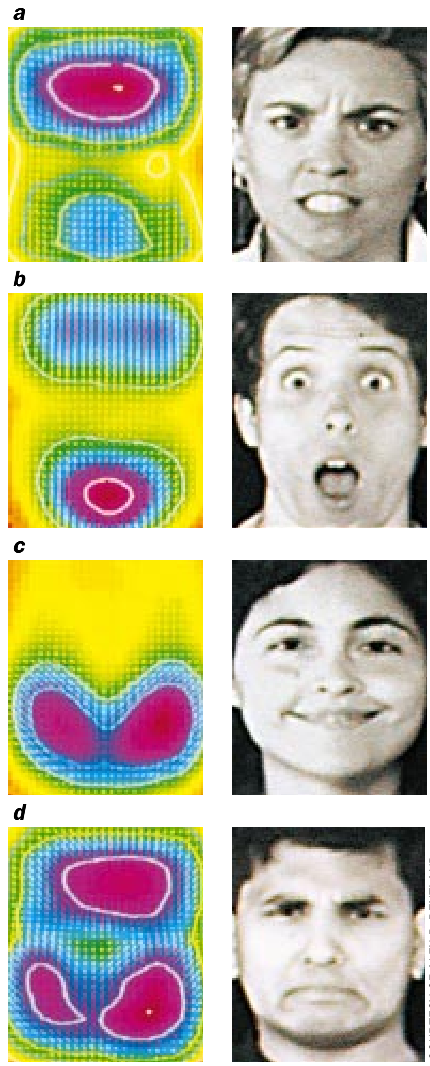
sess what people in the smart room are saying and doing. Thanks to this connection, visitors can use their actions, voices and expressions—instead of keyboards, sensors or goggles—to control computer programs, browse multimedia information or venture into realms of virtual reality.

The key idea is that because the smart room knows something about the people in it, it can react intelligently to them. Working together with Pattie Maes and me, graduate students Trevor Darrell and Bruce M. Blumberg constructed the first smart room in 1991 at M.I.T. The initiative quickly grew into a collaborative experiment and now involves five such rooms, all linked by telephone lines, around the world: three in Boston, one in Japan and one in the U.K. (Installations are also planned for Paris, New York City and Dallas.)

Each room contains several machines, none more powerful than a personal computer. These units tackle different problems. For instance, if a smart room must analyze images, sounds and gestures, we equip it with three computers, one for each type of interpretation. If greater capabilities are needed, we add more machines. Although the modules take on different tasks, they all rely on the same statistical method, known as maximum likelihood analysis: the computers compare incoming information with models they have stored in memory. They calculate the chance that each stored model describes the observed input and ultimately pick the closest match. By making such comparisons, our smart-room machines can answer a range of questions about their users, including who they are and sometimes even what they want.



COURTESY OF ALEX P. PENTLAND

MOTION ENERGY MAPS show in warm colors which areas of a person's face have moved the most. Certain expressions produce typical color patterns. When someone is angry, for example, the most facial contortions take place around the brow (*a*). A look of surprise always involves the eyebrows and the mouth (*b*). Happiness is expressed primarily with the mouth (*c*). And disgust is conveyed using the entire face (*d*).

Where?

Before a smart room can begin to figure out what people are doing, it needs to locate them. So graduate students Christopher R. Wren, Ali Azarbayejani and Darrell and I developed a system called Person Finder (Pfinder for short) that can track one person as he or she moves around in the room. As do our other systems, Pfinder adopts the maximum likelihood approach. First, it models the person the camera records as a connected set of blobs—two for the hands, two for the feet and one each for the head, shirt and pants. It describes each blob in two ways: as a distribution of values for the blob's color and placement, and as a so-called support map, essentially a list indicating which image pixels belong to the blob (pixels are "picture elements," similar to the dots that make up a television image). Next, Pfinder creates textured surfaces to model the background scene. Each point on one of these surfaces correlates to an average color value and a distribution around that mean.

Whenever the camera in the smart room picks up a new picture in the video stream, Pfinder compares that image with the models it has made and with other references as well. To start, the sys-

JOKE DETECTOR picks out comedian Jay Leno's punch lines. The computer system, which was developed by graduate students Joshua Wachman, Michael Casey and Alan Wexelblat in collaboration with the author, Essa and professors Rosalind W. Picard and Justine Cassell, tracks changes in Leno's timing, voice pitch and hand gestures.

tem guesses what the blob model should look like in the new image. If, for example, a person's upper body was moving to the right at one meter per second a tenth of a second ago, then Pfinder will assume that the center of the upper body blob has moved a tenth of a meter to the right. Such estimates are also checked against typical patterns of movement that we have derived from testing the system on thousands of people. For instance, we know that blobs corresponding to the torso must move slowly, whereas those relating to hands and feet generally move much faster.

Predictions finished, Pfinder then measures the chance that each pixel in the new image belongs to each blob. It does so by subtracting the pixel's color and brightness values from each blob's mean color and brightness values. It compares the result with each blob's distribution to determine how likely it is that the difference happened by chance. If, for example, the brightness difference between a pixel and a blob were 10 percent, and the blob's statistics said that such a difference happened only 1 percent of the time, the chance that the pixel belonged to the blob would be a mere one in 100. Shadows present a minor problem in that they cause brightness differences that have nothing to do with the probability that some pixel belongs to some blob. So Pfinder searches out shadows, areas that are darker than expected, and evens out their color hue and saturation using the area's overall brightness.

Pfinder must also overcome slight changes in the lighting or arrangement of objects in the room, either of which might make it place certain pixels in the wrong models. To avoid this difficulty, the system continuously updates the pixels that are visible behind the user, averaging the old color information with the new. In this way, it keeps track of changes that occur, for instance, when the user moves a book and thus alters the scene in two places: where the book was and where it now is. After completing these various calculations and compensations, Pfinder at last assigns each pixel in the new image to the model that most likely contains it. Finally, it updates the statistics describing the blob model and the background scene, as well as those anticipating which way the blobs will move.

Who and How?

Aside from knowing where people are, a smart room must also know who they are and what they are saying. Many workers have invented algorithms that allow computers to understand speech. Virtually all those systems work well only when the user wears a microphone or sits near one. A room that interpreted your actions only when you stood in a particular spot would not seem so smart. So graduate students Sumit Basu and Michael Casey and I looked for another solution—one that would let a computer decode a user's speech as he or she moved freely about some room, even if the room were quite noisy.

Our end product takes advantage of the fact that Pfinder follows the user's position at all times. Borrowing this information, the speech-recognition system electronically "steers" an array of fixed microphones so that they reinforce only those sounds coming from the direction of the user's mouth. It is an easy job. Because sound travels at a fixed speed, it arrives at different locations at slightly different times. So each sound location yields a different pattern of time delays. Thus, if the system takes the outputs from a fixed array of microphones and adds them to time delays that characterize a certain location, it can reinforce the sound from that location. Then it need only compare the sound with those of known words until a match is found.

A smart room must also know who is speaking in it or to it. To act with seeming intelligence, it is absolutely vital that a system know its users' identity. Who gives a command is often as important as the command itself. The fastest way to identify someone may well be to recognize his or her face. So we developed a system for our rooms to do just that. To employ the maximum likelihood approach, this system first needed to build models of all the faces it "knew." Working with M.I.T. graduate students Matthew A. Turk and Baback Moghaddam, we found that it was important to focus on those features that most efficiently described an entire set of faces. We used a mathematical technique called eigenvector analysis to describe those sets, dubbing the results "eigenfaces." To model a face, the system determined how similar that face was to each eigenface.

The strategy has worked well. When the camera detects a person, the identifying system extracts his or her face—located by Pfinder—from the surrounding scene and normalizes its contrast. The system then models the face in terms of what similarities it bears to the eigenfaces. Next, it compares the model with those of known people. If any of the similarity scores are close, the system assumes that it has identified the user. Using this method, our smart

Smart Clothes

A smart room acts somewhat like a butler. It stays out of your way but constantly looks for opportunities to help. Sometimes, though, you want something more like a personal assistant who travels with you, anticipating your needs. The way to get such an assistant is to build the cameras, microphones and computers of a smart room into your clothing.

Such smart clothes can provide personalized information about your environment such as the names of people you meet or the directions to your next meeting. And these garments can replace most computer and consumer electronics. As with the smart room, the key idea is that because your clothing "knows" your environment, it can react intelligently to help you.

The M.I.T. smart-clothes project was started in 1992 by Thad Starner and Steve Mann and is supported by Rosalind W. Picard and myself. When we build computers, cameras, microphones and other sensors into a person's clothes, the computer's view moves from the passive third person of the smart room to an active first-person vantage point. So smart clothes can be more intimately involved in the user's activities, making them potentially intelligent personal (digital) assistants.

For instance, if you built a camera into the frames of your eyeglasses, our face-recognition software could help you remember the name of whomever you are looking at by whispering his or her name in your ear.

Or if you built a phased array of microphones into your jacket, then our word-spotting software could remind you of important facts: whenever someone mentioned "the Megadeal contract," the software could project Megadeal's finances onto the display in your glasses. With a global positioning sensor built into your shoes, you could take advantage of high-flying navigation software to find your way around.

Our current smart-clothes prototypes use off-the-shelf head-mounted displays to provide their users with both privacy and convenience. Their central processing units are designed to be small and unobtrusive. We have developed alternative input devices that allow people to use these machines in just about any context, and they use wireless communications to stay in contact with the Internet.

Our goal is to offer devices that would be so small and light that they could be worn constantly—much as eyeglasses and watches are now—providing access to computing power at all times. Today's smart clothes are not yet inconspicuous, particularly the head-mounted displays; they project a rather cyberpunkish look (shown below, from left to right, are Mann, Starner, Picard and Ken Kung). But the coming of continuous computing is not far off. Two Media Lab cyborgs, Mann and Starner, already wear their devices all day every day. *—A.P.P.*

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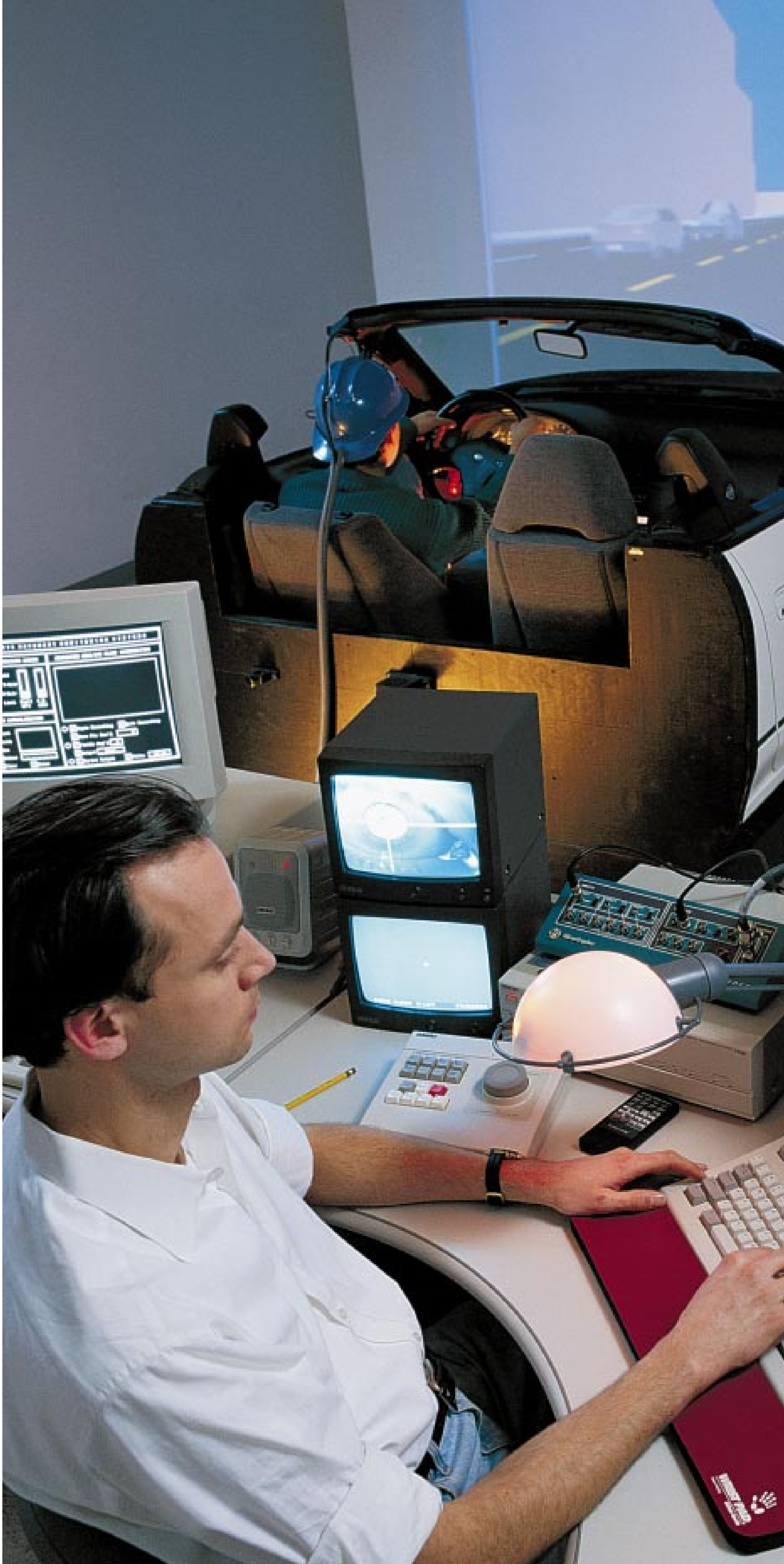
SMART CARS are a goal at Nissan Cambridge Basic Research in Massachusetts. Scientist Andy Liu, working there with the author, has devised a computer system that determines a driver's actions mere seconds after they have begun. The system, operated at right by Nissan's Erwin Boer, monitors a driver steering through a simulated course; sensors record his or her hand, leg and eye movements. To figure out what the person intends to do, these readings are compared with models of typical driving activities. A car that knew when you planned to change lanes could, for example, warn you if there were a truck in the way you had not seen.

rooms have accurately recognized individual faces 99 percent of the time amid groups of several hundred.

Facial expression is almost as important as identity. A teaching program, for example, should know if its students look bored. So once our smart room has found and identified someone's face, it analyzes the expression [*see illustration on page 70*]. Yet another computer compares the facial motion the camera records with maps depicting the facial motions involved in making various expressions. Each expression, in fact, involves a unique collection of muscle movements. When you smile, you curl the corners of your mouth and lift certain parts of your forehead; when you fake a smile, though, you move only your mouth. In experiments conducted by scientist Irfan A. Essa and me, our system has correctly judged expressions—among a small group of subjects—98 percent of the time.

What?

Recognizing a person's face, expression and speech is just the first step. For houses, offices or cars to help us, they must be able to put these basic perceptions in context. The same motions, after all, can be interpreted quite differently depending on what the person making them intends. When you drive a car, for example, you sometimes take your foot from the gas pedal because you want to slow down. But you do the same when you get ready to make a turn. The difference is that in preparing for a turn, you adjust the steering wheel as you move your foot. So a computer system would need to consider how your movements had changed over time, in combination with other movements, to know what you were doing at any one moment.



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In designing such a system, we borrowed ideas from the scientists working on speech recognition. They model individual words as sequences of sounds, or, as they call them, internal states. Each word has a characteristic distribution of internal states, which are sometimes phonemes (the smallest distinguishable units of speech) and sometimes just parts of phonemes. A computer system tries to identify words by comparing the sequence of sounds they contain with word models and then selecting the most likely matches.

We generalized this approach in the hope of determining people's intentions from their movements. We devised a computer system that can tell, for example, whether a person with one arm extended is pointing or merely stretching. The system recognizes the action involved in pointing by referring to a model having three internal states: raise the hand, hold it steady and return it quickly. The system sees stretching as one continuous movement. So by observing these internal states—characterized by the acceleration of the hand and the direction of its movement—our system works out what someone is doing.

To date, we have built several different systems for interpreting human actions in this way. The simplest allow people to use their body to control virtual environments. One such application is the Artificial Life Interactive Video Environment (ALIVE), a joint project of Maes's group and my own. ALIVE utilizes the smart room's description of the user's shape to place a video model of the user into a virtual-reality scene, where computer-generated life-forms reside. These virtual critters analyze information about a user's gestures, sounds and positions to decide how to interact with him or her. Silas the virtual dog, for example, plays fetch. When a smart-room user mimics the motions involved in picking up and throwing Silas's virtual ball, the dog sees the video image in the ALIVE environment do the same and gets ready to chase after its toy. Silas also sits and rolls over on command.

The smart room's output can be put to work in an even more direct manner. The user's body position can be mapped into a control space of sorts so that his or her sounds and gestures change the operating mode of a computer program. Game players, for example, have used this interface, instead of a joystick or trackball, to navigate three-dimensional virtual environments. If opponents appear on the left, the player need only turn to the left to face them; to fire a weapon, the player need only say, "Bang."

Why?

Virtual-reality games aside, many more practical applications of smart-room technology exist. Consider American Sign Language (ASL), a set of sophisticated hand gestures used by deaf and mute people. Because the gestures are quite complex, they offer a good test of our room's abilities. Hence, graduate student Thad Starner and I set out to build a system for interpreting ASL. We first built models for each sign, observing many examples of the hand motions involved, as described by Pfinder. We found that if we compared these models with Pfinder's models of an actual user while he or she was signing, we could translate a 40-word subset of ASL in real time with an accuracy rate of 99.2 percent. If we can increase the size of the vocabulary that our system understands—and it seems very likely that we will be able to do so—it may be possible to create interfaces for deaf people as reliable as the speech-recognition systems that are now being introduced for people who can hear.

Automobile drivers, too, stand to benefit from smart-room technology. In many parts of the U.S., the average worker spends 10 hours a week in a car. More than 40,000 motorists die in traffic accidents each year, the majority of which can be attributed to driver error. So together with Andy Liu, a scientist at Nissan Cambridge Basic Research, we have been building a smart-room version of a car interior. The ultimate goal is to develop a vehicle that can monitor what the driver is doing and provide useful feedback, such as road directions, operating instructions and even travel warnings.

To compile a set of driving models—including what actions people took when they were passing, following, turning, stopping, accelerating or changing lanes—we observed the hand and leg motions of many drivers as they steered their way through a simulated course [*see illustration at left*]. We used the resulting models to classify a test driver's action as quickly as possible. Surprisingly, the system could determine what the driver was doing almost as soon as the action had started. It classified actions with an accuracy of 86 percent within 0.5 second of the start of an ac-

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AMERICAN SIGN LANGUAGE consists of a complex set of hand gestures, many of which can now be interpreted in real time using a system developed by M.I.T. computer scientist Thad Starner. In the photograph the camera registers Starner's hand movements as he signs "bicycle." The computer system models his motions and compares them with models of known signs. When the match is found, the machine says the word "bicycle."

tion. Given two seconds, the accuracy rose to 97 percent.

We have shown that, at least in simple situations, it is possible to track people's movements, identify them and recognize their expressions in real time using only modest computational resources. By combining such capabilities, we have built smart rooms in which, free from wires or keyboards, individuals can control computer displays, play with virtual creatures and even communicate by way of sign language. Such perceptual intelligence is already beginning to spread to a wider variety of situations. For instance, we are now building prototypes of eyeglasses that recognize your acquaintances and whisper their names in your ear. We are also working on television screens that know when people are watching them. And we plan to develop credit cards that can recognize their owners and so know when they have been stolen.

Other research groups at the Media Lab are working to grant our smart rooms the ability to sense attention and emotion and thereby gain a deeper understanding of human actions and motivations. Rosalind W. Picard hopes to devise a system that can tell when drivers or students are not paying attention. Aaron Bobick is writing software to interpret the human motions used in sports—imagine a television camera that could discriminate between two football plays, say, a quarterback sneak and an end run, and follow the action. As smart-room technology develops even further, computers will come to seem more like attentive assistants than insensible tools. In fact, it is not too farfetched to imagine a world in which the distinction between inanimate and animate objects actually begins to blur. SA

The Author

ALEX P. PENTLAND received his Ph.D. from the Massachusetts Institute of Technology in 1982 and began working at SRI International's Artificial Intelligence Center. In 1983 he was appointed industrial lecturer at Stanford University's computer science department and won the Distinguished Lecturer Award three years later. In 1987 he returned to M.I.T., where he is now head of the Perceptual Computing Section at the Media Lab. The group consists of more than 50 researchers investigating computer vision, music, graphics, speech, and human-machine interactions. Pentland's smart-room research was supported by British Telecom, Texas Instruments, U.S. agencies ARPA, ONR and ARL, and Nissan CBR.

Further Reading

VISUALLY CONTROLLED GRAPHICS. A. Azarbayejani, T. Starner, B. Howowitz and A. Pentland in *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vol. 15, No. 6, pages 602–604; June 1993.

THE ALIVE SYSTEM: FULL-BODY INTERACTION WITH AUTONOMOUS AGENTS. P. Maes, T. Darrell, B. Blumburg and A. Pentland in *Proceedings of Computer Animation '95*. 1995.

FACIAL EXPRESSION RECOGNITION USING A DYNAMIC MODEL AND MOTION ENERGY. I. A. Essa and A. P. Pentland in *Proceedings of the Fifth International Conference on Computer Vision.* IEEE Computer Society Press, 1995.

TOWARD AUGMENTED CONTROL SYSTEMS. A. Pentland and A. Liu in *Proceedings of the Intelligent Vehicles '95 Symposium*. IEEE Industrial Electronics Society, September 1995.

REAL-TIME AMERICAN SIGN LANGUAGE FROM VIDEO USING HIDDEN MARKOV MODELS. T. Starner and A. Pentland in *International Symposium on Computer Vision, 1995.* IEEE Computer Society Press, 1995.

PFINDER: REAL-TIME TRACKING OF THE HUMAN BODY. C. Wren, A. Azarbayejani, T. Darrell and A. Pentland in *Integration Issues in Large Commercial Media Delivery Systems.* Edited by A. G. Tescher and V. M. Bove. SPIE, Vol. 2615; 1996.

Many papers and technical reports available at http://www-white.media.mit.edu/vismod

Alcohol in American History

National binges have alternated with enforced abstinence for 200 years, but there may be hope for moderation

by David F. Musto

The young American ship of state floated on a sea of distilled spirits. In the period immediately after the American Revolution, a generally favorable view of alcoholic beverages coincided with rising levels of consumption that far exceeded any in modern times. By the early decades of the 19th century, Americans drank roughly three times as much alcohol as they do in the 1990s.

The country also had its abstemious side. Even as consumption of alcohol was reaching unprecedented levels, an awareness of the dangers of drink began to emerge, and the first American temperance movement took hold. At its peak in 1855, 13 of 40 states and territories had adopted legal prohibition. By the 1870s, public opinion had turned back, and liquor was flowing freely again; then, around the turn of the century, a movement for abstinence gained steam, culminating in the 13-year experiment of Prohibition that began in 1920.

Over the history of the U.S., popular attitudes and legal responses to the consumption of alcohol and other mood-altering substances have oscillated from toleration to a peak of disapproval and back again in cycles roughly 70 years long. Although other nations appear to have embraced the virtues of moderation, the U.S. continues to swing slowly back and forth between extremes.

The length of these trends may explain why most people are unaware of our repetitive history. Few contemporary Americans concerned about the abuse of illegal drugs, for example, know that opiate use was also a burning issue in the first decades of the 20th century, just as few of today's nutrition and exercise enthusiasts know about their health-minded predecessors from the same period.

Furthermore, a phenomenon analogous to political correctness seems to control discourse on alcohol and other "vices": when drinking is on the rise and most believe that liquor poses little risk to life and health, temperance advocates are derided as ignorant and puritanical; in the end stage of a temperance movement, brewers, distillers, sellers and drinkers all come under harsh attack. Citizens may come of age with little knowledge of the contrary experiences of their forebears. Even rigorous studies that contradict current wisdom may be ignored—data showing both the damaging and beneficial effects of alcohol appear equally susceptible to suppression, depending on the era.

It now appears that a third era of temperance is under way in the U.S. Alcohol consumption peaked around 1980 and has since fallen by about 15 percent. The biggest drop has been in distilled spirits, but wine use has also waned. Beer sales have fallen less, but nonalcoholic brews—replicas of Prohibition's "near beer"—have been rising in popularity.

The shift in attitude is apparent in the cyclic movement of the legal drinking age. In 1971 the 26th Amendment to the Constitution—the most rapidly ratified in the nation's history—lowered the voting age to 18. Soon after, many state legislatures lowered the drinking age to conform to the voting age. Around 1980, however, states started rolling back the drinking age to 21. Surprisingly, the action was praised even among the 18- to 20-year-olds it affected. In 1984 the U.S. government, which cannot itself mandate a national drinking age, threatened to withhold federal highway funds from any state or territory that did not

JEFF MERMELSTEIN

MODERN BARFLIES may be drinking fruit juice or "designer water" as well as—or even in

raise its drinking age to 21. Within a short time every state and the District of Columbia were in compliance. Puerto Rico has been the only holdout.

Alcohol, Driving and Youth

Drunk driving is the most recent catalyst for public activism against alcohol abuse. At the end of the 1970s, two groups appeared with the goal of combating alcohol-related accidents: Remove Intoxicated Drivers (RID) on the East Coast and Mothers Against Drunk Driving (MADD) in California. Both groups attacked weak drunk-driving laws and judicial laxness, especially in cases where drivers may have been repeatedly arrested for drunk driving—including some who had killed others in crashes—but never imprisoned.

Across the nation RID and MADD have strengthened the drunk-driving laws. Although sometimes at odds with each other, both have successfully lob-

place of—alcoholic beverages. Patrons at this juice bar on the Lower East Side of Manhattan are part of a long cyclic trend in which the U.S. alternates between sobriety and intoxication. Alcohol consumption is down by almost a sixth from its most recent peak in 1980.

bied for laws reducing the legal threshold of intoxication, increasing the likelihood of incarceration and suspending drivers' licenses without a hearing if their blood alcohol levels exceed a state's legal limit, typically about 0.1 percent.

In 1981 Students Against Driving Drunk (SADD) was established to improve the safety of high school students. The group promotes a contract between parents and their children in which the children agree to call for transportation if they have been drinking, and the parents agree to provide it. As a result, however, RID and MADD have accused SADD of sanctioning youthful drinking rather than trying to eliminate it.

Political action has reinforced the prevailing public beliefs. In 1988 Congress set up the Office of Substance Abuse Prevention (OSAP) under the auspices of the Department of Health and Human Services. The OSAP provided what it called "editorial guidelines" to encourage media to adopt new ways of describing drug and alcohol use. Instead of referring to "responsible use" of alcohol, for example, the office suggested that newspapers and magazines should speak simply of "use, since there is a risk associated with all use." This language suggests that there is no safe threshold of consumption—a view also espoused by the American Temperance Society in the 1840s and the Anti-Saloon League early in this century. The OSAP also evaluated information on alcohol and drugs intended for distribution to schools and communities. It asserted that "materials recommending a designated driver should be rated unacceptable. They encourage heavy alcohol use by implying it is okay to drink to intoxication as long as you don't drive."

Another example of changing attitudes is the history of beliefs about alcohol's effects on fetal development. In the early 1930s, after Prohibition had ended, Charles R. Stockard of Cornell University, a leading authority on embryology, published animal studies that suggested minimal effects on fetal development. At about the same time, Harold T. Hyman of the Columbia University College of Physicians and Surgeons reviewed human experiments and found that "the habitual use of alcohol in moderate amounts by the normal human adult appears to be without any permanent organic effect deleterious in character."

Fetal Alcohol Syndrome

Then, in the 1970s, researchers at the University of Washington described what they called fetal alcohol syndrome, a set of physical and mental abnormalities in children born to women who imbibed during pregnancy. At first, the syndrome appeared to require very heavy consumption, but after further investigation these researchers have come to assert that even a tiny amount of alcohol can cause the disorder. Drinks consumed at the earliest stage of embryonic

The Fall and Rise and Fall of Alcohol

The average annual consumption in equivalent gallons of ethanol per adult is charted across the past three centuries.

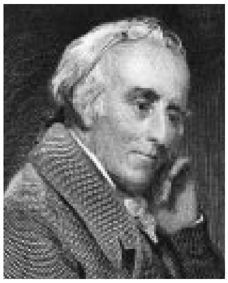
1790 ***5.8 gallons***

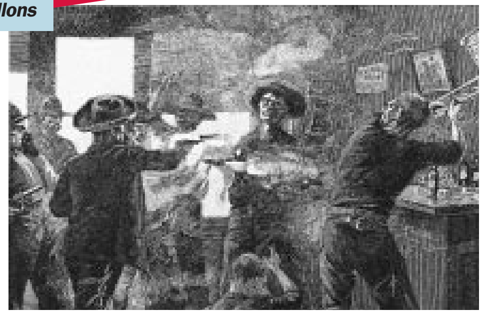
1830 ***7.1 gallons***

1840 ***3.1 gallons***

The licentious behavior associated with hard liquor was targeted by 18th-century British reformers.

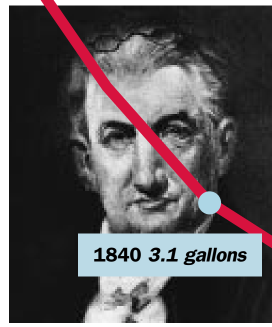
Benjamin Rush, temperance physician





Even as American pioneers in the post-Revolutionary period drank more heavily than at any other time (*above*), early temperance crusaders were warning of liquor's dangers.

Lyman Beecher, prohibitionist preacher



1700 **1800**

London Gin Epidemic, 1710–1750 *Revolutionary War, 1775–1783* *War of 1812* *Opening of Erie Canal, 1825*

development, when a woman may have no idea that she is pregnant, can be a particularly potent teratogen. Since 1989, all alcoholic beverages must bear a warning label for pregnant women from the U.S. Surgeon General's office.

Societal reaction to these findings has resulted in strong condemnation of women who drink any alcohol at all while pregnant. In a celebrated Seattle case in 1991, a woman nine months and a couple of weeks pregnant (who had abstained from alcohol during that time) decided to have a drink with her meal in a restaurant. Most embryologists agree that a single drink at such a late stage of pregnancy produces minimal risk. The waiters, however, repeatedly cautioned her against it; she became angry; the waiters lost their jobs. When the story became known, letters appeared in a local newspaper questioning her fitness as a mother. One University of Washington embryology expert even suggested that pregnant women should no longer be served alcohol in public.

The current worry over the effect of small amounts of alcohol during pregnancy is particularly interesting because belief in alcohol's ability to damage the fetus is a hallmark of American temperance movements in this and the past century. Indeed, as far back as 1726, during the English "gin epidemic," the College of Physicians of London issued a formal warning that parents drinking spirits were committing "a great and growing evil which was, too often, a cause of weak, feeble, and distempered children." There is little question that fetal alcohol syndrome is a real phenomenon, but the explosion in diagnosed cases in conjunction with changing social attitudes merits closer scrutiny.

AKG PHOTO

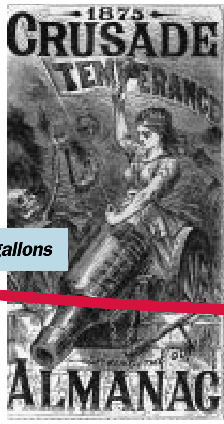
GIN LANE **(*left*) AND *BEER STREET* (*right*), 18th-century engravings by William Hogarth, show the different attitudes Londoners held toward distilled spirits and beer, which were consumed as alternatives to unpalatable water and also for their perceived medicinal benefits. In the U.S., however, the trend of temperance movements has been to condemn all beverages containing alcohol.**

The First Temperance Movement

Like today's antialcohol movement, earlier campaigns started with temperance and only later began pushing abstinence. In 1785 Benjamin Rush of Philadelphia, celebrated physician and inveterate reformer, became America's most prominent advocate of limited alcohol use. Tens of thousands of copies of his booklet, *An Inquiry into the Effects of Ardent Spirits upon the Human Mind and Body,* were distributed throughout the young nation. Like many of his compatriots, Rush censured spirits while accepting the beneficent effects of milder beverages. His "moral thermometer" introduced a striking visual tool to illustrate the graduated effects of beer and wine (health and wealth) and spirits (intemperance, vice and disease). When reformers "took the pledge" in the early years of the 19th century, it was a pledge to abstain from distilled spirits, not all alcoholic beverages.

The same kind of distinction had been made almost a century earlier in England, during an antispirits crusade in response to the gin epidemic. Rapidly increasing consumption of cheap distilled spirits swamped London during the first half of the 18th century. Gin was blamed for a dramatic rise in deaths and a falling birth rate. William Hogarth's powerful prints *Gin Lane* and *Beer Street* were designed to contrast the desolation caused by gin with the healthy prosperity enjoyed by beer drinkers [*see*

Women were at the forefront of the second wave of antialcohol movements. The issue helped to legitimize their participation in political life, because alcohol abuse impinged on the family sphere to which women had been relegated.



Frances Willard, president of the Women's Christian Temperance Union (*left*); Carry Nation, turn-of-the-century saloon vandal (*right*).

Beverage manufacturers, especially brewers, tried to fight back against temperance movements by portraying their product as a healthy part of the national culture.

CORBIS–BETTMANN (*all photographs in timeline*)

1860 ***2.1 gallons***

1890 ***2.1 gallons***

1850 **1880**

Maine temperance law, 1851 *Civil War, 1861–1865* *WCTU founded, 1874*

bottom illustration on opposite page].

Despite the exhortations of Rush and others, until the 1830s most Americans believed that strong alcoholic drinks imparted vitality and health, easing hard work, warding off fevers and other illnesses, and relieving colds and snakebite. Soldiers and sailors took a daily ration of rum, and whiskey had a ceremonial role for marking any social event from a family gathering to an ordination. Even as concern grew, so did the distilling business. Annual consumption peaked around 1830 at an estimated 7.1 gallons of alcohol per adult.

Total Abstention

The creation of the Massachusetts Society for the Suppression of Intemperance in 1812 heralded the first organized antidrinking crusade on a state level. Through the inspiration and determination of one of the most dynamic writers and speakers of the century, the Reverend Lyman Beecher, the tide began to turn in earnest. That same year the annual meeting of the Connecticut Congregational Church received a report on the enormous rise in drinking and concluded, regretfully, that nothing could be done about it. An outraged Beecher demanded that a new report be written, then produced one himself overnight. He called for a crusade against alcohol. In 1826 Beecher limned the specifics of his argument in his epochal *Six Sermons on Intemperance.*

Beecher's words swept hundreds of thousands into America's first temperance movement. One of his signal contributions was to throw out compromise—how can you compromise with a poison? He extended the condemnation of spirits to all alcohol-containing beverages and denounced "prudent use."

"It is not enough," Beecher declaimed, "to erect the flag ahead, to mark the spot where the drunkard dies. It must be planted at the entrance of his course, proclaiming in waving capitals—THIS IS THE WAY TO DEATH!!" Beecher's argument that abstinence is the inevitable final stage of temperance gradually won dominance. In 1836 the American Temperance Society (founded in 1826) officially changed its definition of temperance to abstinence.

Not until 1851 did Maine pass its groundbreaking prohibition law, but after that, things moved quickly. By 1855 about a third of Americans lived under democratically achieved laws that prohibited the sale of alcohol. Alcohol consumption fell to less than a third of its pretemperance level and has never again reached the heights of the early republic.

The Woman's Crusade

As the first temperance movement was reaching its peak, another moral debate claimed national attention: slavery. Proabstinence forces began to lose their political strength, especially during the Civil War, when the federal government raised money by means of an excise tax on liquor. Starting in the 1860s, some states repealed their prohibitions, courts in others found the statutes unconstitutional, and prohibition laws in yet other states and territories fell into disuse.

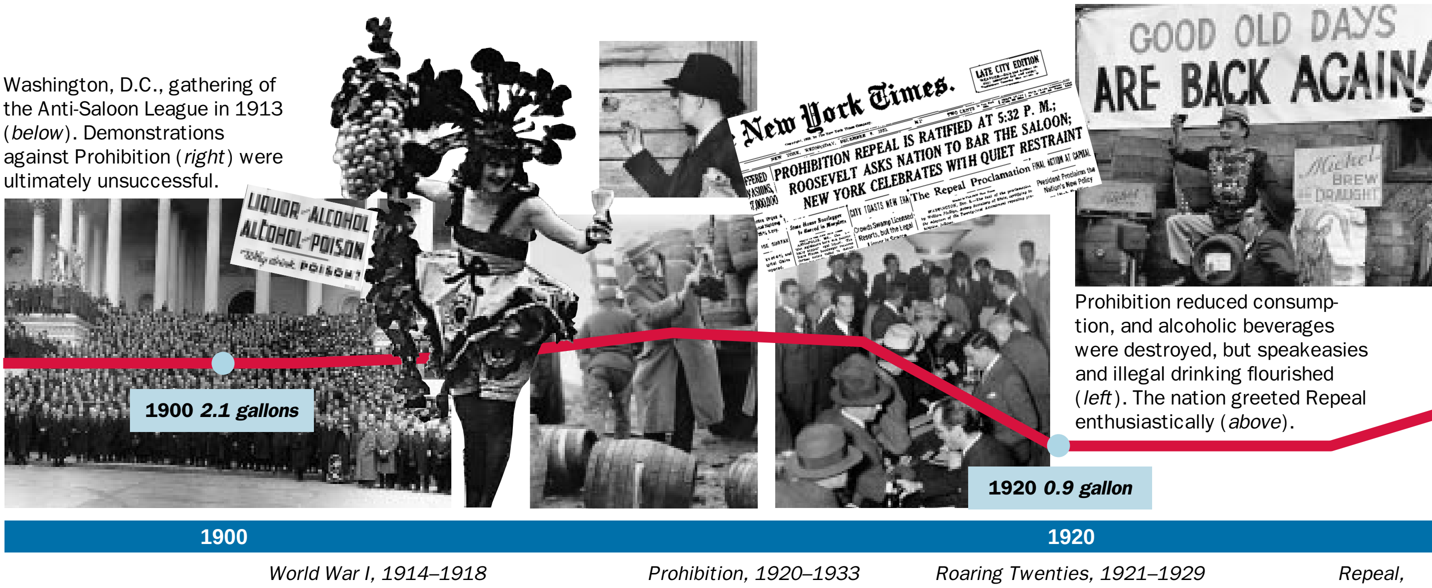
Nevertheless, important antialcohol events continued. The most dramatic, the Woman's Crusade, began in Ohio in 1873. Large groups gathered and employed hymn singing and prayers to sway onlookers against saloons. Out of this movement evolved the Women's Christian Temperance Union (WCTU). Although it is now associated only with prohibition in the popular mind, during the union's prime it pushed for far broader reforms: its platform included equal legal rights for women, the right of women to vote, the institution of kindergartens and an attack on tobacco smoking.

Opposition to alcohol legitimized women's participation in national political life. Because women had been relegated to defense of the home, they could reasonably argue that they had a duty to oppose alcohol and saloons—which were efficiently separating men from their paychecks and turning them into drunken menaces to their families.

In each era of reform, people have tried to influence the education of children and to portray alcohol in a new, presumably more correct light. Today the federal Center for Substance Abuse Prevention (CSAP, the successor to the OSAP) works through prevention materials distributed to schools, but the champion of early efforts was the WCTU's Department of Scientific Temperance Instruction. It successfully fought for mandatory temperance lessons in the public schools and oversaw the writing of approved texts. Pupils would learn, among other things, that "the majority of beer drinkers die of dropsy"; "when alcohol passes down the throat it burns off the skin, leaving it bare and burning"; and "alcohol clogs the brain and turns the liver quickly from yellow to green to black."

The WCTU's multifarious agenda

Washington, D.C., gathering of the Anti-Saloon League in 1913 (*below*). Demonstrations against Prohibition (*right*) were ultimately unsuccessful.



Prohibition reduced consumption, and alcoholic beverages were destroyed, but speakeasies and illegal drinking flourished (*left*). The nation greeted Repeal enthusiastically (*above*).

hampered its effectiveness, though, and in 1895 national leadership of the antialcohol movement was seized by the Anti-Saloon League, which went on to become the most successful single-issue group in American history. At first, the new organization had as its ostensible goal only abolition of the saloon, a social cesspool that had already elicited wide public outcry. As sentiment against alcohol escalated, however, so did the league's intentions, and finally it aimed at national prohibition.

In 1917, aided by a more general national push for health and fitness, what would become the 18th Amendment passed in both houses of Congress by a two-thirds majority. Two years later it became part of the Constitution, coming into effect in January 1920. In the span of one generation, antialcohol campaigns had reached a point where prohibition seemed reasonable to a political majority of Americans. Although brewers and vintners had attempted to portray their products as wholesome, they could not escape the rising tide against intoxicating beverages of any kind.

The first temperance movement had rallied a broad segment of society alarmed at excessive drinking of spirits; only later did the concern move to alcohol in general. Similarly, this second temperance movement initially focused on that widely criticized feature of urban life, the saloon, and then gradually took aim at all drinking.

The Great Experiment

Prohibition lasted almost 14 years. On the positive side, the incidence of liver cirrhosis reached an all-time low: the death rate from the condition fell to half its 1907 peak and did not start to

Down the Memory Hole

Deeply held attitudes can rewrite popular history. An 1848 lithograph of George Washington saying farewell to his officers shows the father of his country drinking a toast with his compatriots. In the 1876 edition the wineglasses and bottle are gone. If teetotalism was the only moral lifestyle, Washington could not possibly be a drinker.

Indeed, late in the first temperance movement, the American Tract Society "reprinted" Philadelphia physician Benjamin Rush's essay against distilled spirits but abruptly truncated the text before his praise of wine and beer. On the other side, many people today may find it more comfortable to remember First Lady Eleanor Roosevelt, for example, as a compassionate social reformer than as an ardent supporter of Prohibition.

N. CURRIER (*left*) and CURRIER & IVES (*right*) *Museum of the City of New York*

Soldiers, dry during the first world war, drank during the second.

1940 *1.56 gallons*

Singer and actor Dean Martin, notorious for his drunken persona, created his own brand of liquor.

First Lady Betty Ford was later a founder of alcohol and drug clinics.

Victims Wall put up by Mothers Against Drunk Driving in Washington, D.C., in 1990 displayed photographs of people who died in alcohol-related crashes.

1980 *2.76 gallons*

1940 **1990**

World War II, 1939–1945 *MADD founded, 1980* *Federal support for age 21 drinking law, 1984* *Warning labels on alcoholic beverages, 1989*

increase again until the amendment was repealed. On the negative side, Prohibition was a blatant failure at permanently convincing a large majority of Americans that alcohol was intrinsically destructive, and it made a significant contribution to the growth of already entrenched criminal organizations. These factors—combined after 1929 with the specious hope that revival of the alcoholic beverage industry would help lift the nation out of the Great Depression—all brought about the overwhelming national rejection of Prohibition in 1933.

As we look at the ways in which the U.S. has addressed issues related to alcohol, we might ask whether prohibition is the inevitable—if brief—culmination of temperance movements. Is our Puritan tradition of uncompromising moral stances still supplying righteous energy to the battle against alcohol? During the 1920s, when many nations of the Western world turned against alcohol, a sustained campaign in the Netherlands led by the workers' movement and religious groups reduced alcohol consumption by 1930 to a very low level, but without legal prohibition. Likewise in Britain: the antialcohol movement reduced consumption even though it did not result in legal bans. Apparently, each nation has its own style of control.

Underlying the U.S. travail with alcohol is the persistence of a sharp dichotomy in the way we perceive it: alcohol is either very good or very bad. Those who oppose alcohol doubt that it might have any value in the diet; those who support it deny any positive effect of prohibition. Compromise seems unthinkable for either side.

Dealing with alcohol on a practical level while maintaining either a totally favorable or totally condemnatory attitude is fraught with trouble. The backlash to Prohibition made discussion of the ill effects associated with alcohol extremely difficult, because those worried about drinking problems would often be labeled as straitlaced prudes. Not until another 50 years had passed and new generations had emerged did grass-roots movements such as RID and MADD arise and, without apology, promote new laws against drinking. Yet public acceptance of such restrictions on alcohol consumption has a natural limit that can be exceeded only with great danger to the temperance movement itself: that is the lesson of Prohibition.

During the past 15 years, groups such as RID, MADD and the CSAP, aided by advances in medical understanding, have been transforming the image of alcohol into a somber picture heretofore unknown to the current cohort of Americans. This reframing may bring about a healthy rebalancing of our perception of alcohol. But how far will this trend go?

Can we find a stance toward drink that will be workable in the long term? Or will we again achieve an extreme but unsustainable position that will create a lengthy, destructive backlash? There are some signs of moderation—in particular, recent pronouncements by the U.S. Department of Agriculture that it should be considered permissible for men and women to consume a glass of wine a day to reduce their risk of heart disease—but it is still unclear whether the U.S. will be able to apply history's lessons. SA

The Author

DAVID F. MUSTO, a professor of child psychiatry and history of medicine at Yale University, has studied attitudes toward alcohol and other drugs since the 1960s. He received a B.A. in classical languages from the University of Washington in 1956, an M.A. in the history of science and medicine from Yale in 1961, and an M.D. from Washington in 1963. He has been a member of the alcohol policy panel of the National Academy of Sciences and the Connecticut Drug and Alcohol Commission. Musto spent his medical internship at the Pennsylvania Hospital in Philadelphia, where the pioneering temperance author Benjamin Rush was an attending physician in the late 18th century.

Further Reading

DELIVER US FROM EVIL: AN INTERPRETATION OF AMERICAN PROHIBITION. Norman H. Clark. W. W. Norton and Company, 1976.

THE ALCOHOLIC REPUBLIC: AN AMERICAN TRADITION. W. J. Rorabaugh. Oxford University Press, 1979.

TEMPERANCE AND PROHIBITION IN AMERICA: A HISTORICAL OVERVIEW. Paul Aaron and David Musto in *Alcohol and Public Policy: Beyond the Shadow of Prohibition.* Edited by M. Moore and D. Gerstein. National Academy Press, 1981.

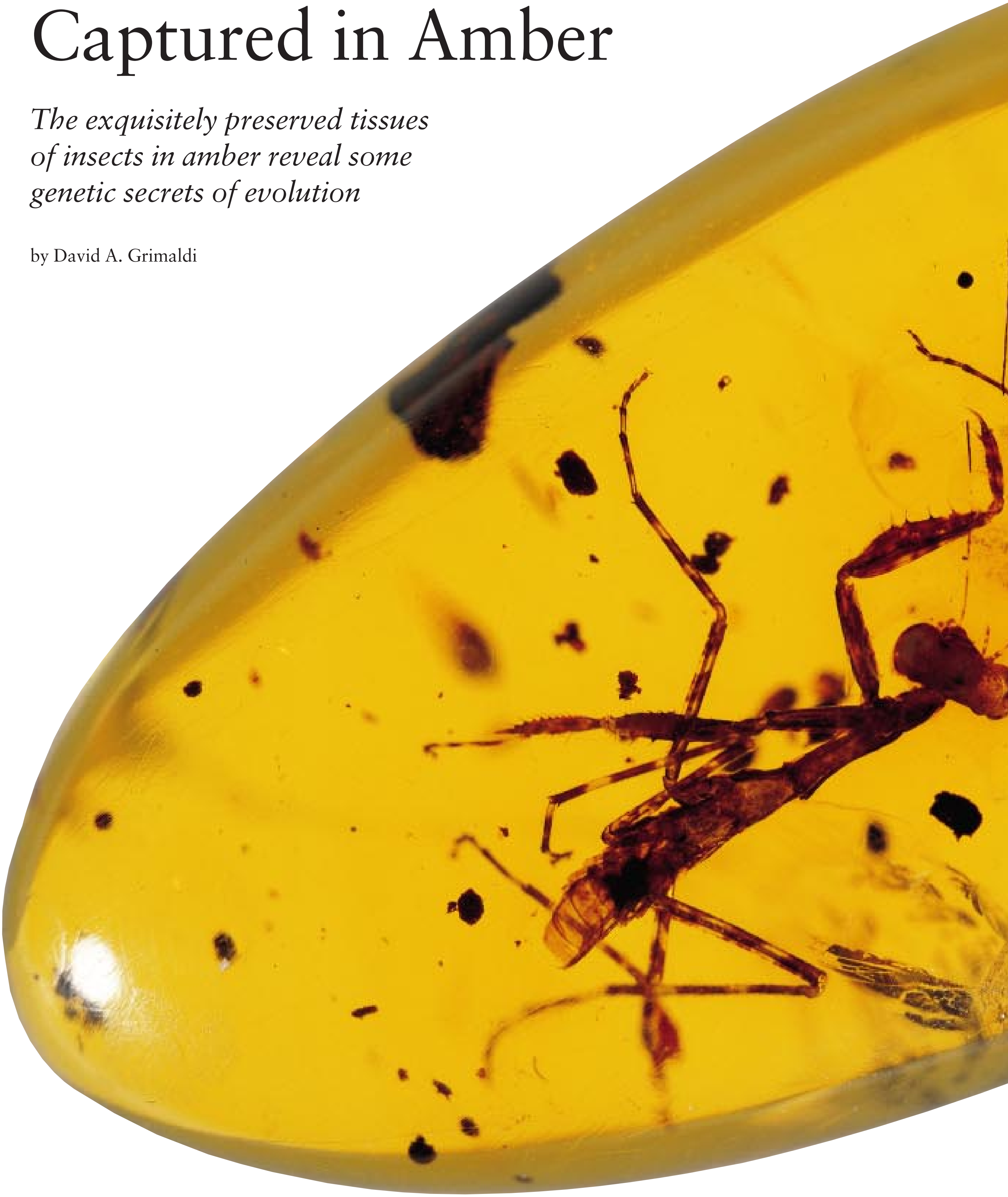
DRINKING IN AMERICA: A HISTORY. Mark E. Lender and James K. Martin. Free Press, 1987.

THE TURNING POINT: REPEALING PROHIBITION, Chapter 2. DRINKING, Chapter 3. In *Bad Habits,* by John Burnham. New York University Press, 1993.

Captured in Amber

The exquisitely preserved tissues of insects in amber reveal some genetic secrets of evolution

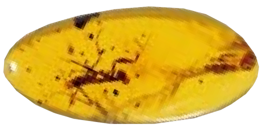
by David A. Grimaldi



ED BRIDGES *American Museum of Natural History*

PRAYING MANTIS preserved in Dominican amber—most of which is 25 million years old—is related to cockroaches and termites. This one was probably caught while stalking prey along the trunk of a tree that exuded the amber-producing resin.

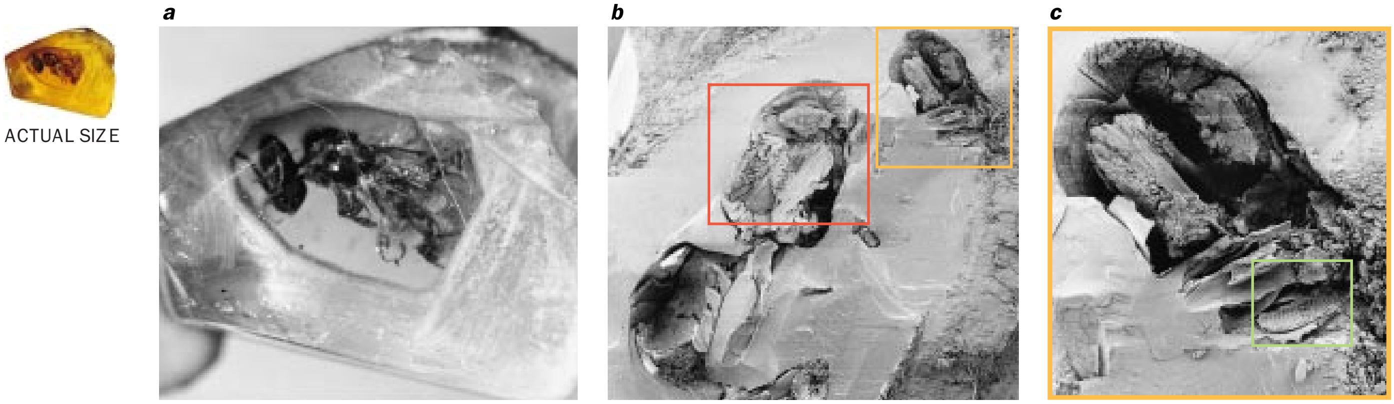
ACTUAL SIZE

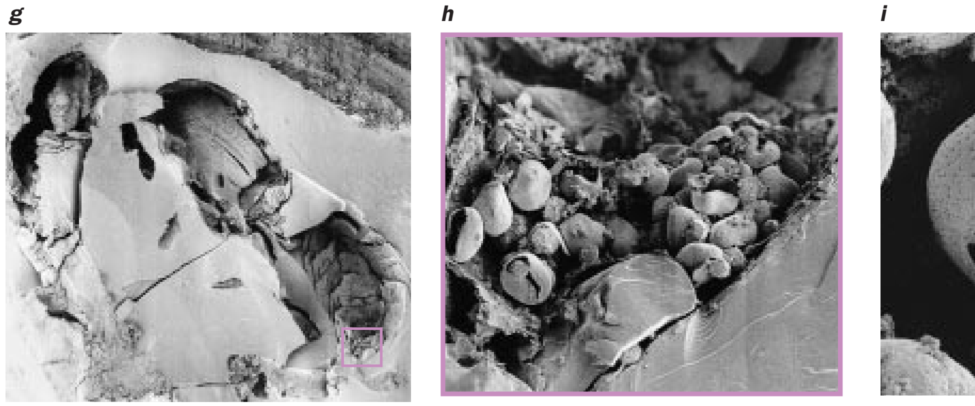


A hurricane had savaged the forest of giant *Hymenaea* trees along a Central American coastline. Yellow streams of resin oozed from mangled branches and gashed trunks, while insects bred in the wreckage. One termite happened to brush against the resin and stuck fast, ultimately becoming enveloped in its flow. Terpenes and other fragrant vapors from the resin penetrated the termite's tissues, replacing the water and killing bacteria.

Air, along with light and heat from the sun, induced chemical reactions in the resin, so that the carbon atoms in its long molecules began to link up. The chunk of hardening sap fell to the ground, one among thousands. Tides from tropical storms of a later year washed the resin fragments and rotting logs into a lagoon, where coastal sediments covered them. Twenty-five million years of subterranean pressure polymerized the resin even further, making it solid and chemically inert. Tectonic movements eventually lifted the coastline into steep mountains 3,000 feet high, to become the island of Hispaniola in the Caribbean.

Wandering in those hills some years ago, a Dominican miner came on a small landslide that revealed a black vein of fossilized wood. Digging for hours along the seam,





he unearthed a pile of nuggets. A deft stroke of his machete chipped a window into one stone, revealing the glassy glint of amber. Within the piece lay a very large termite, wings slightly parted and legs splayed.

The amber piece with its embalmed *Mastotermes electrodominicus* found its way into the teeming drawers of the American Museum of Natural History. Entomologists have long been intrigued by these primitive insects, which share some anatomical features with cockroaches and were thought to connect the latter with modern termites. Relatives of *Mastotermes* that have been extinct for 130 million to 30 million years show up in rocks and amber around the world. One species, *M. darwiniensis,* survives to this day in Australia, an evolutionary relic.

In 1992 I worked with Rob DeSalle, Ward Wheeler and John Gatesy from the Molecular Systematics Laboratory at the museum. The Hispaniola specimen was sliced open, allowing us to extract tissues from the termite (one of several in our collection). The sample contained exquisitely preserved cells, many with even the mitochondria intact. The tissues were dehydrated, yet they had not shrunk, as one would expect with the water gone. The process by which resin "fixes" tissue, so that it retains its original size, is still a mystery.

The dehydration was critical to the success of our experiment. After death, DNA degrades in the presence of water; the desiccation had allowed large segments of DNA to survive unaltered. We isolated snippets of the 18s and 16s ribosomal DNA genes. Mapping the sequence of bases on a DNA fragment, we compared it with corresponding sections from living termites, cockroaches and praying mantises, which constitute the group Dictyoptera.

The physical similarity between *Mastotermes* and roaches, it turned out,

DENIS FINNIN *American Museum of Natural History* d

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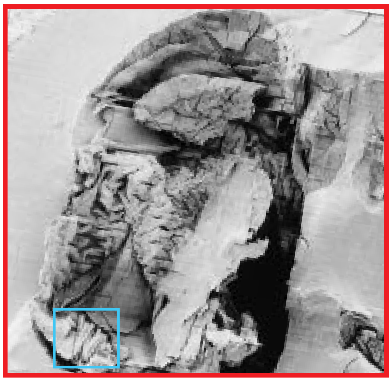
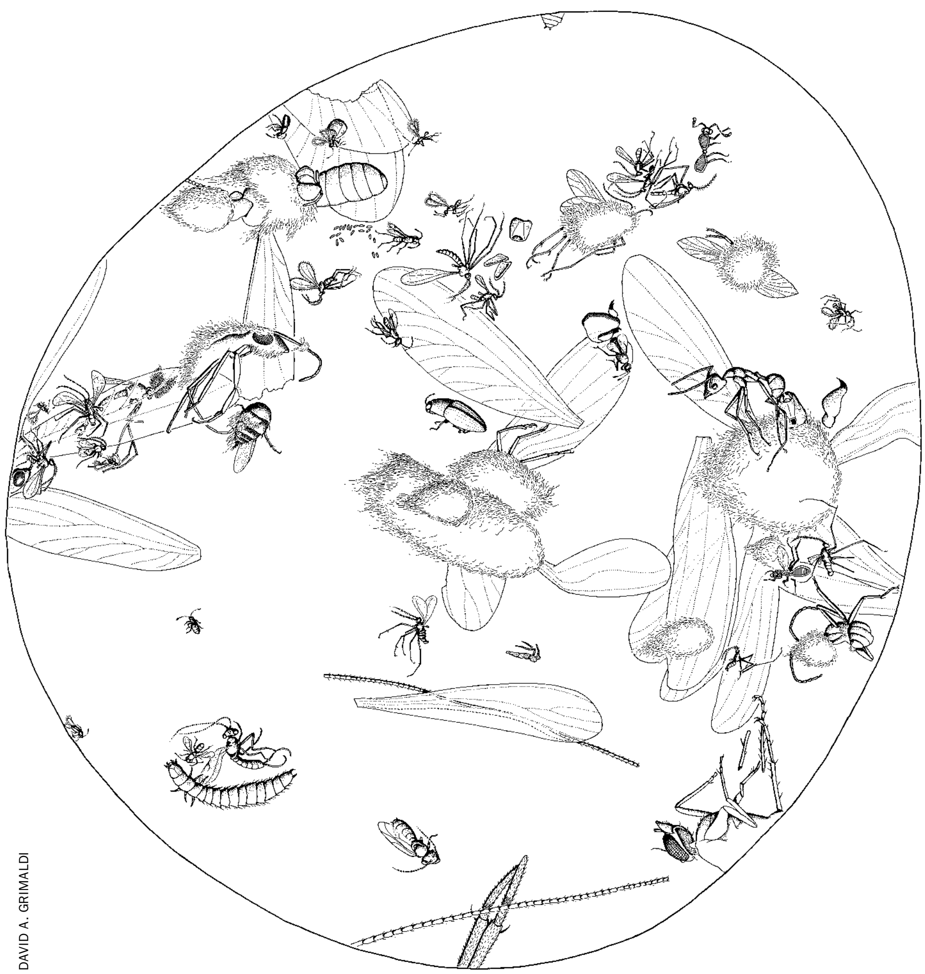


f

American Museum of Natural History (a–i)

SCANNING ELECTRON MICROGRAPHS of a stingless bee, *Proplebeia dominicana,* attest to the astonishing preservation of tissues in amber. The polished piece (*a*) is sawed to within a hair's breadth of the insect, cleaned and gently pried open. The left half of the specimen (*b*) contains parts of the head (*top*), thorax (*middle*) and abdomen (*bottom*). Within the head (*c*) lie the brain (*top middle*) and the long muscles used for sucking (*left*), along with the bee's small tongue (*bottom*). The scales on the tongue (*d*) are each about 10 microns long. The thorax (*e*) contains folded air sacs and, among other structures, a small bundle of muscles (*f*), each fiber of which is about 15 microns thick. The right half of the specimen (*g*) holds another half of the abdomen (*lower right*), along with pollen grains (*h*) that the bee had ingested. A single grain (*i*), viewed here from a different angle, is about 30 microns across. Stingless bees are common in Dominican amber: while harvesting the resin to construct their nests, the bees were often trapped instead.



DAVID A. GRIMALDI

MENAGERIE IN AMBER (*far left*) contains 62 whole and partial insects, all within a piece just 2.8 centimeters across. A map of the specimen (*left*), drawn by the author, depicts insects belonging to five orders and 14 families. Among them are several gall midges, ants, adult and larval beetles, and parasitoid wasps—including one that has just deposited her eggs (*top left*). Termite wings and antennae float across the scene; parts of three termites are sticking out of fuzzy mold. (Some of the insects were probably only partially trapped at first. The exposed parts decomposed, became moldy and were then covered by another layer of resin.)

was a vestige of an even more ancient ancestry. The extinct and living *Mastotermes* were very closely related, both being purely termites. The two species differed by nine base pairs in a segment of the 16s gene with 100 base pairs. The extinct DNA enabled us to reconstruct the evolutionary tree for the group and helped to clarify the relation of *M. darwiniensis* to other termites.

Since that study, DNA has been sequenced from a *Drosophila* fruit fly, a stingless bee, a wood gnat, a fungus gnat, and tree leaf and chrysomelid beetles, all preserved in Dominican amber. In 1993 Raul Cano and his colleagues at California Polytechnic State University sequenced DNA from a weevil in Lebanese amber; at 125 million years old it is the most ancient DNA known.

Right now amber from the Cretaceous period of 140 million to 65 million years ago is attracting all our attention. Dinosaurs died out at the end of this period (with the exception of their bird descendants); more important, the landscape transformed during it. Flowering plants, now the dominant life-form on earth, blossomed onto the scene. At the same time, many modern groups of insects evolved: ants, termites, bees, moths, butterflies, beetles and other creatures intimately associated with flowering plants.

One of the most important deposits of Cretaceous amber, from 90 million to 94 million years old, was discovered in central New Jersey some five years ago. Very recently, this trove has yielded some extraordinary fossils. Among the startling finds is a bird feather—the oldest terrestrial record of a bird in North America—and the oldest definitive bee and ant, as well as several other insects. We have uncovered the only flower in Cretaceous amber, a small inflorescence of the most primitive known oak.

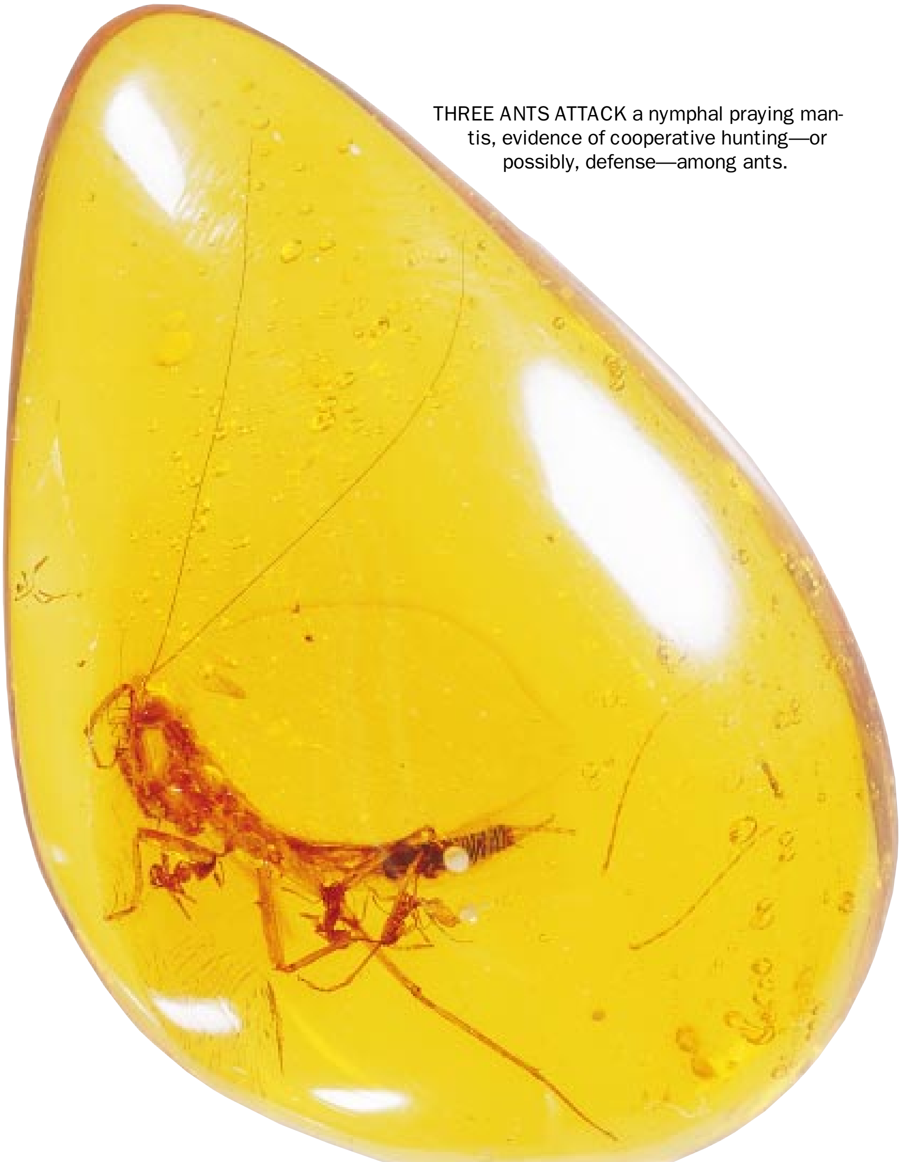
The New Jersey amber may well contain some of the most diverse and beautifully preserved insects from the Cretaceous. We eagerly await whatever else our discoveries will reveal.

Caught in the Act

Insect tableaux sealed in Dominican amber have demonstrated that some familiar behaviors are at least 25 million years old.

DAVID A. GRIMALDI

STRANDS OF A SPIDER'S WEB snag one of two delicate gall midges, in the family Cecidomyiidae.



THREE ANTS ATTACK a nymphal praying mantis, evidence of cooperative hunting—or possibly, defense—among ants.

JACKIE BECKETT *American Museum of Natural History*

DAVID A. GRIMALDI

LOVE AND DEATH unite two mating gall midges, providing specimens of both sexes. The female would have laid about 100 eggs, the larvae of which feed on fungi.

DAVID A. GRIMALDI

LAYING EGGS as it dies, a moth demonstrates a reflexive action observed in many insects. Larvae of this moth (family unknown, probably Tineoid) are thought to have fed on hard, woody bracket fungi that infected *Hymenaea* trees.

DAVID A. GRIMALDI

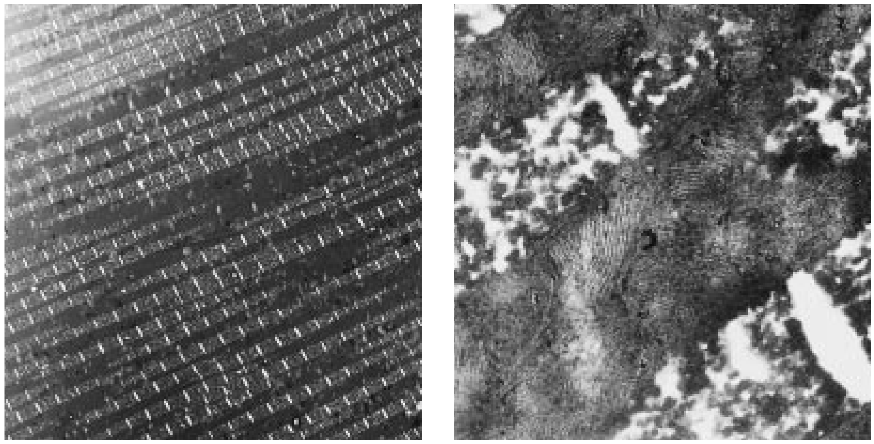
QUEEN ANT of the genus *Acropyga* carries a scale insect in her jaws, in an exceptional example of symbiosis. Some ants tend colonies of such insects, from which they harvest a sugary secretion called honeydew. (Some modern-day relatives of scale insects are common garden pests, such as whiteflies.) As the queen departs her old colony, she takes a scale insect along on her nuptial flight to start her new nest.

DAVID A. GRIMALDI

MITE CLINGS to the abdomen of a chironomid midge. These midges live in water or very damp soil during their larval stages, picking up the mites.

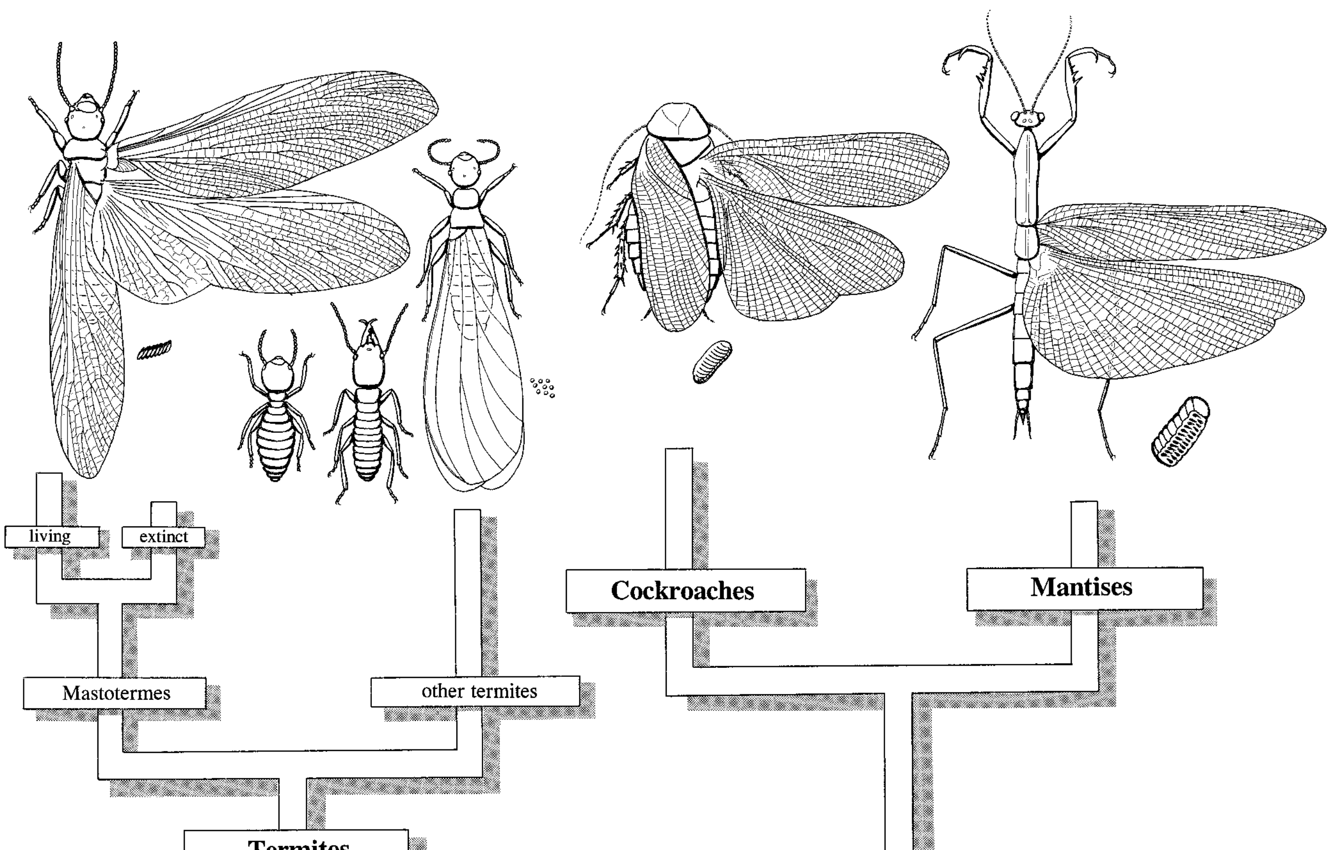
DAVID A. GRIMALDI

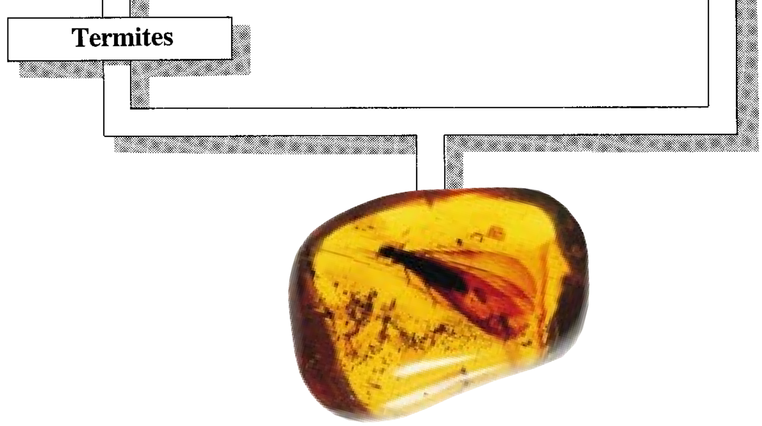
BITING MIDGE (family Ceratopogonidae) is bloated after a blood meal. Popular culture holds that blood from similar midges in Cretaceous amber was ingested from dinosaurs. This midge, however, lived 40 million years after the dinosaurs had vanished.



STEPHEN DOBERSTEIN AND MICHAEL DELANNOY *Johns Hopkins University*

FLIGHT MUSCLES
of a fossilized stingless bee (*left*) are magnified to reveal banded muscle fibers. Each fiber is up to one micron across. Between the strands are packed the folded membranes of mitochondria, which, when sliced through, look like fingerprints (*right*). It is from similar cells in a termite that the author and his colleagues extracted DNA.

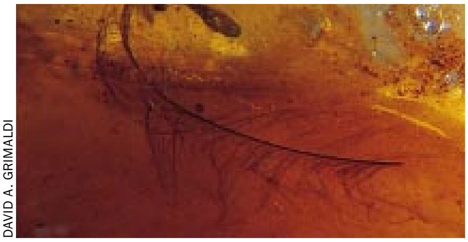




DAVID A. GRIMALDI (*drawings*); ED BRIDGES *American Museum of Natural History*

EVOLUTIONARY TREE
for the group Dictyoptera—which comprises termites, cockroaches and mantises—was partly constructed with help from DNA preserved in Dominican amber. The DNA, from an extinct *Mastotermes electrodominicus* (one specimen of which appears at the bottom), proved that despite its morphological resemblance to cockroaches, the insect was truly a termite. (The illustration is by the author.)

DAVID A. GRIMALDI



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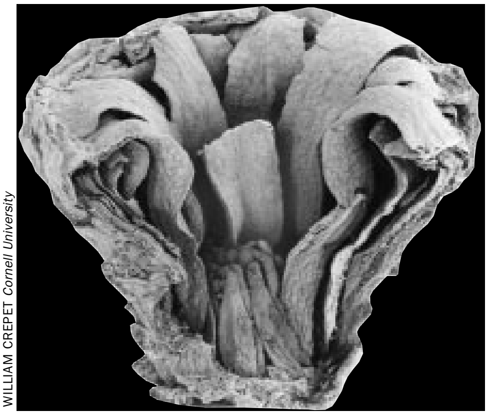


WILLIAM CREPET *Cornell University*

NEW JERSEY AMBER,
between 90 million and 94 million years old, is nowadays yielding many of the most exciting fossils. The cluster of oaklike flowers (*left*) constitutes the most ancient blooms in amber, from a time when flowering plants first evolved. The feather (*top*) is the oldest record of a terrestrial bird in North America. The amber also contains the oldest specimens of several insects, such as a parasitoid wasp (*bottom*). Preserved in clays alongside the amber are diverse flora, such as a two-millimeter-wide *Detrusandra* flower (*right*), a relative of magnolias. This specimen, photographed with a scanning electron microscope, was converted to pure charcoal, probably by forest fires.

JACKIE BECKETT *American Museum of Natural History*

JACKIE BECKETT *American Museum of Natural History*

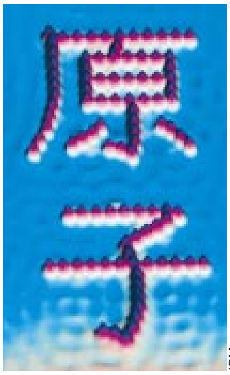
***ELEUTHRODACTYLUS* FROG**
and *Sphaerodactylus* gecko are trapped in pieces of Dominican amber 5.8 and 4.3 centimeters in size, respectively. Poised above the frog is the decayed carcass of another one, surrounded by fly larvae. The gecko's back is broken, perhaps because it struggled to escape from the resin; the leaf adjoining it has been chewed, most likely by a leaf-cutter bee. Dominican amber is renowned for the variety of life it embalms, including these rare vertebrates.

The Author

DAVID A. GRIMALDI chairs the department of entomology at the American Museum of Natural History in New York City. He obtained his Ph.D. in 1986 from Cornell University, where he is now adjunct professor of entomology. He is also adjunct professor of ecology and evolutionary biology at the City University of New York and the Center for Ecological Research and Conservation at Columbia University. Grimaldi's main interests are systematics (especially of Drosophilidae flies), paleontology and biogeography, the science of why life-forms are where they are. Trained also as an artist, he is known in scientific circles for his illustrations. Grimaldi is the author of *Amber: Window to the Past,* just published by Harry N. Abrams, and is currently curating an exhibition on amber at the museum.

Waiting for Breakthroughs

by Gary Stix, *staff writer*



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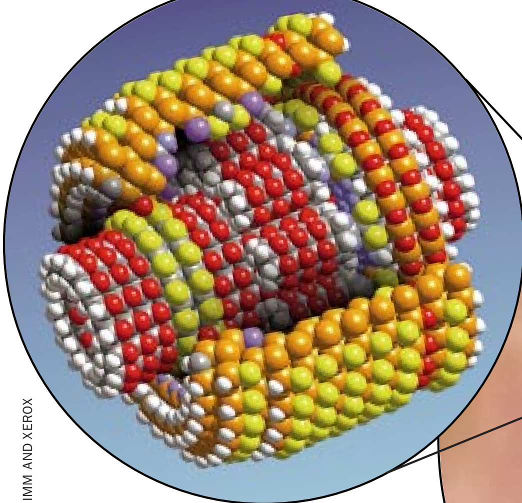
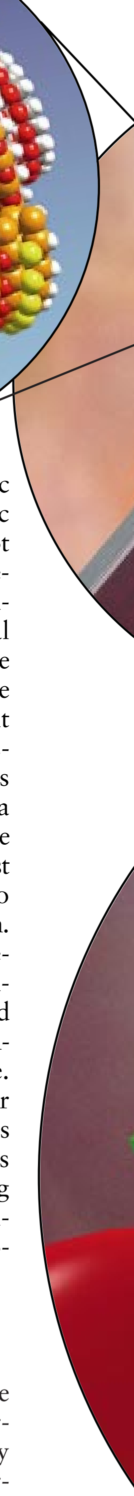


IMM AND XEROX



"That's the messiah," confides Edward M. Reifman, D.D.S. The Encino, Calif., dentist has paid hundreds of dollars to attend a conference to hear about robotic machines with working parts as small as protein molecules. Reifman nods toward K. Eric Drexler, the avatar of nanotechnology. Drexler has just finished explaining to a strange mix of scientists, entrepreneurs and his own acolytes that nanotech may arrive in one to three decades. The world, in his view, has not fully grasped the implications of molecular machines that will radically transform the way material goods are produced.

Nanotechnology is the manufacture of materials and structures with dimensions that measure up to 100 nanometers (billionths of a meter). Its definition applies to a range of disciplines, from conventional synthetic chemistry to techniques that manipulate individual atoms with tiny probe elements. In the vision promulgated by Drexler, current nanoscale fabrication methods could eventually evolve into techniques for making molecular robots or shrunken versions of 19th-century mills. In the course of a few hours, manufacturing systems based on Drexler's nanotechnology could produce anything from a rocket ship to minute disease-fighting submarines that roam the bloodstream. And, like biological cells, the robots that populate a nanofactory could even make copies of themselves. Finished goods in this new era could be had for little more than the cost of their design and of a raw material—such as air, beet sugar or an inexpensive hydrocarbon feedstock. The Drexlerian future posits fundamental social changes: nanotechnology could alleviate world hunger, clean the environment, cure cancer, guarantee biblical life spans or concoct superweapons of untold horror.

Scientific visionaries have shifted their attention from outer to inner space, as the allure has faded from dreams of colonizing another planet and traveling to other galaxies. Computer mavens and molecular biologists have replaced rocket scientists as the heroes that will help transcend the limits imposed by economics and mortality. "Whether or not Drexler's utopian ideas are correct, they come at a time when a variety of fields have reached stasis," says Seth Lloyd, a professor and specialist in quantum computation at the Massachusetts Institute of Technology. "You don't come across many fields that have as bold a project as the space program was."

Submicroscopic machines that can save or destroy the world appeal to anyone from a retired navy admiral to a technophile dentist to eager students—all of whom attended the nanotechnology conference. Reifman, the dentist, is a disciple who carries the message of nanotech to patients waiting nervously in his dental chair. He tells them of robots as small as a microbe that will painlessly refurbish a tooth or build a new one from scratch. "You'll be able to be a chocoholic without guilt," he predicts.

Drexler has purveyed his nanovisions for almost two decades. In recent years, however, his intricately constructed pictures of the next century and beyond have begun to be overtaken by real investigations into nanotechnology. What inspires actual researchers at the nanoscale is infinitely more mundane than molecular robots—but also more pragmatic. Nanotechnology, in this guise, may not contain the ready promise of virtually limitless global abundance and human mastery of the material world. But it may move beyond mere speculation to produce more powerful computers, to design new drugs or simply to take more precise measurements.

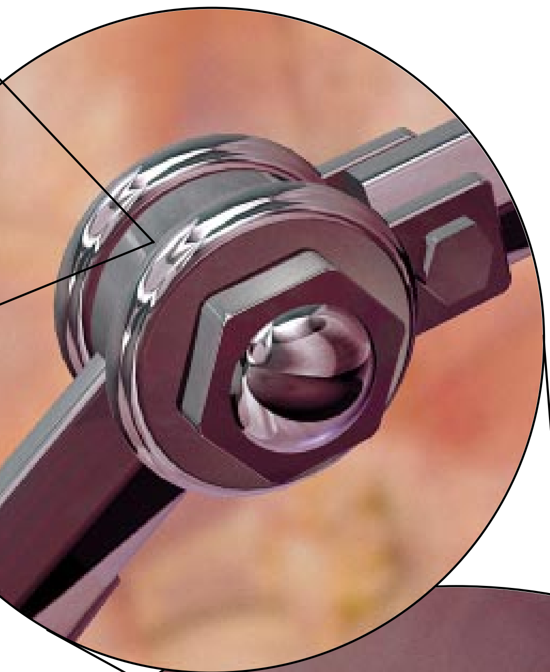
Researchers can now manipulate atoms or molecules with microscopic probe elements, marshal the 20 basic amino acids to form new proteins not found in nature, or help organic molecules spontaneously assemble themselves into ordered patterns on a metal surface. This work certainly presents the prospect of providing new tools for the engineering community. Ironically, it also demonstrates the difficulties of using individual atoms or molecules as building blocks, given the presence of a host of physical forces that may displace them. In fact, some of Drexler's sharpest critics are engineers and scientists who spend their time toiling in the nanorealm.

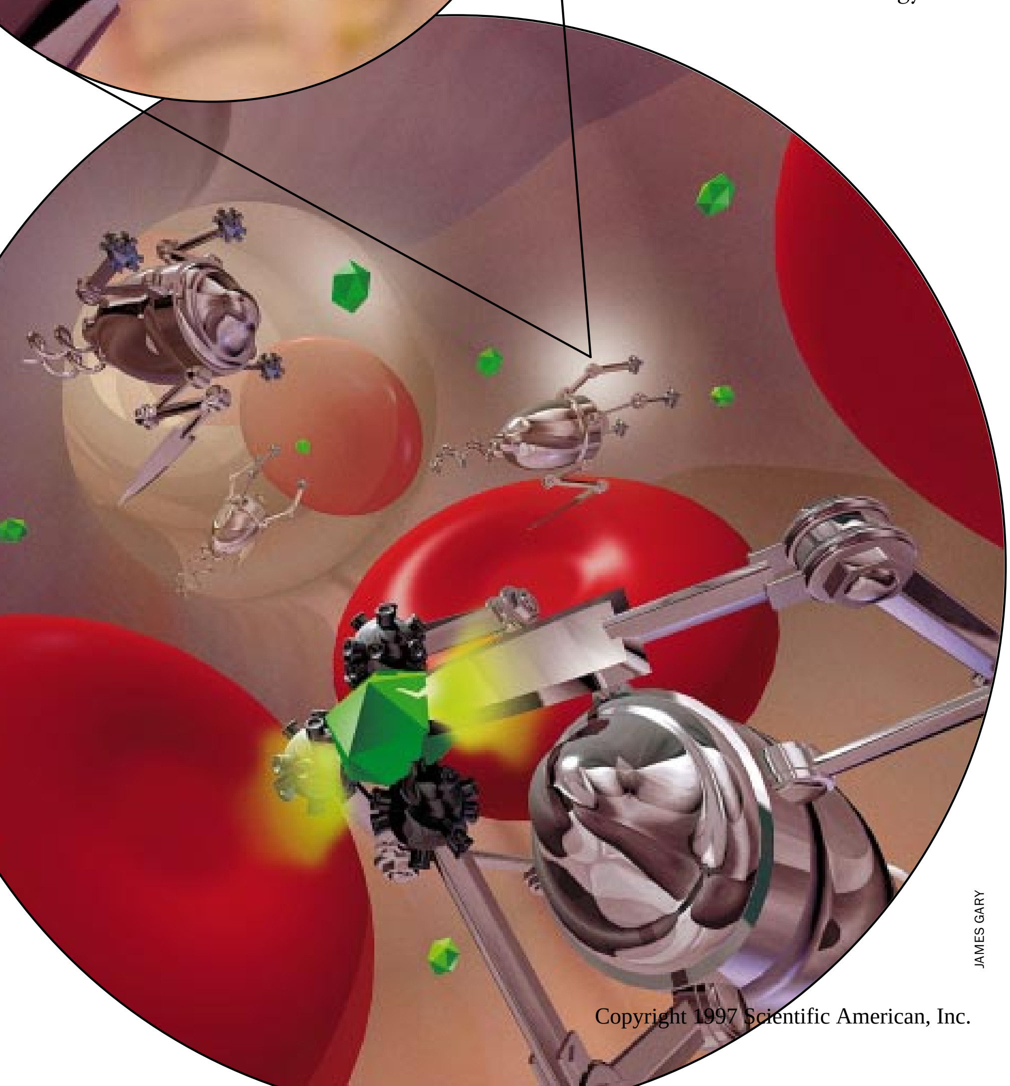
Drexler's fanciful scenarios, nonetheless, have come to represent nanotechnology for many aesthetes of science and technology. The phenomenon is not uncommon in the sociology of science. The public image of a certain field or concept, shaped by futurists, journalists and science-fiction scribes, contrasts with the reality of the often plodding and erratic path that investigators follow in the trenches of day-to-day laboratory research and experimentation.

Nanoism

Drexler, the 40-year-old guru of the nanoists, speaks with an exaggerated professorial tone that is faintly reminiscent of the pedantic 1960s cartoon character Mr. Peabody. Over a buffet lunch in early November at the biennial conference sponsored by his Fore-

"Nanoists" envision global abundance emerging from the manipulation of single atoms and molecules. But this prophecy has been challenged by researchers who work at a scale of billionths of a meter





sight Institute—an organization he set up in Palo Alto, Calif., to help pave the way for nanotechnology—Drexler pours milk into his ice tea. He explains that the milk binds the tannins that may lead to throat cancer.

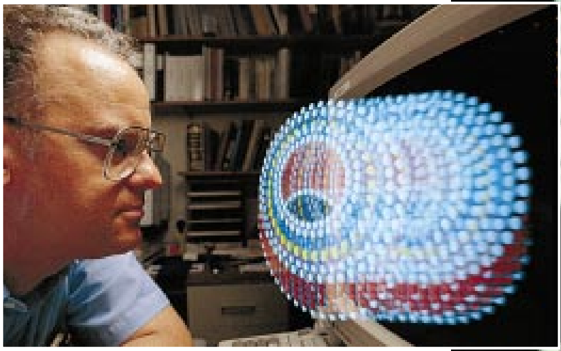
During the meal, he complains about the shortsightedness of the scientific and technological research establishment in the U.S., which has largely ignored his brand of nanotechnology. Drexler is familiar with dreams that don't come true. In the 1970s he volunteered to work with space colonization advocate Gerard K. O'Neill to plan various scenarios for extraterrestrial living; he even wrote a paper on mining asteroids in his freshman year at M.I.T. Drexler and other nanoists view their technology as a means to rejuvenate a moribund space program that has no immediate plans to create retirement communities on Mars. Nanotechnology would allow the manufacture of strong, light materials that would go into space transport vehicles.

The basic ideas behind small, self-replicating machines did not originate with Drexler. The renowned mathematician John Von Neumann, a father of the field of artificial life, ruminated about a machine that could make copies of itself. And in a much cited 1959 speech, Nobelist Richard P. Feynman talked about the ability to build things by placing each atom in a desired place. The self-assured Feynman used to toy playfully with the notion of making things small, musing on the theme with the humor of a Brooklyn-accented, Borscht Belt comic. Feynman even proposed a competition between high schools: "The Los Angeles high school could send a pin to the Venice high school on which it says [on the pinhead], 'How's this?' They get the pin back, and in the dot of the 'i' it says, 'Not so hot.' " Drexler, unlike the puckish Feynman, approaches his passion with a dour earnestness. The message: Nanotechnology is coming; we must prepare now.

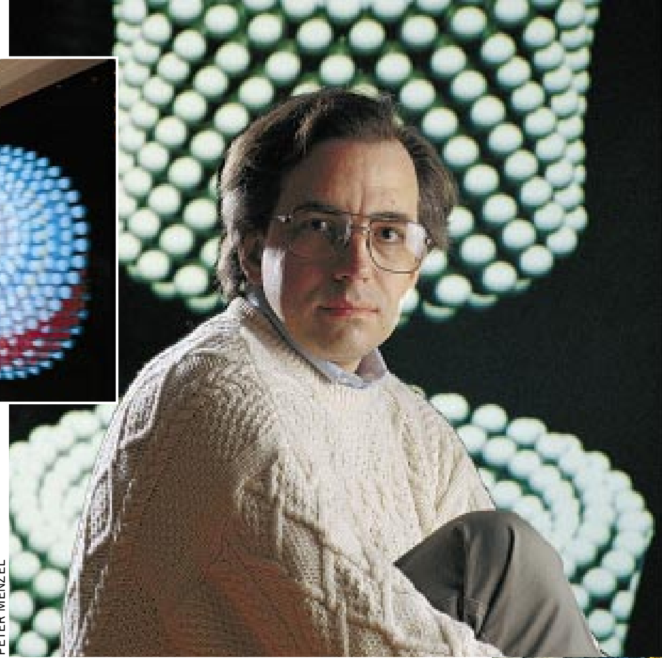
Drexler, though, can rightly claim credit for bringing wide exposure to an enticing idea. In his 1986 work *Engines of Creation,* Drexler, like Jules Verne and H. G. Wells, succeeded in depicting a world altered forever by the advent of a new technology. In *Engines,* Drexler introduced the concept of an "assembler," a robotic device with dimensions of a tenth of a micron (a millionth of a

IMMUNE MACHINES could destroy viruses roaming the bloodstream in the futuristic visions of nanotechnologists (*left*). Inside these robots would reside tiny gears no bigger than a protein molecule. (The atoms in the gear can be seen as colored balls in the top illustration.) In the laboratory, meanwhile, researchers have actually used atoms to spell the word "atom" in Japanese (*far left*).

JAMES GARY



PETER MENZEL



PETER MENZEL

K. ERIC DREXLER (*right*) and his colleague Ralph C. Merkle (*above*) have articulated a vision of a society transformed by machines that can construct objects large and small by moving single atoms and molecules. This dream has attracted science-fiction writers (*book covers*) and an Encino, Calif., dentist, Edward M. Reifman (*bottom*).

meter) or less, that can pick up and position a reactive molecule so that it interacts with another molecule, as though it were a Lego block snapping into place. He has also described mills equipped with belts and rollers to process molecules. A battery of nanocomputers—perhaps collections of molecular rods that change position to represent distinct logic states—could broadcast instructions to trillions of assemblers at once. The computers could also instruct assemblers to self-replicate. In his book, Drexler set down a detailed description of how society would be transformed by nanotechnology. *Engines* presents a picture of a Manichaean balance of utopian/dystopian scenarios.

The Good and the Goo

Combining nanocomputers with molecular machines would allow almost anything that can be designed to be made from a variety of inexpensive raw materials, perhaps even dirt, sunlight and air. Assemblers could string together atoms and molecules so that most goods could be made from diamond or another hard material, giving the most ordinary objects a remarkable combination of strength and lightness.

The cost per kilogram of goods produced by nanomanufacturing would equal the price of potatoes. The resulting nanoworld, in which everyone is wealthy because of the drastic reduction in the cost of goods, would flummox economists, those scientists of scarcity. A jumbo airliner could be purchased for the current price of an automobile. A homeowner would pour acetone into a household manufacturing system, similar in appearance to a microwave oven. An hour later, out would come a computer, a television set or a compact-disc player. A home food-growing machine could rapidly culture cells from a cow to create a steak, a godsend to the animal-rights movement.

Minuscule submarinelike robots made by assemblers would extend life or reverse aging by killing microbes, by undoing tissue damage from heart disease or by reversing DNA mutations that cause cancer; the nanomachines would help revive bodies preserved in cryogenic storage by repairing frostbite damage to the brain and other organs. (Drexler, in fact, plans to sign up to have his body frozen after death.) *Engines of Creation* even speculates about nanotechnology providing the basis for telepathy or for radically changing one's body.

On the dark side, assemblers would streamline the production of superweapons, allowing rapid fabrication of a tank or a surface-to-air missile. And then there is the "gray goo" problem—the possibility that nanodevices might be designed to replicate uncontrollably, like malignant tumor cells, and reduce everything to dust within days.

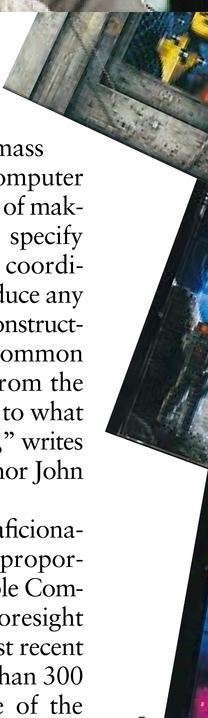
Ruminations in *Engines of Creation* about gray goo and extended life spans provoked guffaws from many scientists. In 1992 Drexler responded to the criticism with *Nanosystems,* which attempts to give his tiny machines a grounding in the underlying essentials of physics, chemistry and biology. *Nanosystems*'s heavy technical emphasis was a plea from Drexler for respectability. The subtext: I am not a flake. But the book remains largely an object of curiosity to the scientific community. It has been hard for many scientists, engineers and technicians to take seriously a section at the end that shows components of assemblers similar to large-scale mechanical devices. For example, a six-legged platform imitates the ones used to tilt flight simulators into different attitudes of yaw, pitch and roll. Its size: only 100 nanometers across, no bigger than a virus. "This is not science—it's show business," says Julius Rebek, a leading researcher in the chemistry of self-assembly at M.I.T.

Despite his alienation from mainstream science and engineering, Drexler continues to amass devotees, particularly among computer scientists enticed by the prospect of making tangible anything they can specify with a set of three-dimensional coordinates. "Nanotechnology will reduce any manufacturing problem, from constructing a vaccine that cures the common cold to fabricating a starship from the elements contained in seawater, to what is essentially a software problem," writes physicist and science-fiction author John G. Cramer.

Silicon Valley, that mecca for aficionados of things small, hosts a disproportionate number of nanoists. Apple Computer has helped sponsor the Foresight Institute's conferences—the most recent one last November drew more than 300 people, double the attendance of the 1993 gathering. A researcher at the Xerox Palo Alto Research Center, Ralph C. Merkle, who made a name for himself in computer cryptography, spends his time creating models of molecular machine components. (Merkle has already signed up to have his head frozen.)

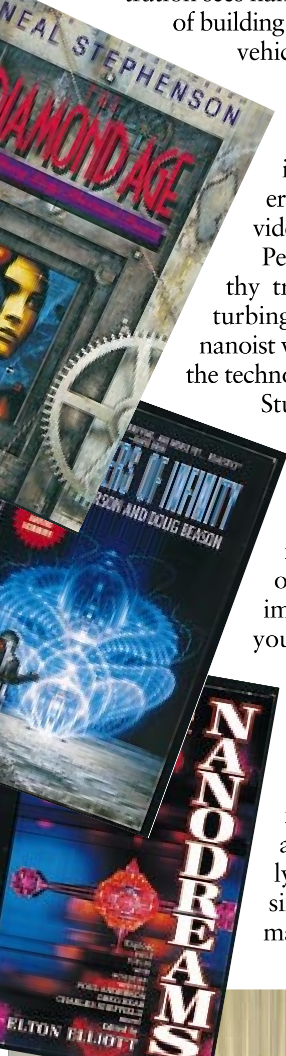
In 1991 John Walker, the reclusive founder of Autodesk, a California software company, donated $175,000 to help start the Institute for Molecular Manufacturing, a research organization. Most of the institute's grant money has gone to pay Drexler to work on projects such as computer simulations of molecular gears, bearings and other parts.

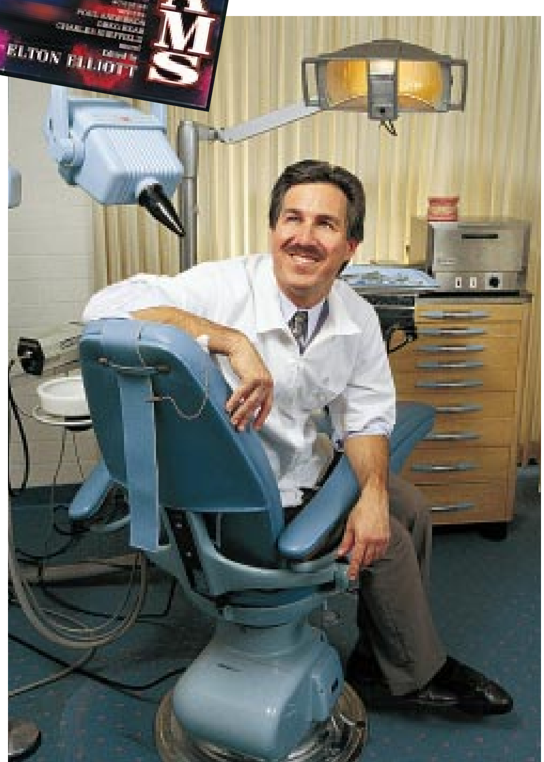
The Drexler following includes speculative thinkers such as artificial-intelligence pioneer Marvin L. Minsky. Nanotechnology also seems to inspire govern-



BOOKS (*top to bottom*): Courtesy of Bantam Spectra, illustration by Bruce Jensen; Courtesy of Bantam Books, art by Pamela Lee; Courtesy of Baen Books, art by Stephen Hickman ment laboratories seeking to remake their image. Oak Ridge National Laboratory has let one of its modeling groups devote extensive effort to simulations of molecular bearings and shafts. Administrator Daniel S. Goldin of the National Aeronautics and Space Administration sees nanotechnology as a means of building smaller and lighter space vehicles. And the NASA Ames Research Center has scheduled a workshop for this spring to examine how its supercomputers might be used to provide models of nanodevices.

Perhaps the most noteworthy trend—or the most disturbing one, to critics of the nanoist vision—is the appeal that the technology holds for students. Study groups in nanotechnology have established themselves at universities such as M.I.T. and the California Institute of Technology. "It's captured the imagination of bright, young scientists and engineers," says William A. Goddard III, a professor of chemistry and applied physics at Caltech. Goddard, an admirer of both Drexler and Merkle, occasionally works with them on simulations of molecular machine parts.





JAMES ARONOVSKY *Zuma*

Drexler and his nanoist disciples view molecular nanotechnology as a grand challenge of science and technology. And they comb the pages of journals such as *Science* and *Nature* for evidence of research advances that might lay the groundwork toward the ultimate self-replicating assembler. At the Foresight conference last fall, Merkle showed a schematic chart illustrating how the current work being done at a scale below 100 nanometers by chemists and materials scientists might one day lead to nanomachines. Lines on the left of the chart represented experimental approaches, such as probes that can manipulate atoms, tubes of graphite about a nanometer in diameter, and novel types of proteins. On the right side resided lines that corresponded to computer simulations of molecular machine parts for assemblers. In the center appeared a noticeable gap.

Real Nanotechnology

Most researchers whose work moves beyond computer simulations and into the laboratory do not view the challenges of nanotechnology as leading toward the goal of nanoists such as Merkle. A number of them, some of whom even capitalize on the "nano" label in promoting their work, pursue a series of more modest objectives. Differences of opinion about Drexlerian nanoism do not prevent the two camps from occasionally rubbing elbows.

Harvard University chemistry professor George M. Whitesides presented a review of his work at the Foresight conference. Whitesides investigates how simple natural objects self-assemble by minimizing thermodynamic instabilities at a surface, such as those between air and water [see "Self-Assembling Materials," by George M. Whitesides; SCIENTIFIC AMERICAN, September 1995]. At the meeting, Whitesides described how he and his colleagues have used self-assembling hydrocarbon molecules, called alkanethiols, to form ordered rows on a gold surface. They have demonstrated how this fabrication method might be used in a process to pattern far thinner circuit lines on a computer chip than can be achieved through conventional lithographic methods. Eventually, self-assembly of small silicon cubes that contain devices that alter information might lead to new methods for manufacturing computer processors.

Whitesides does not see the goal of his work as edging toward the assembler. He distinguishes between his investigations into self-assembling monolayers and the still distant goal of achieving self-assembly by following a coded set of instructions. Biological cells use this latter approach to make copies of themselves, and so would nanoassemblers. "What makes [Drexler's vision] exciting is self-replication, and at the moment, it is pretty much science fiction," Whitesides says. "Even after a fair amount of thought, there's no way that one could see of connecting this idea to what we know how to do now or can even project in the foreseeable future."

The complexity of making objects with individual molecular building blocks may eliminate any of the dramatic cost savings envisioned by the nanoists, except in a few clearly delineated technological areas. Fabricating computer chips has already become a form of engineering the small, with the tiniest circuit elements measuring less than a micron. The cost of a new semiconductor plant now reaches into the billions of dollars, in part because of the technical challenges posed by the need to craft ever smaller features onto the surface of a chip. Chipmakers can still justify the added expense because packing circuits more densely leads to higher computational performance and ultimately lower costs. For most other goods, nanotechnologies may receive tough competition from Mother Nature. "Drexler's grand vision is a nice one, but sometimes some of the specifics are not entirely correct," comments Jane A. Alexander, who established the nanoelectronics program at the Advanced Research Projects Agency. "I once heard him say we'd make tables out of nanotechnology. Wood is awfully cheap, and trees do it very nicely."

Keeping every atom in its place may also prove exceedingly onerous at the atomic level. David E. H. Jones, a researcher in the department of chemistry at the University of Newcastle upon Tyne, who may be best known as the author of the irreverent "Daedalus" column in *Nature,* has provided a pointed critique of the idea that individual atoms and molecules could serve as construction elements in the ultimate erector set. Jones made his case a year ago in a review of a popular book about Drexler by science writer Ed Regis, called *Nano*. Regis's account generally treats the chief nanoist's ideas favorably.

Jones describes the contortions often

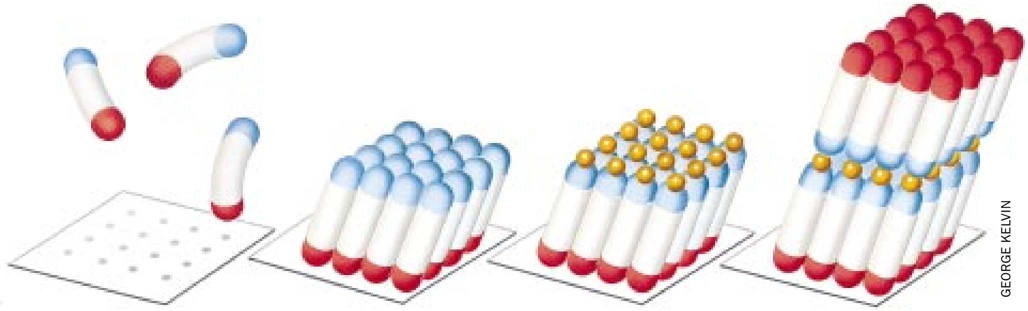
Nanometer Manufacturing

Although K. Eric Drexler's molecular machines may forever remain computer-based apparitions, laboratory research on materials science below the scale of 100 nanometers continues. A few nanotechnological fields described include:

DAVID SCHARF

Scanning probe microscopy. A tiny sharpened tip, such as that on a scanning tunneling microscope, can move atoms and create atomic-scale images. If many developmental hurdles can be overcome, the technology holds the promise of being suitable for storing bits of information by moving atoms on or off a surface.

Self-assembling monolayers. A layer of organic molecules, evenly spaced, adsorbs to a substrate, creating a two-dimensional crystal structure. Different chemical groups can be attached to the exposed tips of molecules, allowing them to build additional layers. They might be used for making optical diffraction gratings or in lithography for making computer chips.



GEORGE KELVIN

required to achieve atomic control of matter. In 1989 two IBM researchers penned their employer's acronym by manipulating 35 xenon atoms with a scanning tunneling microscope—a device that dragged the atoms across a nickel surface. The atoms moved because of chemical bonding interactions that occurred when the microscope's tungsten tip came to within a tenth of a nanometer or so of each atom. Jones notes the difficulties involved: The IBM logo was created in an extremely high vacuum at the supercooled temperature of liquid helium using inert xenon atoms. Outside this rarefied environment, the world becomes much less stable. "Single atoms of more structurally useful elements at or near room temperature are amazingly mobile and reactive," Jones writes. "They will combine instantly with ambient air, water, each other, the fluid supporting the assemblers, or the assemblers themselves."

Jones believes that the nanoists fail to take into account critical questions about the thermodynamics and information flow in a system of assemblers. "How do the assemblers get their information about which atom is where, in order to recognize and seize it? How do they know where they themselves are, so as to navigate from the supply dump [where raw atomic material is stored] to the correct position in which to place it? How will they get their power for comminution [breaking up material] into single atoms, navigation and, above all, for massive internal computing?" The list continues before Jones concludes: "Until these questions are properly formulated and answered, nanotechnology need not be taken seriously. It will remain just another exhibit in the freak show that is the boundless-optimism school of technical forecasting."

The nanoists' response to this fusillade is simple: read Drexler's technical tome *Nanosystems,* which contains a response to virtually any general point raised by detractors. Acoustic waves, for example, can be used to supply power to assemblers, an answer to one of Jones's objections.

Drexler contends that his critics, with their need to focus on new products or the next grant-funding cycle, have trouble thinking far enough into the future. "To people outside who don't understand that you're talking about the year 2020 or whatever, these ideas raise confused, unrealistic expectations about the short term," Drexler maintains. "That makes researchers uncomfortable because it's not a yardstick they want to be measured by. It also brings in ethics and the future of the human race, which are not the usual cool, scientific, analytical concerns."

For engineers who build things, finding the relevant page in *Nanosystems* is not enough. Drexler touts his work as "theoretical applied science": research constrained only by physical law, not by the limits of present-day laboratory or factory manufacturing capabilities. To hard-nosed engineers, though, the juxtaposition of "theoretical" and "applied" quickly becomes an oxymoron. Their response to the author of *Nanosystems*? Come back when you can tell me how to make those things.

The accumulation of small details may doom the best theories for small machines. Phillip W. Barth, an engineer at Hewlett-Packard, characterizes simulations of molecular bearings as "computer-aided speculation." "The holes are bigger than the substance," he says of *Nanosystems.* "There's a plausible argument for everything, but there are no detailed answers to anything." Barth is a leading engineer in micromechanics, a field that builds microscopic sensors and machines from silicon [see "Silicon Micromechanical Devices," by James B. Angell, Stephen C. Terry and Phillip W. Barth; Scientific American, April 1983]. Barth observes a lack of discussion of a number of basic engineering considerations that could make many of Drexler's nanodevices impossible to build. Drexler's nanobearings may be molecularly stable. But *Nanosystems,* he notes, does not address the stability of structures synthesized during intermediate steps in building the bearings. Unresolved details, moreover, may not be so trifling. "Energy is a fundamental concern," Whitesides declares. "It is no good to say it comes from somewhere—acoustic waves or whatever. If we can forget the details of energy supply, we have a perpetual motion machine."

The present inability to build an assembler—coupled with elaborate speculation about what the future may hold—gives nanotechnology a decidedly ideological or even religious slant, in Barth's view. In early January he posted a mes-

ANDREAS THESS AND PAVEL NIKOLAEV *Rice University*

Nanotubes. Cylindrical tubes of graphite, as small as one nanometer in diameter, can be fabricated up to a tenth of a millimeter in length, creating nanoscopic wires. This material has extraordinarily high tensile strength, conducts electricity well and might one day be used to build cathodes to illuminate picture elements on a computer display.

D. EISENBERG AND W. DEGRADO

Artificial proteins. During the past decade, several research and development teams have made new types of proteins by starting with groups of amino acids and getting them to fold into novel shapes. De novo protein design, as it is called, lends a deeper understanding of how a linear chain of amino acids forms into three-dimensional molecules. It might also allow the design of proteins specifically tailored for pharmaceutical or industrial needs.

sage to an Internet bulletin board (sci.nanotech) suggesting that subscribers comment on whether molecular nanotechnology has the makings of a mass social/political movement or a religious faith in the traditions of Marxism or Christianity. Barth bolsters the case for nanoism as a form of salvation by citing a passage from a new magazine called *NanoTechnology:* "Imagine having your body and bones woven with invisible diamond fabric. You could fall out of a building and walk away."

On the Border of Science and Fiction

The nanoists' legacy may be to stoke science-fiction writers with ideas for stories. The latest genre in science fiction employs nanotechnology as its centerpiece. A follow-on to the cybernetic fantasies of authors such as William Gibson, it is sometimes even called "nanopunk." The world depicted by nanowriters goes beyond cybernetic mind control and downloading one's brain into a computer. It postulates ultimate control over matter. "It seems like nanotech has become the magic potion, the magic dust that allows anything to happen with a pseudoscientific explanation," says Istvan Csicsery-Ronay, Jr., an editor of the journal *Science-Fiction Studies,* published by DePauw University.

A collection of "nano" stories that appeared last year features the imaginings of noted science-fiction writers, such as Poul Anderson. The volume, *Nanodreams,* even contains an introductory essay by Drexler on the merits of science fiction as a means of exploring the societal implications of a nanotechnological future. "Saying something sounds like science fiction should not be regarded as a form of dismissal," Drexler said in a recent interview. "Much of what science-fiction writers described in the 1950s happened, and you need to distinguish between antigravity and flying to the moon, between time travel and making a robot that works in the factory."

Nanodreams includes a story in which the pain experienced by a fetus during an abortion is telecommunicated to nanomachines that reproduce the sensation within the father of the child—and then, finally, kill him. Another nanotale describes a company that has just achieved a breakthrough by making nanomachines that can repair tissue damaged by a bullet wound. In one scene a poster on a laboratory wall depicts Albert Einstein handing a candle to Drexler.

The fantasies of nanoists posted on Internet bulletin boards and World Wide Web sites often outstrip the imaginings of the best science-fiction writers. Take the often discussed idea of a utility fog: nanobots that link together to create materials and objects in a desired form and shape, from paint to furniture. "When you got tired of that avant-garde coffee table, the robots could simply shift around a little, and you'd have an elegant Queen Anne piece instead," reads one description on the Web.

Chemistry has distant roots in alchemy, the belief that transmutation of materials will bring health and wealth (though perhaps not ultimate mastery of interior decoration). Nanoism resembles a form of postmodern alchemy—and one that awards cash for molecular machine parts. Toward the end of November's Foresight conference, an announcement was made about a new prize, named for Feynman.

The prize of $250,000 comes courtesy of Jim Von Ehr, an executive at Macromedia, a software company in San Francisco, and Marc Arnold, a St. Louis venture capitalist. It is to be awarded for the fundamental breakthroughs that will usher in the era of molecular nanotechnology: a robot arm and a computing component for an assembler.

For the time being, the nanoists can only wait for these breakthroughs to arrive, while continuing to formulate their computerized models of molecular machine parts. It may be a long time coming. In fact, Drexler himself has said that his fortitude has been weakened by jibes from critics and that he might consider a calling other than nanotechnology. "I'm tired of it," he says.

Nanoists' convictions about the inevitability of a breakthrough evoke memories of another idea once posed by Feynman, their adoptive mentor. In a commencement speech given to the 1974 graduating class at Caltech, Feynman noted that some Pacific Islanders religiously awaited the return of the U.S. troops who had landed in World War II. He described the elaborate preparations the islanders made for the return of the planes that would bring them advanced technological accoutrements and limitless wealth. Fires mark the sides of runways. A man plays air-traffic controller by sitting in a hut with carved wooden headphones from which pieces of bamboo stick out, like antennas. The believers wait patiently in this preindustrial imitation of an airfield.

"They're doing everything right," Feynman said. "The form is perfect. It looks exactly the way it looked before. But it doesn't work. No airplanes land." Similarly, some scientific endeavors rely on wish fulfillment—and an inability to consider why something may not work, Feynman noted. "So I call these things cargo cult science," he concluded, "because they follow all the apparent precepts and forms of scientific investigations, but they're missing something essential, because the planes don't land." Until the nanoists can make an assembler and find something useful to do with it, molecular nanotechnology will remain just a latter-day cargo cult. SA by Shawn Carlson

The New Backyard Seismology

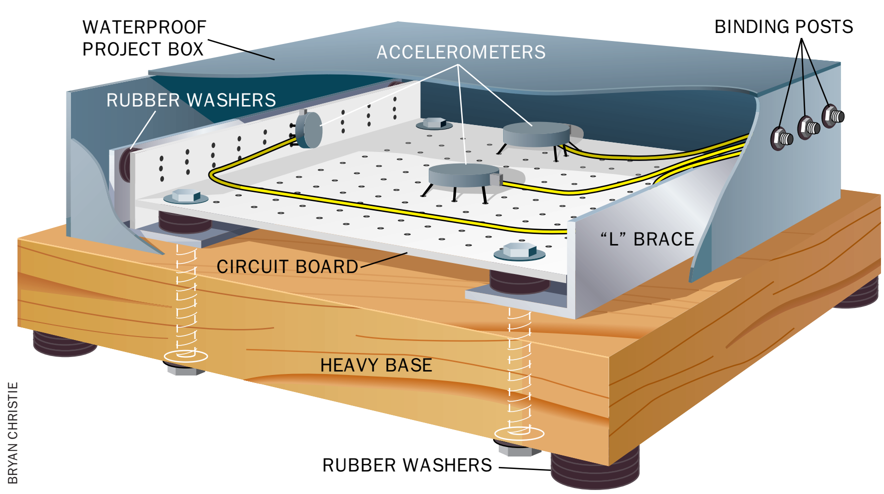
Earthquakes have long held a special fascination for science buffs. In the past, this column has described seismographs no fewer than eight times, so you might think there would be little more to say. But something exciting has just happened that makes this topic well worth revisiting. Using a breakthrough technology, amateurs can now, for about $100, easily build seismographs that are robust and that approach professional quality.

The breakthrough is a remarkable micromachined accelerometer on a silicon chip. Made by Analog Devices in Norwood, Mass. (telephone number: 800-262-5643, ext. 3), the ADXL05 chip costs about $20 and can detect fantastically small accelerations—less than five thousandths of 1 g (g is the acceleration caused by the earth's gravity and equals a change in velocity of 9.8 meters per second every second). That sensitivity is sufficient to detect extremely tiny tremors. The largest acceleration it can detect is 5 g, which is just about the limit of the largest earthquakes recorded.

The chip requires several resistors and capacitors to function as a seismograph. The circuit diagram on page 102 shows the arrangement. This design ignores the constant acceleration of gravity, so you do not have to level your seismograph precisely. The device is, however, quite efficient at detecting shaking rates from 0.1 hertz (one shake every 10 seconds) up to 100 hertz, which is the frequency range in which an earthquake releases most of its fury.

Unfortunately, the ADXL05 chip can be destroyed by the stray, static electrical charges that build up on our bodies. We often have up to 4,000 volts sitting on our fingertips, just waiting to be discharged to any convenient ground. We usually do not even feel these static discharges, because the amount of current that flows is relatively low. But those tiny pulses of energy can fry these delicate chips. Never handle them without keeping yourself discharged. Tying a wire between your wrist and something grounded, such as a metal pipe under the sink, is a good way to prevent static disasters. Also, dropping the chip on a hard surface may break the inner mechanism, so lay a soft towel over your workbench when building the circuit.

My seismograph uses three ADXL05 chips; two measure horizontal accelerations, and one measures vertical accelerations. Mount these chips on ordinary circuit boards. The tab on the chip points along its sensitive axis. Mount two chips such that these tabs face away from each other at 90 degrees—one forward, the other facing right (that is, so they span the *x-y* plane). Affix a separate piece of circuit board at a right angle to the first, making it stand upright [*see illustration on this page*], then mount the third accelerometer with its tab facing straight up to record vertical accelerations.



SEISMOGRAPH USING THREE ADXL05 ACCELEROMETER CHIPS mounted perpendicularly to one another (along the x, y *and z axes) can detect the tiniest of tremors. Not all the components are shown.*

House the completed unit in a weatherproof box and orient your seismograph so that the *y* axis points to true (not magnetic) north and the *x* axis points due east. (Hiking supply stores sell local topographic maps that indicate the difference between true and magnetic north.) Ideally, the seismograph should be bolted directly onto a concrete foundation that descends at least one meter into the ground. Failing that, bolt it to a weighted base and rest it on a surface—preferably concrete—away from foot and automobile traffic.

The chip's output is 2.5 volts at rest. A 1-g acceleration changes it by 0.4 volt. In general, the acceleration (*a*) along the chip's sensitive axis is given by $a = (V_{out} - 2.5)/0.4$, where V_{out} is the voltage output and *a* is in units of g.

These days your most important scientific tool is usually a home computer. Research often entails converting measurements (in this case, an acceleration) into voltage, which can then be digitized and fed directly into your computer. Vernier Software in Portland, Ore. (telephone: 503-297-5317), makes a versatile interface that will directly link your computer to this seismograph. It is their three-channel "Multipurpose Lab" card ($310), available for both IBM-compatible and Macintosh systems. BSOFT Software in Columbus, Ohio (telephone: 614-491-0832), offers several hardware solutions for IBM compatibles for under $100, as does Prairie Digital in Prairie Du Sac, Wis. (telephone: 608-643-8599), which also sells a serial device driver for Macintosh aficionados.

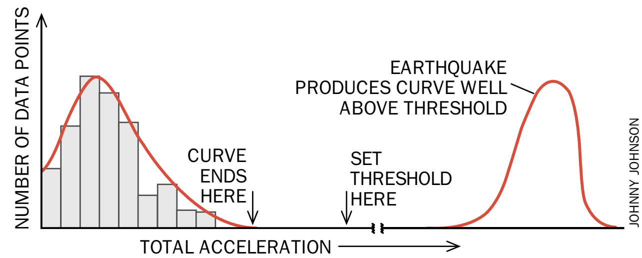
Finally, there is LabView, put out by National Instruments in Austin, Tex.

How to Tell an Earthquake from a Truck

Amateur seismologists using a computer must be discriminating. To tell an earthquake from, say, a rumbling truck, you first must record what your seismograph picks up during a normal day. The following pseudo-code outlines the procedure:

```
START:
READ DATA (Vx, Vy, Vz)          Read all three ADXL05 voltages
Ax = (Vx – 2.5)/0.400           Calculate the measured accelerations
Ay = (Vy – 2.5)/0.400
Az = (Vz – 2.5)/0.400
A_LENGTH = SQUARE_ROOT(Ax*Ax + Ay*Ay + Az*Az)
                                Calculate the length of the acceleration vector
WRITE(DATA_FILE, A_LENGTH, CURRENT_TIME)
                                Write the length and current time to a data file
WAIT (00:05:00)                 Wait five minutes
GO TO START                     Repeat
```

Let your program run without interruption for 24 hours. Then plot your data on a histogram. That is, plot the number of data points that fall within given ranges of the acceleration readings. Make at least eight such ranges (divide the difference between the minimum and maximum accelerations by eight). Adjust these ranges so that the acceleration range with the most data points has about 30 of them. Connect the points to form a curve (a real earthquake would show up well above the curve). Pick the acceleration at which the curve intersects the acceleration axis and multiply that acceleration by 1.5. That marks your threshold. Program your computer to begin recording data only if it detects an acceleration that exceeds this threshold. To make sure you record everything, instruct the machine to collect data continuously for four minutes.



A sample histogram for setting the acceleration threshold

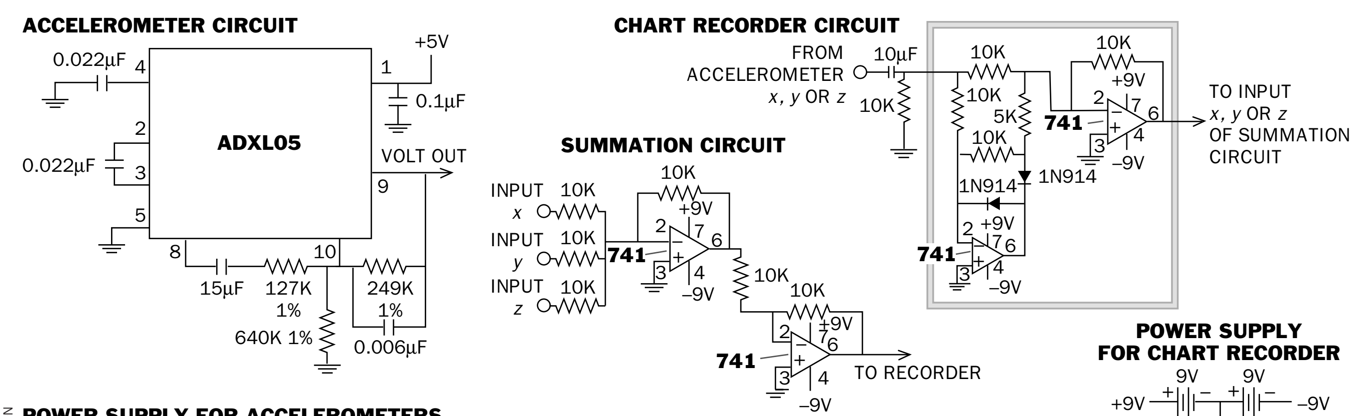
(telephone: 800-433-3488). This truly amazing program will read data from any interface and enable your computer to mimic almost any scientific instrument imaginable. You can buy the student edition for just $65 from Prentice Hall (telephone: 800-947-7700).

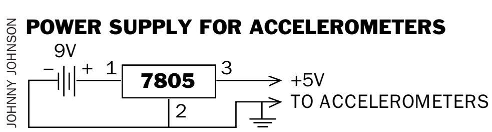
You will still need a bit of programming wizardry to avoid filling up your hard drive with useless data. The software accompanying your computer interface should be able to analyze data and select what to record on the fly, so you will need to write a program that makes those decisions [*see box above*]. Working with this modification to the commercial packages mentioned above is easier for some than for others, so be sure to pick the software most suitable for your level of programming skill.

If you do not have a computer, you will need a chart recorder [see "The Amateur Scientist," Scientific American, November 1955, July 1966, May 1970 or March 1972]. There is a bit of a problem with chart recorders, though. The voltage shift from each chip can be either positive or negative depending on the way the device lurches. If the different voltages are simply added together, then a negative horizontal "zig" would cancel a positive vertical "zag" and erroneously reduce your estimate of the actual acceleration.

To get around this problem, you will need to combine the signals into a single voltage that is a good measure of the total strength of the shaking. The summation circuit shown below does the trick. It takes the absolute value of the voltage shifts and adds them together.

The Society for Amateur Scientists is organizing an international network of amateur seismological observation stations. To get involved or to learn more about amateur seismology, send $5 to the Society for Amateur Scientists, 4951 D Clairemont Square, Suite 179, San Diego, CA 92117. You may download the information for free from its Web site at http://www.thesphere.com/SAS/ or from Scientific American's *America Online area.* SA





CIRCUITRY FOR EACH ADXL05 NEEDS HIGH-QUALITY RESISTORS, rated to within 1 percent. A chart recorder requires an additional circuit for each chip as well as a summation circuit; both use type 741 operational amplifiers.

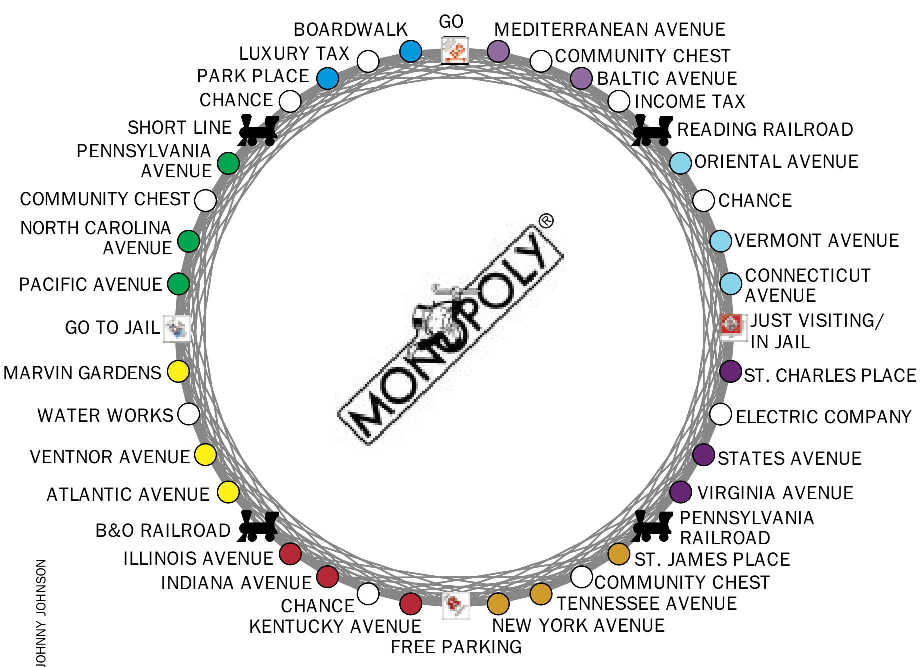
by Ian Stewart

How Fair Is Monopoly?

Everyone has played Monopoly. But few, I'd imagine, have ever thought about the math involved. In fact, the probability of winning at Monopoly can be described by interesting constructions known as Markov chains. In the early 1900s the Russian mathematician Andrey Andreyevich Markov invented a general theory of probability. I will ignore much of his work. And I won't review all of Monopoly's rules, but I will convince you that the game is fair. First, we must recall how to play it. Players take turns throwing a pair of dice. The number of dots on the dice determines how many squares around the board a player may move. A player who throws a double—say, two 1's (snake eyes)—throws again. All players start from the square labeled GO.

Some rolls, such as 7, naturally happen more often than others. There are six ways to roll a 7 (1 + 6, 2 + 5, 3 + 4, 4 + 3, 5 + 2, 6 + 1) from 36 possible sums of dots on the dice. So the probability of a 7 is 6/36, or 1/6. Then come 6 and 8, each having a probability of 5/36; then 5 and 9, having a probability of 1/9. Next, 4 and 10 have a probability of 1/12; 3 and 11 have a probability of 1/18; and finally 2 and 12 have a probability of 1/36. From these values we know that, over the course of many games, the first player is most likely to land on the seventh square, a CHANCE square. If he does not roll a 7, he will probably land on Oriental Avenue or Vermont Avenue, to either side of CHANCE. Thus, the first player has an excellent chance of securing one of these properties. If he does buy one, it lessens the opportunity for the other players to make a purchase on their first throw.

This fact is no doubt one reason why the game's designers put cheap properties near the start. The expensive but lucrative Park Place and Boardwalk are several turns around the board, by which time, presumably, the probabilities have evened out. But have they? To tackle that question, I shall introduce another simplification. Instead of considering a throw of both dice, let's imagine that they are thrown one at a time. Each player is allowed to make two moves: a "ghost" move, in which he ignores where he lands, and a real move. Similarly, we will adopt a mathematician's view of the game board.



JOHNNY JOHNSON

MATHEMATICIANS VIEW A MONOPOLY BOARD as a circle on which each property connects to the next six.

For convenience, number the squares from zero to 39. Square 40 "wraps around" to square zero, GO, and we can think of the numbers as being counted modulo 40—meaning that anything larger than 39 can be replaced by what remains when it is divided by 40. Now imagine a single player making repeated throws of a single die, moving accordingly. What is the probability of landing on a given square after a given number of throws? We would hope that when the number of throws becomes large, this probability nears 1/40, for any of the 40 squares. In other words, they should all become equally likely.

The way to find these probabilities is to see how their distribution "flows" over time. Each distribution can be represented by a sequence of 40 numbers, giving the probability of landing on each square individually. At the start of the game, the player is on square zero (GO), having a probability 1 (or always). So the probability distribution is 1 followed by 39 zeros. After a single ghost toss, the distribution becomes 0, 1/6, 1/6, 1/6, 1/6, 1/6, 1/6, 0,..., 0—that is, the probability of landing on the first six squares is 1/6, and the player cannot reach any others.

Notice that the total probability of 1—originally concentrated on square zero—has been split into six equal parts and distributed to the squares that are one to six units farther along. This procedure is general. After each toss of the die, the probability on a square is divided by six. These six equal parts flow clockwise on to each of the next six squares. So on the next throw, the 1/6 on square one is redistributed as follows: 0, 0, 1/36, 1/36, 1/36, 1/36, 1/36, 1/36, 0,..., 0. The 1/6's on squares two through six are similarly redistributed but shifted along one step each time.

Finally, we add up the probabilities that have landed on each particular square. For example, square six acquires 1/36 from each of the first five sequenc-

Markov's Matrix Magic

Let M be the transition matrix. First, calculate a set of 40 numbers, called the eigenvalues of M. A number *m* is an eigenvalue of M if you can write 40 numbers on the 40 vertices of the network so that when you split each into six and let it flow along the six clockwise lines emanating from that vertex, the resulting numbers are exactly *m* times the size of the numbers with which you started. (Phew! It's more easily expressed in symbols: $Mv = mv$ for some *v*.) But there's a twist: the eigenvalues need not be real numbers between 0 and 1. They can be complex numbers, expressible using the number $i = \sqrt{-1}$.

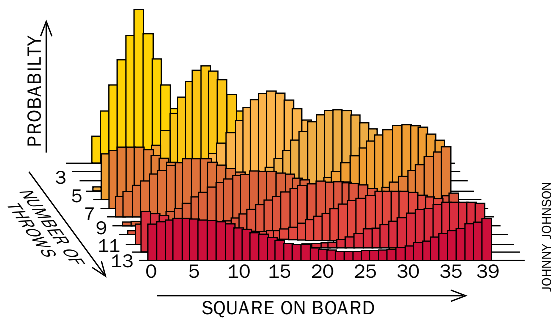
The sequence formed by these 40 numbers is called an eigenvector. Now all you have to do is find the biggest eigenvalue among the 40 you've calculated. Then the probability distribution will be approximated as closely as you wish by the corresponding eigenvector, once "normalized" so that its entries add to 1, as genuine probabilities should. (This step just means that you divide every entry by the total.)

Because of the rotational symmetry, it is actually not hard to find the eigenvalues and eigenvectors. One eigenvector shows all 40 entries equal to 1/40. What is its eigenvalue? Well, suppose you start from this distribution, split each 1/40 into six equal pieces of size 1/240 and shove them along their six clockwise lines. Each vertex receives exactly six contributions: one from each of the six preceding vertices. So it ends up as $6 \times 1/240$, or 1/40. This is what an eigenvector should do, and in this case the eigenvalue is 1. I won't tell you the other 39 eigenvalues, whose expressions are beautiful (perhaps only to mathematicians). In fact, the next largest one has an absolute value of 0.964. So 1 is the largest eigenvalue, and its eigenvector does indeed represent the long-term state of the probability distribution.

es, but 0 from the last one, so the total is 5/36. The final result is 0, 0, 1/36, 2/36, 3/36, 4/36, 5/36, 6/36, 5/36, 4/36, 3/36, 2/36, 1/36, 0,…, 0. Notice that this distribution matches our earlier expectations for tossing two dice. But now we can continue. On the third (ghost) throw, we multiply every term in the new sequence by 1/6, then shift it up one, two, three, four, five and six terms. Next, we add the numbers on each square.

It's easy to write a computer program to calculate these probability distributions one by one. The results are represented in the illustration at the right, starting with the "triangular" distribution obtained on the second throw. On each subsequent throw, the probability graph moves one step forward in the figure. You can see that the probability peak moves several squares to the right at each step. (In fact, on average, it moves 3.5 squares, the mean value of the numbers 1, 2, 3, 4, 5, 6.) If you continue the computer simulation, you find that the triangular shape eventually flattens out, and all the values are pretty much the same. But why does the simulation follow this pattern?

For an explanation, we need Markov's theory, which provides a systematic method to track the probability flow. It begins by writing down the so-called transition matrix for the first figure. The matrix, call it M, is a square table having 40 rows and 40 columns, each numbered zero through 39. The entry in row *r* and column *c* of the table is the probability of moving, in one step, from square *r* to square *c*. The value is 1/6 if $c = r + 1, r + 2, \ldots, r + 6$ (modulo 40), and 0 otherwise. Next comes a technical calculation, carried out using M [*see box above*]. The result shows that after many throws, the probability does indeed approach 1/40 for any given square. So, with a little help from Markov, we can prove that a game as complicated as Monopoly is fair, in the sense that—in the long run—no particular square is more or less likely to be landed on. Of course, the first player still has a small advantage, but this bonus is mitigated by the finiteness of his or her bank balance. SA



***DISTRIBUTION OF PROBABILITIES** over the 40 squares is shown above, as well as how it changes at each throw of a die. The height of each bar gives the probability of landing on the corresponding square. The graphs for throws 2 through 13 are stacked from back to front.*

FEEDBACK

Several readers asked for a full reference to the work of Colin C. Adams on knotted tiles [November 1995]. It is "Tilings of Space by Knotted Tiles" in the *Mathematical Intelligencer,* Vol. 17, No. 2, pages 41–51; Spring 1995. I also strongly recommend Adams's *The Knot Book* (W. H. Freeman, 1994), although I should point out that it doesn't mention tilings.

Michael Harman, a chartered patent agent living in Camberley, England, sent me a long letter about several novel approaches to finding knotted tiles. An especially interesting idea is to start with a torus knot, formed by winding a length of string around a solid torus (as on page 348 of *Mathematical Snapshots,* by Hugo Steinhaus, Oxford University Press, 1960). Several congruent copies of such a string can tile the surface of the torus, and this tiling can be extended to fill the interior, with the tiles remaining congruent.

It is well known that a cube can be dissected into two congruent toruses. Harman further observes that each cube can then be broken into two congruent knots. "It is also worth noting," he adds, "that the dissections of the two toruses can be either directly matching or mirror images of each other." —*I.S.*

LOUIS PSIHOYOS *Matrix*; from the American Museum of Natural History

NATURE READ IN TOOTH AND CLAW?

Review by David Norman

The Lost World
BY MICHAEL CRICHTON
Alfred A. Knopf, 1995 ($25.95)
Raptor Red
BY ROBERT T. BAKKER
Bantam Books, 1995 ($21.95)

Dinosaurs are big business following the enormous success of Steven Spielberg's film *Jurassic Park,* based on the best-selling novel by Michael Crichton. There is the old Fleet Street adage attributed to the late Lord Beaverbrook (a major newspaper proprietor) that "any publicity is good publicity." Nevertheless, I can't help wondering if the attention afforded by the media spotlight is really a good thing for science. These musings have been prompted by the arrival on my desk of two new works of dinosaur fiction, *The Lost World* and *Raptor Red.*

In keeping with the new economic power of dinosaurs, *The Lost World* is a blatantly commercial enterprise—*Jurassic Park II* in transparent disguise. The story picks up a few years after the debacle set out in *Jurassic Park,* with the discovery of rotting dinosaur remains along the coast of Central America. The source of these remains turns out to be an island that held the original breeding facility that provided the livestock for the "Jurassic Park" safari grounds. Our plucky heroes (paleontologists, behaviorists and theorists) set off in search of this lost island to study the dinosaurs at close quarters—and, lo and behold, the beasts are still there, alive and kicking in their own inimitable way.

Of course, all the plans go, little by little, awry. The intrepid but ever so slightly unworldly scientists lugging lots of clever but untested equipment face off against dastardly plotters trying to pinch and sell dinosaur eggs using a fiendishly cunning dinosaur immobilizer kit. A couple of resourceful and highly intelligent kids stow away on board the utility/laboratory vehicles in order to save the grown-ups from inevitable doom. A curvaceous animal behaviorist adds a touch of sexual interest. And there are, of course, some appallingly loutish dinosaurs. Little more can be said about the book. All the originality apparently went into *Jurassic Park,* which had a surprisingly original and clever plot—rather lost in the film, alas.

Crichton does not pretend to be a world-class scientist; he just writes popular fiction, and very successfully. But it is clear, from a number of asides in the text, that he is actually interested in the subject matter that forms the backdrop to the plot and that he is well informed. He demonstrates an awareness of recent scientific work, evidently from consulting with a number of scientists active in the field. (These researchers are, I am pleased to see, generously acknowledged at the end of the book.)

Raptor Red follows a less familiar formula for bringing dinosaurs to the readers of fiction. The book purports to tell the story of a year in the life of a large carnivorous dinosaur of the type known as *Utahraptor* (a gigantic version of the *Velociraptor,* alias *Deinonychus,* which played a central role in *Jurassic Park*). Remains of this dinosaur were discovered in Cretaceous-era rocks in Utah about four years ago. Bakker's book presents a "life" painted through the mind's eye of the dinosaur, populated by other dinosaurs and contemporaneous reptiles as well as by little mammalian insectivores.

In brief, the dinosaur named Raptor Red suffers the tragedy of losing her mate early on in the story, after which she teams up with a sibling and her youngsters and embarks on a series of difficult but ultimately triumphant adventures—rather in the manner of an old Walt Disney wildlife epic. The narration takes place in the head of Raptor Red and of various bit-part participants, who are credited with varying degrees of mental capacity—ranging from the wily but benevolent old pterosaur to the moronic pond turtle. Such anthropocentricity was trite even in the Disney movies; it is downright painful to see in a book claiming to describe the psychological attitudes of dinosaurs, especially one written by an author who is credited as "one of the world's foremost paleontologists."

Here lies the rub. *Raptor Red* is being sold on the basis of Bakker's scientific credibility. Yet the book is no more than a children's adventure story—and a rather poorly written one at that. The geological setting for the story is interesting and mostly accurate, as is the cast of characters, even if they are given cute names such as "whackity-whacks," "dactyls" and "multis." Everything else is fictional. The text is excessively punctuated by "sound effects" such as "Ghurk-snurg-GULP," "Eeeep...sssss-wsh...bmp-bmp-bmpity-bmp" and far too many others. The merging of science and fantasy is at its worst in books like *Raptor Red* because none but the experts can disentangle fact from fiction; this type of nonsense turns an uninformed reader into a misinformed one.

So, on balance, is the sort of fictionalized popularizations represented by these two books a good thing? Well, yes...and no. I think there is a reasonable case to be made for maintaining some form of public visibility for twilight areas of science (by which I mean that paleontology, despite its high profile, is funded poorly in comparison to the amount and quality of research that is done). But can we rely on the public to discriminate between science and science fiction in esoteric areas of paleontological interpretation? My answer has to be a resounding no.

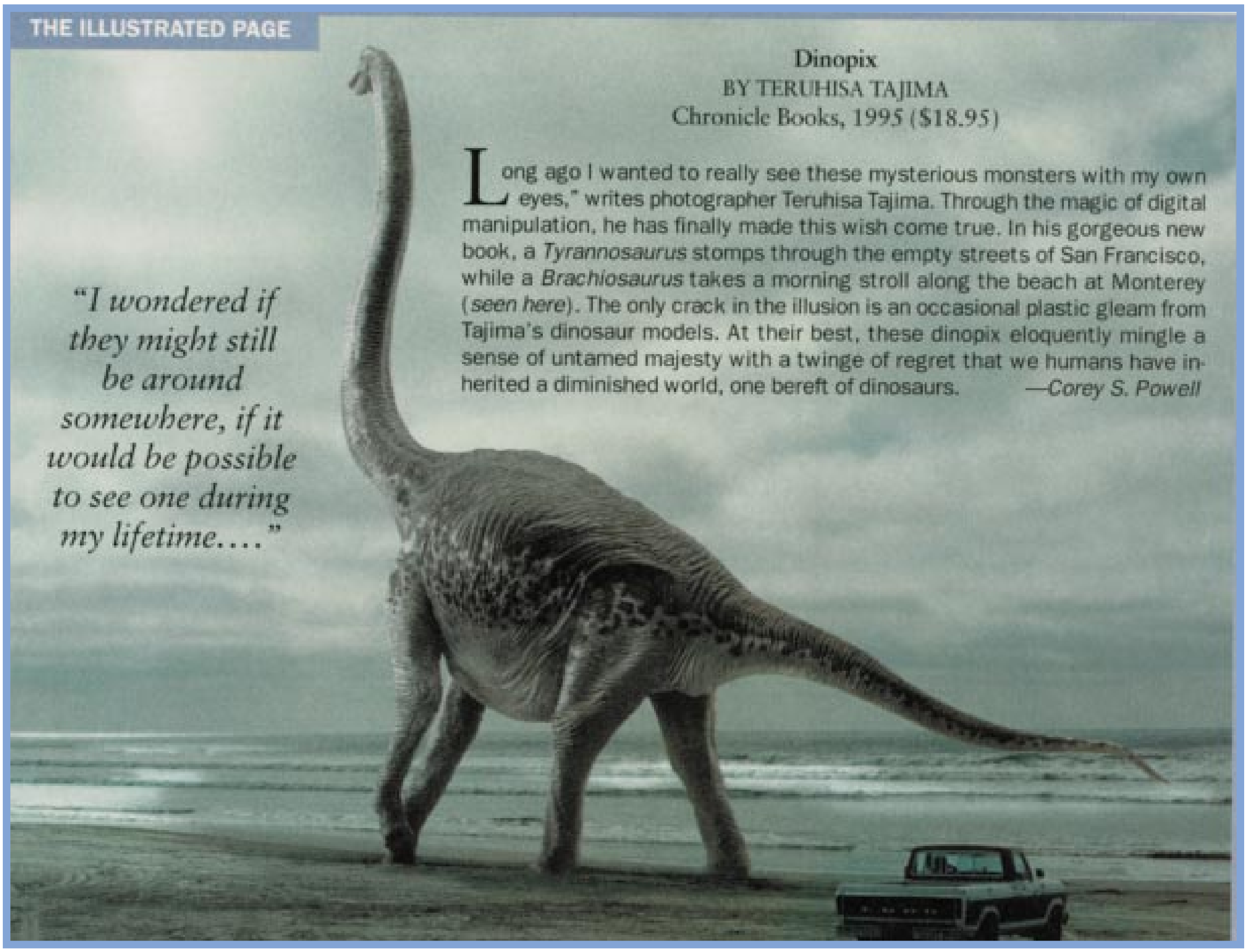
Fictional works such as *Jurassic Park* and *Jurassic Park II* (sorry, *The Lost World*) are something we just have to live with. Especially when converted to celluloid, these books raise public awareness about paleontology (and other sciences), but they give the public an inaccurate picture of what we spend most of our time doing. We have a responsibility to educate and influence the general perception of what our work is about.

Bakker is "one of us" in a strict sense, trained in paleontology (at Yale, no less), but one who has become heavily involved in dinosaur hype and one who has willingly adopted the alluring mantle of "rebel." I think his new book was a mistake. It continues the distressing trend started in Bakker's earlier nonfiction book *The Dinosaur Heresies*—the popularization of one particular paleontological interpretation, unsullied by any dissenting opinions.

There is no doubt that we need popularizers who have the massive appeal of a Robert Bakker. But, please, could we have ones who use their imagination a little more effectively? The only part of *Raptor Red* that I found truly readable was the epilogue. In those last eight pages, Bakker summarizes some recent work being done on the dinosaurs featured in the novel, mixed in with some table thumping about the possible effects of migration and disease in the dinosaur extinction—a rather quaint and little regarded theory. This postscript comes across as comparatively even tempered and knowledgeable; what a pity it had to be at the end.

Jurassic Park and its ilk certainly have stirred up great public interest in paleontology. But popularization for its own sake, and at any cost? Give me good-quality, well-written science any day. One of the greatest essayists of our time, Stephen Jay Gould, has taught by example the power of clear exposition. We should learn from it and use it.

DAVID NORMAN is director of the Sedgwick Museum of Geology at the University of Cambridge.



WORLD OF NUMBERS

Review by Rudy Rucker

Trust in Numbers: The Pursuit of Objectivity in Science and Public Life
BY THEODORE M. PORTER
Princeton University Press, 1995 ($24.95)

A Mathematician Reads the Newspaper
BY JOHN ALLEN PAULOS
BasicBooks, 1995 ($18)

In our increasingly quantified world, news stories bristle with numbers, but most of these have little to do with science and mathematics. Math is not really numbers; math is shapes and forms in the landscape of the mind. The digits that clog our public discourse are really just cosmetic trappings, comparable to the wooden airplane wings hopefully attached to a cargo cultist's back. Two new books aim to help guide the reader through this brain-deadening procession of numskull numbers.

Trust in Numbers is a closely reasoned, densely written historical account of how nonscientific people came to use numbers for political purposes. Theodore M. Porter, a historian at the University of California at Los Angeles, appears to have no intrinsic interest in mathematics. This lack of training occasionally makes itself known; surely no true math lover could have overlooked an error such as defining a meter as "one 10,000th part of the distance from the pole to the equator." Ten kilometers from Africa to the North Pole?

The book begins by making the valuable point that it is exceedingly rare for one researcher to be able to reproduce another's experiment without some kind of personal contact—a visit or, at least, a letter or a phone call. The number-studded written record is never enough. Even in pure science, in other words, numbers are not quite so objective as they appear to be.

In the social sciences, the use of numbers becomes deeply intermeshed with the goals of those who use them, whether teachers or CEOs. Going out and extracting numbers from society—IQ scores, opinion-poll ratings, cultural statistics—is a complicated procedure that involves hiring and training hordes of people and then interpreting the data they collect. As Porter succinctly puts it, "Quantification is a social technology."

One attraction of the social use of numbers is that they depersonalize the phenomenon they document, tending to blunt its impact. Looking back, Porter skewers the tactics of the industrial age: "Middle-class philanthropists and social workers used statistics to learn about kinds of people whom they did not know, and often did not care to know, as persons.... A method of study that ignored individuality seemed somehow right for the lower classes." That attitude is as prevalent today as ever.

A large part of *Trust in Numbers* presents somewhat tedious histories of the rise of accountants, actuaries and the tool of cost-benefit analysis. There are some interesting lessons lurking in these cases, however, as when Porter discusses the trade-offs involved in numerical standardization: the workers in the above professions have "in varying degrees, abandoned their open reliance on expert judgment in the name of public standards and objective rules." They are forced to do so because the very people who make use of these professions are those who strive perpetually to undermine them for their own gain. That is, the number crunchers became faceless slaves to protocol so as to minimize bureaucratic conflict.

In modern times, we have seen the spread of cost-benefit analysis, which has become a near-universal guide for political decision making. Porter convincingly argues that the popularity of this technique is a result of "bureaucratic conflict in a context of overwhelming public distrust." When there is nothing else to trust, it seems, people trust numbers.

A Mathematician Reads the Newspaper accepts the media's use of numbers as a given and takes a much lighter, more topical approach than *Trust in Numbers* does. Author and mathematician John Allen Paulos's method is to latch on to various kinds of news items and use them as springboards into small mathematical discussions. As Paulos warns in his introduction, he also likes to "digress, amplify, wax curmudgeonly, and muse."

Any popular book on mathematics is doomed to recycle notions that may already be familiar to aficionados. But a good math writer like Paulos finds ways to make the material fresh and spicy. He even throws in a little sex.

In a chapter entitled "Local, Business, and Social Issues," Paulos has us envision the U.S. population as a big network of nodes and lines. Each node represents a person, and a line connects person A and person B if and only if A and B have had sex. Now, Paulos asks, for which A and B is there a linked sequence of sex

ON THE SCREEN

12 Monkeys
DIRECTED BY TERRY GILLIAM
Universal Pictures, 1995

In this hallucinatory thriller, a convict from the year 2035 (*right*) is sent back in time to learn about the origin of a viral epidemic that wiped out most of the world's population in 1996. One of the film's provocative conceits is that he cannot change the past; he can only carry information into the future (although dramatic necessity quickly sullies the purity of the premise).

Underneath the topical killer-virus motif, *12 Monkeys* paints a picture of science run amok. The virus in question emerges from (unspecified) genetic-engineering experiments; in the future, the surviving humans huddle underground, ruled by a Big Brother technological elite. But the movie's politics, like its narrative, are complex and ever shifting. There are hints that the villain who spreads the germs is in fact protesting scientific advance; meanwhile the technology of time travel appears to offer future humanity a hope for returning to a normal life. Perhaps the most subversive element of *12 Monkeys* is the effective way it blurs reality and delusion, grimly implicating science as the cause of, or the product of, insanity. —*Corey S. Powell*

lines connecting A to B through other nodes? From this simple beginning, he launches into a clever visual analysis. “If we place all people who are connected to one other in this way into the same group, this relation divides all Americans into nonoverlapping groups of people. My guess is that there are celibates who are in their own single-person groups; a large number of monogamous dyads neither of whose members ever had sex with anyone else and thus constitute their own two-person groups; relatively few groups having three, four, five, or a small number of members; and then the rest of the U.S. adult population in one large group containing 100 million or so members. The vast majority of the latter group is not promiscuous. The huge size of the group derives from our interconnectedness.”

Each short chapter of the book is headed by a typical newspaper headline that somehow relates to the topic discussed. “Rodent Population Patterns Difficult to Fathom,” for example, contains a very nice, artfully simple presentation of the period-doubling route to chaos. But Paulos sometimes fails to follow through as deeply as might be desired. “Clinton, Dole in Sparring Roles,” for instance, begins a discussion on Zipf’s law about the frequency of word use: “The frequency of a word in a written document is inversely proportional to the [popularity] of that word.” This is a fascinating and counterintuitive topic, but Paulos drops a forbidding formula on us and then deviates into a discussion of how to utilize your computer’s grammar checker to simulate the word-use patterns of tabloid journalism—a much less interesting notion, at least from a mathematician’s perspective.

PHILLIP CARUSO *Everett Collection*

A Mathematician Reads the Newspaper is also a bit flawed by the inclusion of some truly corny jokes. On the other hand, we have a good anecdote about a museum guard who says the dinosaur skeleton on display is 90,000,006 years old—because when he was hired six years earlier, he was told that it was 90,000,000 years old! (This tale makes a point about misplaced precision in numbers, a practice not always as obvious or humorous as it is here.) Another nit to pick is that one passage, an analysis of the 1993 New York City mayoral contest between David N. Dinkins and Rudolph W. Giuliani, is repeated word for word in two places.

Minor blemishes aside, *A Mathematician Reads the Newspaper* is irresistible. The book should do a lot to advance mathematics—albeit in a stealthy way. At first, a chapter like “Computers, Faxes, Copiers Still Rare in Russia” seems to contain no math at all, but on a more careful read you realize that you have been learning about computer architecture, slyly hidden in a text discussing why “the Jeffersonian model of many parallel processors is superior to the Stalinist model of one central processor.”

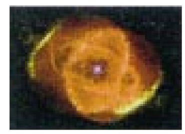
One last Paulos nugget: the misplaced precision of the “standard” body temperature of 98.6 degrees Fahrenheit arose simply because this is the exact conversion of the rounded-off value of 37 degrees Celsius. The actual measured range—36.5 to 37.5 degrees C—really corresponds to the range 97.7 to 99.5 degrees F.

What are the deep structures of our thought processes that make facts such as these so interesting? Paulos is silent on this question; perhaps some further advances in Porter’s history of quantification will tell us.

RUDY RUCKER is an author and a professor in the department of mathematics and computer science at San Jose State University.

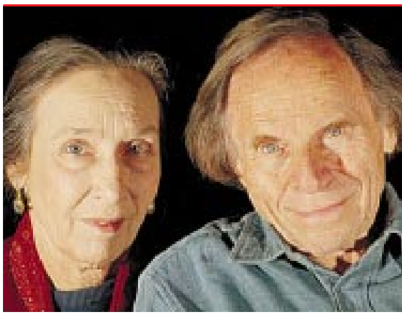
BRIEFLY NOTED

A JOURNEY THROUGH TIME: EXPLORING THE UNIVERSE WITH THE HUBBLE SPACE TELESCOPE, *by Jay Barbree and Martin Caidin. Penguin Studio, 1995 ($29.95).*
The ambitious title promises both a thorough astronomy overview and a guided tour of the scientific results from the *Hubble Space Telescope.* What the book actually delivers is lumps of overripe prose containing innumerable errors, misleading statements and incomplete explanations; it is not even much fun to read. Results from *Hubble* make up only a small fraction of the book, and some of the telescope’s most spectacular images are too new to appear here. A true disappointment.



HUBBLE VISION: ASTRONOMY WITH THE HUBBLE SPACE TELESCOPE, *by Carolyn Collins Petersen and John C. Brandt. Cambridge University Press, 1995 ($39.95).*
This is an altogether richer and more challenging book than the one described above. Here the authors have effectively captured the excitement of doing science with *Hubble.* They lay out the history of the space telescope honestly and clearly, keeping the book tightly focused on *Hubble*’s most notable findings. The only downside is a tendency toward tech talk (especially in the discussion of the telescope’s individual instruments), which may intimidate novices. A glossary and list of references aid the serious reader.

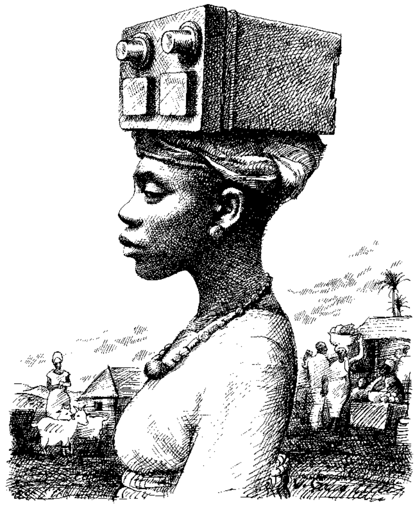
LONGITUDE, *by Dava Sobel. Walker and Company, 1995 ($19).*
Before the middle of the 18th century, sailors could not reliably determine their exact longitude at sea—sometimes with fatal results [see “Connections,” December 1995]. Dava Sobel vigorously recounts the efforts of John Harrison, a cantankerous but brilliant clockmaker, to solve that problem and battle his rivals. It makes one long to visit his successful nautical clock, still on view at the National Maritime Museum in London. —*C.S.P.*



WONDERS

by Phylis and Philip Morrison

Symmetries and Civilizations



This is the second half of our report on our sabbatical in South Africa. Last month we recounted the intriguing parallels and divergences between the earth's northern and southern halves. In this column, we reflect on a sadder kind of symmetry-breaking. South Africa has pursued for more than 80 years an unusual, fateful social asymmetry, profoundly dividing our single sentient species by decree.

For a couple of months, we have lived in the zip code of Alice 5700, eastern Cape Province, South Africa. Alice was an old British settlement, a political and military strong point during the Victorian colonial wars that raged in this Border region. The town—no longer so single in purpose, in ancestry or in speech—now spans a square mile or more. Perhaps 1,000 dwellings, some set along old tree-lined roads, some along dusty recent ones, surround the fragmented sidewalks that mark out the half-dozen business blocks.

Here the informal and formal economies of a very poor province are on daily, side-by-side display. The ladies in the market chat among their crates of bananas, potatoes and tomatoes, while the shoppers effortlessly balancing headloads stop or pass by. Hand trolleys carrying more varied goods roll out from the Saveway and the other storefronts, mostly transporting cargo to the crowded vans that perform as unscheduled, unofficial buses.

The broken symmetry of human beings is here—slowly—under restoration.

A short distance from Alice, past the BP petrol station and across the river bridge, lies the University of Fort Hare and its 4,000 resident students. The university opened at the end of World War I as a place of higher education for black Africans, then unique in South Africa. We spent many of our hours at the university, teaching physics, forging new relationships and receiving lessons in the distorted legacy of apartheid.

At first blush, Alice seems surprisingly well wired. The best evidence of this connectivity is the robot bank (what Americans call an automatic teller machine) that dispenses bundles of cash in rand. The machine reads our Bostonian bank card and accesses our account data after a delay of less than 30 seconds, no longer than the familiar wait back home in Cambridge, Mass. You can see 16 open pairs of telephone wires loop from pole to pole, strung along next to route R63 on their crowded metal racks of porcelain insulators. Follow the wires, however, and a picture of South African asymmetry begins to appear.

Half of the pages in the regional telephone directory list the phone lines in the large "township" that adjoins the port city of East London. It is the residence of the black Africans who work in East London, a smaller counterpart of Soweto. In all, 10,000 phones are listed for a population that numbers perhaps a quarter of a million. Among the Alice listings—fewer than 800 in total—more than 100 are clearly connected with the university, and about as many are for other public and private organisms: the police, the furniture and the hardware stores, the textbook shop, the town waterworks, a noisy hotel-bar (alas, no cinema). Maybe 350 telephone lines serve Alice households.

Nearly 300 of those connect to the "locations," a term of some small impoliteness for the rural villages of cement-block or daub-and-wattle houses, augmented by some shacks, that lie across the ridges and rolling hills of this semiarid region. The phone lines reach schools, churches, clinics, a store or two, and a few local leaders. In our region, telephones are as scarce as paved roads, electrical power, piped water and the rest of the basics that most of the people in these somewhat isolated villages lack—including jobs and arable land.

Almost all the residents of the locations are Xhosa speakers (say "kosa" if you can't begin the word with a click), members of one of the largest South African polities. These African people came to these parts a millennium ago, to build a society first of cattle growers and later of farmers—a musical, religious and articulate culture. Much later, after a century of deadly conflict with the European settlers, the Xhosa were evicted just before World War I, from their own wide lands to less fertile locations. They now make up 85 percent of the provincial population.

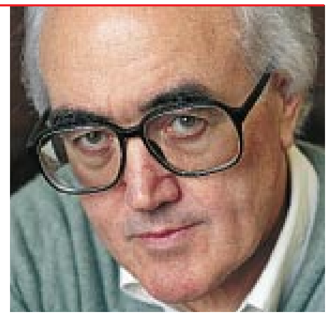
By common report, three quarters of the Xhosa adults now have no work. They eke out a living by drawing on the diversity of their extended families, stretching thin the income from someone's pension, another's wage check from a distant city, or some trading or craft skill. Goats and sheep still manage pretty well here; husbandry stands as a major economic activity of the region. But reliable means of life are no longer at hand for most Xhosa people in this hard and beautiful land.

National statistics support our local observations. There are roughly 42 mil-

Continued on page 114

CONNECTIONS

by James Burke



What's in a Name?

Not long ago, while I was wandering through that treasure-house of technological history, the Smithsonian Institution in Washington, D.C., I was reminded that evolution seems to have made us the only animal on the planet with a conscious appreciation of its own past.

Which may be why, in 1801, James Macie, scientific dabbler and the illegitimate son of the duke of Northumberland, took on the aristocratic family name when the death of his father meant there was nobody left to prevent him from doing so. Macie had two notable claims to fame: he (a) wrote one of those monographs-you-can't-pick-up about a bamboo-joint juice called tabasheer and (b) devised a better way to make coffee. That he was elected to the prestigious Royal Society may have had more to do with the influence of his immensely rich scientific pal Henry, Lord Cavendish, discoverer of hydrogen, who took Macie under his wing and gave him free run of his private lab in London.

Cavendish himself had a historical fetish, dressing in clothes of his grandfather's time. He also became enmeshed in one of those "Who did it first?" rows, about the composition of water. It all boiled down to the Royal Society's misdating by a year (late) Cavendish's 1783 paper, "Experiments on Air." And because everybody and his dog was then investigating the same thing, the society's error led to charges that Cavendish had plagiarized the paper from a similar one by James Watt. In the end, Cavendish and Watt settled the dispute amicably over dinner at the Royal Society, and Watt went back to his steam engines at the Birmingham factory that he owned with his partner Matthew Boulton.

In 1777 Boulton had taken on a job applicant named William Murdock, a handy man on the lathe who went on to invent the "sun and planet" gearing system that transformed the back-and-forth thrusts of Watt's steam-pump shafts into the rotary motion that would drive the wheels of the industrial revolution. And then he made that revolution work a little harder by adding a night shift. In 1802, thanks to a process with which Murdock had been experimenting for 11 years, the Boulton and Watt's Soho Engineering Works became the first industrial premises to be lit by Murdock's amazing, if rather smelly, new coal gas.

Well, not that amazing to a Heidelberg chemist who, 52 years later, wanted a flame free of all those malodorous impurities. Robert Bunsen was fascinated by things that gave off fumes, like volcanoes in Iceland or factory chimneys in Germany. Bunsen was especially concerned with devising ways to recycle the heat being lost up the flues at iron foundries. So he was hot stuff on hot stuff. Which is why his name is familiar to any schoolkid who has ever done any lab work: the Bunsen burner that he invented produced a nonluminous coal-gas flame, free of anything except what you chose to burn in it. In fact, Bunsen chose quite a few materials, aided by his sidekick, Gustav Kirchhoff, who was the one who gave him the idea.

VLAD GUZNER

As ever, Kirchhoff got the idea from somebody else: optician Joseph von Fraunhofer, who some decades earlier had been checking his lenses for imperfections using the fine, dark lines he saw in the rainbow of colors that appeared when he passed light through a prism; flaws made the lines wavy or smeared. Kirchhoff and Bunsen chose the Bunsen burner as their light source and started burning everything. The upshot of all this conflagration was the discovery, among other things, of cesium and rubidium. Today we call what they were up to "spectroscopy." You pass the light from a burning substance through a prism, and you see dark lines in the resulting spectrum at a set of frequencies (or colors) unique to the stuff being burned. Look up the lines in your tables, and you know what the material is. If they're not in there, you've found something new. And all you need to perform this trick is a tiny amount of the material you want to identify.

Evolution has made us the only animal with a conscious appreciation of its own past.

In 1864 this last fact excited the Brit Henry Sorby, who traveled everywhere with his mother and who was a freak for the very small. Sorby had pioneered the technique of slicing rocks so thin that you could read a newspaper through them; he then subjected them to microscopic examination to see how they had been formed. As soon as he found out what was going on at Bunsen's lab in Heidelberg, Sorby broadened his field by sticking a spectroscope on the end of his microscope and analyzing the microconstituents of everything from poison chemicals to autumn leaves. It was while peering at the latter that Sorby found

Continued on page 114

Wonders, *continued from page 112*

lion people in South Africa, two thirds of them urban and one in seven of them white. By a 1995 survey, four million of the nation's seven million dwellings are grossly deficient, lacking running water and electrical power. About 99.9 percent of the homes of whites have piped water, but a modest majority of nonwhite houses, most of them rural, need to fetch water daily. Seventy percent of white homes have home telephones; fewer than 1 percent of the black ones do.

In this lopsided country, the digital global village lives side by side with the impoverished local village. Around Alice it is not uncommon to see a woman carrying an auto battery on her head emerge from the BP station. She is not helping out a stranded car; she is carrying a charged battery to an unelectrified home, where it will run a small black-and-white television for a few evenings' entertainment. A tall new mast on the ridge behind Alice promises vast bandwidth to come, a bonanza of bits for the roomful of PCs at Fort Hare.

We are overjoyed that the petty apartheid of public humiliation and overt disrespect has gone from public view. It is Grand Apartheid, the asymmetrical economic and social privation of a landless and unserved majority, that remains a primary challenge for this energetic country, blessed with resources and watched by the eyes of the world.

The technology that documents South Africa's asymmetries also holds the potential to restore some balance. Far from little Alice, the express highways stretch uncrowded, their fast motorists fueled mostly by coal dug by the miners of Natal. Coal is converted into gasoline in the world's only commercial fuel-synthesis program, developed to escape sanctions on imported oil. Modest offshore finds of gas and oil now augment the miners' work. High-power lines abound, feeding cities and industry, trickling off a little electricity to run security lights in the villages they pass.

The rich mines that still earn most of the country's foreign exchange by winning gold, platinum metals and diamonds are under rapid computerization. Sweaty workers deep underground will carry laptop computers that map the three-dimensional volume of the mine for quick and precise reference amid the very rock. It is now possible to map and monitor the actual distribution of ore, a promise of great economy in labor and life. Miners need no longer blindly excavate too-large chambers while the data they need languish in aging ledgers and drawings far above.

History issues no warranties. But the broken symmetry of human beings is here under restoration—more slowly than we might hope, but more easily than we might have expected. The symmetry of this rainbow nation with its optimistic, six-colored symmetrical flag will grow before us all. Travelers who yearn for new sights would do well to visit South Africa, a special zone for wide-open nature and among humans, a Zone of Hope. SA

Connections, *continued from page 113*

what makes them go russet: carotene, the pigment responsible for the vivid coloration of nearly every red-yellow-orange living thing.

Then, in 1876, Franz Boll, a German professor studying frog retinas in Rome, came across that same material when he discovered the visual pigment that enables the eye to see in both bright and dim light. Boll found that bright light bleached light-sensitive "rods" in the retina from red-purple to orange and finally to white. Further examination revealed that the substance that reverses the process when the light level drops again was a form of carotene. Meanwhile Boll visited Berlin, where he explained his work to various scientific-establishment godfathers, including Ernst Pringsheim.

Radiation physics was Pringsheim's particular line—infrared radiation in very particular. For the investigation of infrared rays, he developed a special version of the radiometer, an instrument for measuring radiant energy. The radiometer (today a toy known as a light-mill) had been invented by the eminent Victorian sage and experimenter Sir William Crookes. It consisted of four tiny vanes, each lampblacked on one side, attached to crossed arms that were delicately balanced atop a steel spindle resting in a cup; the whole was encased in a glass vessel that had been pumped out to a high vacuum. When a light was brought close to the little gizmo, it revolved, a behavior that Crookes (and most others, including Pringsheim) attributed to particles of light hitting the black vanes. Wrong. As was embarrassingly revealed by a British expert on flow called Osborne Reynolds. What was really happening was that the blackened side of the vanes heated up, causing tiny amounts of gas trapped in the pith to expand and leak out. It was this escaping gas, and not the light, that was doing the pushing. Infrared faces all around.

Crookes, unperturbed, was busy with other inquiries. Apart from inventing the cathode-ray tube and being elected president of the Royal Society, Crookes hired himself out as a freelance chemistry consultant; after all, he had 10 children to support. Crookes also had another, less public side to his character. He got his kicks from a ghost, name of Katie King. This lady would appear at seances, where she was photographed arm in arm with the infatuated inventor (who also frequently witnessed other paranormalities, such as self-playing accordions and self-levitating water jugs).

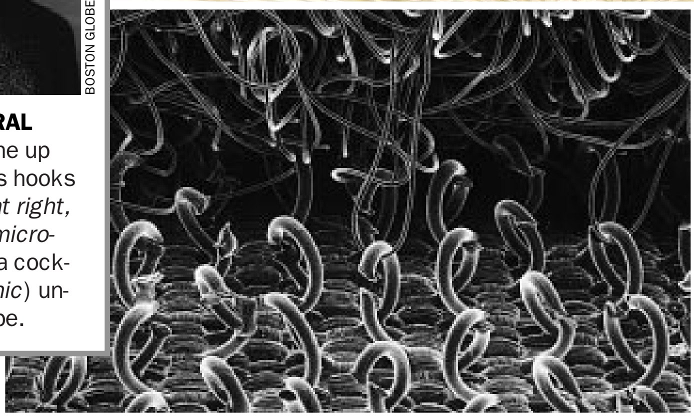
Now, Cookes's fascination with spiritualism was shared by many of his contemporaries, including a young man whose writings on the subject were quite well known. Less so was his other principal area of interest. Alfred Russel Wallace had spent several years in the Malay Archipelago, where, among other pursuits, he identified a peculiar dividing line; to the east and west of that line, there appeared to be species entirely unrelated to one another. As part of his investigations into this unusual phenomenon, he formulated a theory of life that would have put him on the scientific front page, but for the deferential nature of his character. He let himself be persuaded to allow another naturalist, who had come to the same conclusions, read a paper in their joint names at the London Linnean Society, and then publish their thesis as a book. The publication shook the world of natural history to its roots and carried only the other guy's name.

Which is why my opening Smithsonian thoughts about evolution were "Darwinian" and not "Wallacean." And also why I kicked off talking about James Macie. He was the fellow who left the endowment that founded the Smithsonian and forever recorded his proud sense of history; the family name Macie adopted upon his ducal father's death was Smithson. ■

UNZIPPING VELCRO

BOSTON GLOBE PHOTO

GEORGE DE MESTRAL
This Swiss engineer came up with the idea for Velcro's hooks and loops (*photograph at right, taken with an electron microscope*) after examining a cocklebur (*background graphic*) under an optical microscope.



DEE BREGER *Lamont-Doherty Earth Observatory*

by Martin I. Jacobs

Velcro draws its trademarked name from a contraction of the French words for "velvet" and "hook," *velours* and *crochet.* Yet this product is one of those few human designs deliberately modeled after natural structures. (Barbed wire, from Osage orange thorns, and chain saws, from the teeth of beetle grubs, are others.) George de Mestral, a Swiss engineer who died in 1990, had the idea for what became Velcro after pulling cockleburs from his trousers and his dog's hair one day in the early 1940s. An examination of the burrs under a microscope revealed arrays of tiny hooks that would attach to anything looplike. A prickly fruit thus became the inspiration for the nylon hooks and loops that have been used since the 1950s as universal fasteners for everything from disposable diapers to armor for troop carriers.

The strength afforded by attaching miniature rows of hooks and loops, each from 15 thousandths to 100 thousandths of an inch high, is formidable. A two-inch-square piece may contain 3,000 hooks and loops (although only one third may be engaged). It can support the weight of a 175-pound person hanging on a wall. Hooks and loops do detach with less force when pulled at an oblique angle. The diagonal tugging draws against only a single row rather than the entire complement of hooks and loops at once. This smaller amount of force—one to four pounds for a piece of Velcro one inch wide—is sufficient to disconnect one row and then another and so on, producing the familiar ripping sound.

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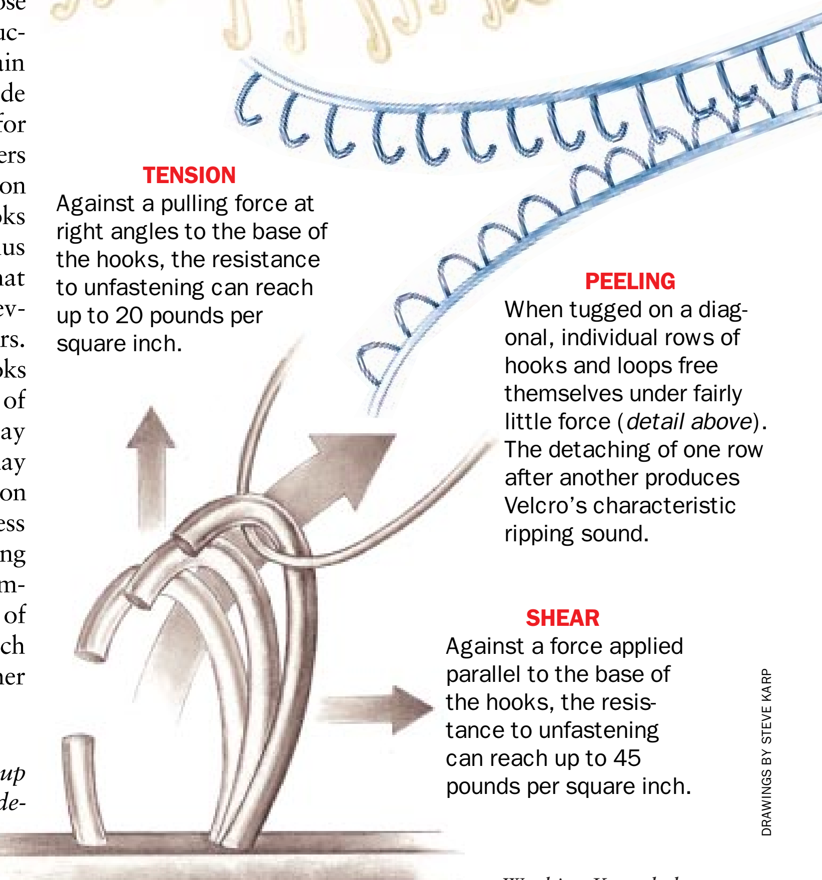

TENSION
Against a pulling force at right angles to the base of the hooks, the resistance to unfastening can reach up to 20 pounds per square inch.

PEELING
When tugged on a diagonal, individual rows of hooks and loops free themselves under fairly little force (*detail above*). The detaching of one row after another produces Velcro's characteristic ripping sound.

SHEAR
Against a force applied parallel to the base of the hooks, the resistance to unfastening can reach up to 45 pounds per square inch.

DRAWINGS BY STEVE KARP