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SOLAR SECRETS
OBSERVATORY IN SPACE WATCHES AND LISTENS TO THE SUN'S CYCLES

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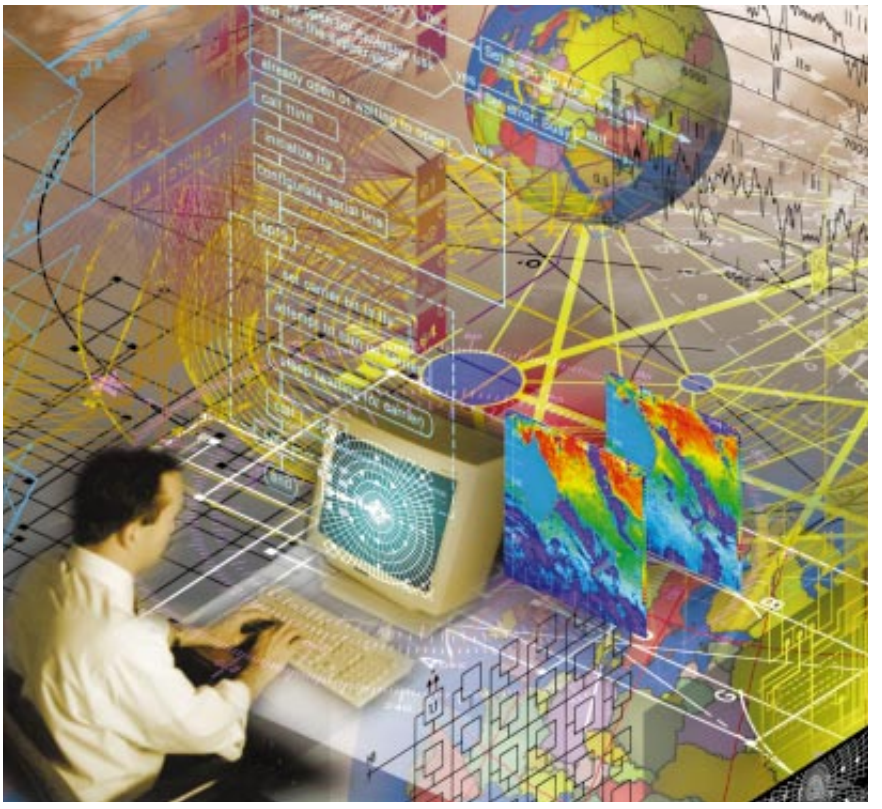

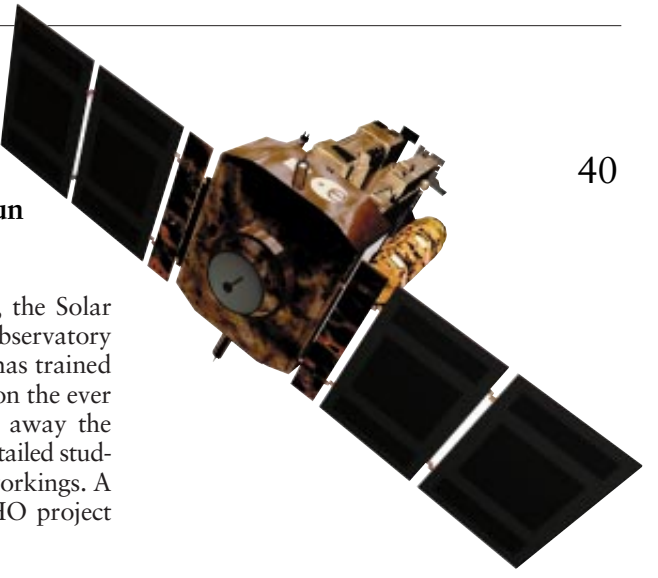

About the Cover

The oceans are rising, but it remains hard to predict how fast. Even much higher seas will not necessarily drown coastal settlements, because the land also rises and falls at varying rates. Image by Slim Films.

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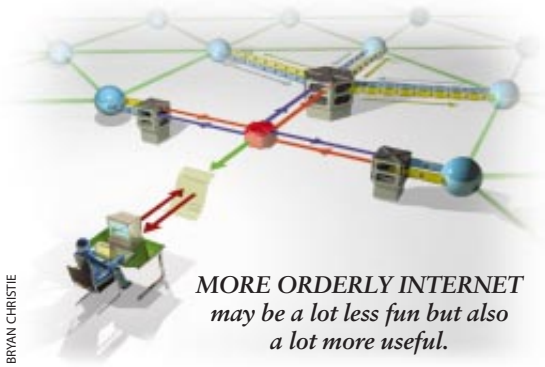
FROM THE EDITORS

Civilizing the Internet

Conan the Librarian"? No, that doesn't fit the profile. Librarians are mousy, bespectacled fussbudgets, as faintly musty as the books they curate, at least in the popular stereotype. They certainly aren't the sort who should be trying to conquer a bold new frontier. For that job, one wants fearlessly independent explorers and tough, two-fisted cowboys in the John Wayne mold, fair but quick on the draw. You can count on them to tame badlands and carve out a safe niche for the simple, civilized townsfolk.



BRYAN CHRISTIE

MORE ORDERLY INTERNET may be a lot less fun but also a lot more useful.

Cowboys, in the persons of hackers, crackers and other members of the plugged-in elite, have been among the most colorful occupants of cyberspace ever since people other than researchers and defense wonks began roaming the Internet. With the invention of e-mail, and later of the World Wide Web, the value of networked communications on a global scale became clear and attractive to masses of humanity. Many of the Net's early denizens, however, who love the terrain's wild beauties, are not happy to see the throngs of newcomers arriving in their Winnebagos. They correctly see the encroachment of civilization as spelling the end of their fun.

True, the crazy profusion of new Web sites on every possible topic has only added to the wonderful clutter. But whole industries are now getting ported to the Net. Kids use it to do homework. People rely on it for their jobs. And so at some point, the Internet has to stop looking like the world's largest rummage sale.

For taming this particular frontier, the right people *are* librarians, not cowboys. The Internet is made of information, and nobody knows more about how to order information than librarians, who have been pondering that problem for thousands of years. Associate editor Gary Stix has assembled a lineup of experts who, beginning on page 49, suggest some of the ways in which technology can rein in the chaos.

Shortly before this issue went to press, we received the sad news of the death of Carl Sagan. I don't think there can be a writer or reader of prose about science who does not feel his passing as a personal loss. For those of us who had the opportunity to work with him, the pain is all the sharper. In person, on camera and through the page, he was an inspiration. We offer a fuller appreciation of the man on our Web site (http://www.sciam.com/explorations/). Good-bye, Carl; we miss you already.

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LETTERS TO THE EDITORS

INTERACTION-FREE MEASUREMENTS

A question immediately sprang to mind after reading "Quantum Seeing in the Dark," by Paul Kwiat, Harald Weinfurter and Anton Zeilinger [November]: Don't the findings presented in the article contradict the Heisenberg uncertainty principle? I always thought the uncertainty principle meant that, at an atomic level, it is impossible to measure something without interacting with it. Yet the authors' clever techniques seem to get around this theory.

PHILIP SLACK
Bolinas, Calif.

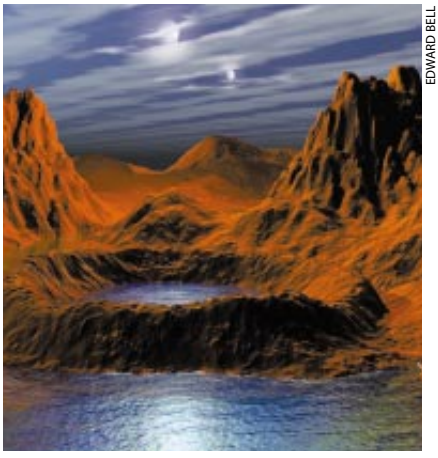
Kwiat, Weinfurter and Zeilinger write that interaction-free measurements can take place when a mirror "pebble" is placed in a photon's path during an Elitzur-Vaidman experiment. It may be true that the photon received at the detector did not reflect off the pebble, but it is not accurate to say that there has been no interaction. The interaction is evidenced by the collapse of the photon's wave function when it begins behaving like a particle. In effect, the pebble takes a measurement of the photon.

JOLAINE ANTONIO
Calgary, Alberta

The authors reply:

Slack's suggestion that interaction-free measurements seem to violate Heisenberg's uncertainty principle is insightful: we have consulted with other experts in our field, but no completely satisfactory answer has been forthcoming—a sign that it is a very interesting question. We all believe there is no conflict with the uncertainty principle, but the precise mechanism by which this comes about is less than obvious. One hint is that the interaction-free measurements work efficiently only if the mirror "pebble" starts off localized to a region about the same size as the interrogating light beam.

Antonio is correct that for the detector to be able to receive the photon, there must be the possibility that the pebble can absorb the photon. But as quantum physicists, we should restrict our statements to observable quantities. In this sense there is no interaction, because we do not observe any change in the state of the pebble—not even when the pebble is a quantum object—whenever the interaction-free measurement succeeds. Intuitively, this fact is clear because the photon took the path without the pebble.



EDWARD BELL

Mars in the rainy season

A HISTORY LESSON

In an article entitled "Alpine Glacial Features of Mars," published in the July 6, 1973, issue of the journal *Nature,* four Garden City High School students—Jeff Kasold, Marilyn Suda, Peter Metcalf and Stephen Caccamo—and I described arêtes (sharp, glaciated ridges), cirques (glacially carved, semicircular features), U-shaped valleys and horns (glaciated mountain peaks) on the surface of Mars. These formations are also clearly depicted in the enhanced NASA photograph of glaciated mountain features included in the article "Global Climatic Change on Mars," by Jeffrey S. Kargel and Robert G. Strom [November]. Our article from 24 years ago also addressed climatic change on Mars: we wrote that "the alpine glaciers responsible for the erosion of the features described herein could have recently disappeared because of a warming trend that did not eliminate the polar ice caps."

JULIAN KANE
Hofstra University

Kargel replies:

My hat goes off to Kane and his coauthors for having pointed out long ago that there are features on Mars that can be interpreted as being of glacial origin. I was not previously aware of this interesting paper. In my opinion, the areas of Mars studied by Kane's group, Cavi Angusti and Cavi Frigores, were formed by erosion because of sublimation of ice rather than the direct action of glaciers, as Kane and his colleagues suggest. The fact is, planetary scientists do not know for sure what these fascinating features are. We await what we hope will be spectacular images from the Mars Global Surveyor.

DYSLEXIA

I was very interested by Sally E. Shaywitz's article on dyslexia [November]. I wonder if she has determined whether people born deaf were subject to the same phoneme blockage that she describes and whether children learning to read Chinese—in which sounds are not represented by characters—have similar problems.

DEAN O. CLIVER
University of California at Davis

Shaywitz replies:

People born deaf do experience more difficulties in learning to read than do nonimpaired people. Congenitally deaf people do use phonetic coding during reading: they show sensitivity to the phonetic structure of words, access phonological information rapidly and can even indicate when nonsense words "sound" like real words. Such awareness of phonology could be acquired from experiences in lip reading or making articulatory gestures in speaking.

Contrary to many assumptions, most Chinese characters have a phonetic component. Estimates suggest that as many as 50 percent of Chinese characters depend on the phonetic component for word identification. Furthermore, in Chinese, just as in English, good readers can be distinguished from poor readers based on their relative efficiency of phonologic processing.

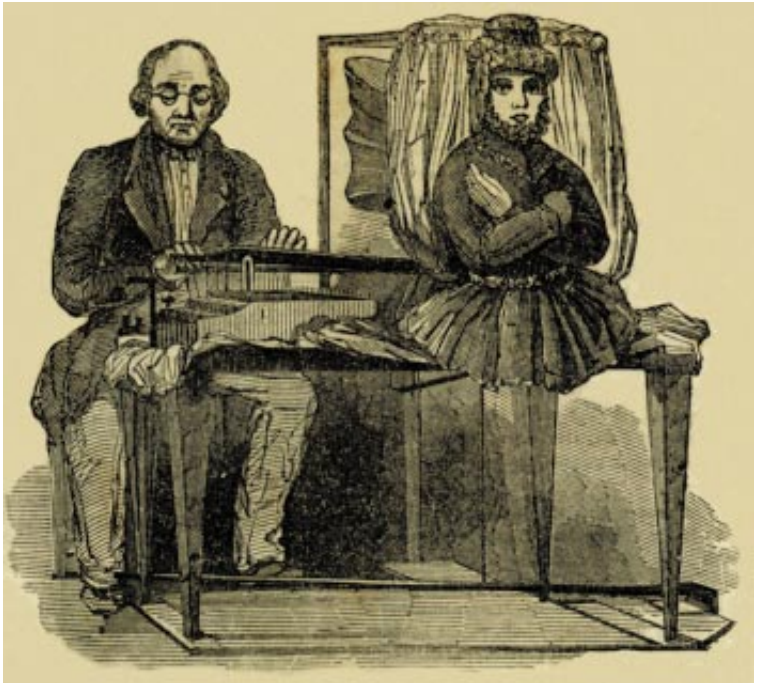
Letters may be edited for length and clarity. Because of the considerable volume of mail received, we cannot answer all correspondence.

50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

MARCH 1947

The problem of giving automatically reproduced form letters that individually typed look has found a solution in a device called the Flexowriter Automatic Letter Writer. Operated by means of a perforated paper tape $^{7}/_{8}$-inch wide, it consists of an electric typewriter, an automatic perforator and an automatic writer. In preparing the form letter, the operator types manually the date and the name and address of the recipient. Then a switch is thrown, and the automatic writer takes over, controlled by the previously prepared tape."



The Speaking Automaton

"Fouling of lenses and other optical parts of instruments used in the tropics was until recently a serious problem, particularly in the Pacific areas. The way this hindrance was checked has now been revealed. Metal foil is treated with radium compounds to give it an alpha-ray emission equivalent to about 15 micrograms of radium per square inch, and narrow strips of the foil are mounted around the lenses."

MARCH 1897

In a recent lecture before the American Geographical Society, Mr. Heli Chatelain made some very startling statements regarding the extent and horrors of the slave trade in Africa. Let no one suppose that the slave trade in Africa is a thing of the past. In this great continent, which the European powers have recently partitioned among themselves, it still reigns supreme. 'The open sore of the world,' as Livingstone termed the internal and truly infernal slave trade of Africa, is still running as offensively as ever. Among 200,000,000 Africans, 50,000,000 are slaves. In the islands of Zanzibar and Pemba alone, which are entirely governed by Great Britain, 260,000 are held in bondage. For each slave that reaches his final destination, eight or nine are said to perish during the journey, so that the supply of 7,000 slaves annually smuggled into Zanzibar represents the murdering of some 60,000."

"Honey bees gather, with great avidity, the maple sap from troughs in the 'sugar bush.' The bees' labors are but half performed when the liquid has been collected; it must be 'boiled down,' so to speak, to reduce it to keeping consistency, and the wings are the only means by which that toilsome process is performed. As in the absence of blotting paper you sometimes blow upon the newly written page to promote evaporation, so by the vibrations of their wings the bees pass air currents over the honey to accomplish the same result."

MARCH 1847

Among all the new inventions and discoveries that are astonishing the world, we have heard of none which promises to be more useful and acceptable, at least to ladies, than 'The Essence of Coffee,' which is now offered to the lovers of that beverage. It is the genuine stuff, put up in bottles, at a low price. You have only to put a tea-spoon full into a cup of water containing the usual complement of sugar and milk, and you have a cup of superior coffee without further trouble."

"Caoutchouc (india rubber) becoming very smooth and viscous by the action of fire has been proposed by an eminent English dentist, as an excellent remedy, for filling hollow teeth, and alleviating the toothache proceeding from that defect. A piece of caoutchouc is to be melted at the flame of a candle, and pressed while warm into the hollow tooth. In consequence of the viscosity and adhesiveness of the caoutchouc, the air is completely prevented from coming into contact with the denuded nerve."

"Our engraving is a representation of Professor Faber's celebrated *Speaking Machine,* which is now in England. The Automaton is a figure like a Turk, the size of life. Connected with it is a series of keys, or rather pedals; and by pressing these down, in various combinations, articulate sounds are produced. We tried it with the following words, which were produced by Mr. Faber as fast as we suggested them: 'Philadelphia,' 'tres bien,' and 'God bless the Queen,' which last sentence it concluded with a hurrah and then laughed loudly. The chief organs of articulation are framed of India rubber, and a pair of bellows are substituted for the lungs."

NEWS AND ANALYSIS

IN FOCUS

COMPUTER BOMBS

Scientists debate U.S. plans for "virtual testing" of nuclear weapons

To those who handle nuclear weapons—and to anyone within several hundred kilometers of them—two questions are paramount. First, will a warhead, having been trucked around from one stockpile to another for 20 years, go off accidentally? Second, will it explode as intended when used in anger? The physicists at the U.S. Department of Energy's weapons laboratories responsible for certifying that hydrogen bombs are both safe and reliable have not been able, since 1992, to check their calculations by either damaging or detonating one underground. If the Senate ratifies, and India reverses its opposition to, the Comprehensive Test Ban Treaty signed by the U.S. last September, they may never be able to do so again. How will they know for certain?

The DOE's answer, a plan called science-based stockpile stewardship, is to use the fastest supercomputers yet devised to simulate nuclear explosions along with all the important changes that occur to weapons as they age. The plan has stirred vigorous debate among arms-control advocates, military strategists and, most recently, university researchers, over whether the approach is cost-effective, feasible and wise.

The DOE expects that stockpile stewardship will cost about $4 billion a year—$400 million more than the DOE's annual weapons budget during the cold war, according to Christopher E. Paine, a nuclear arms analyst with the Natural Resources Defense Council. The agency intends to spend more than $2 billion on new experimental instruments, including the National Ignition Facility. These devices will attempt, using lasers, x-rays and electrical pulses, to measure how bomb components (except for the radioactive pits) behave in conditions similar to those in a nuclear explosion. Another $1 billion or so will go to the Accelerated Strategic Computing Initiative (ASCI) to buy three supercomputers, each of a different design, and to develop computer models based on, and tested against, experimental data. "This level of simulation requires high-performance computing far beyond our current

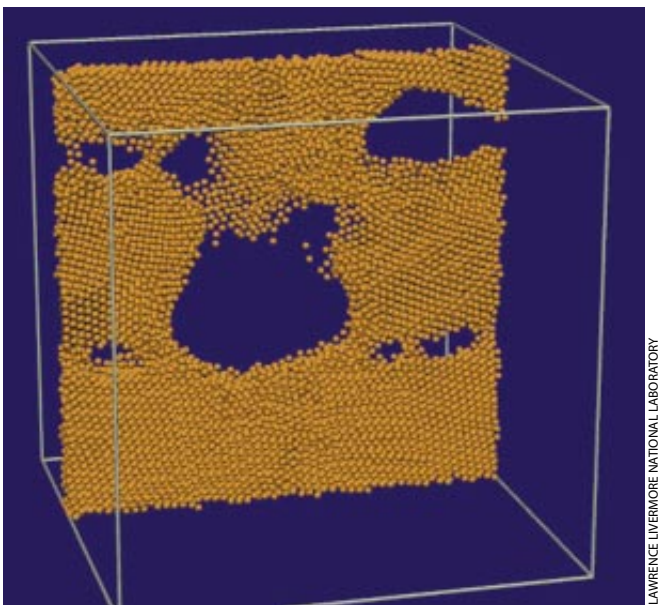
CORBIS-BETTMANN

NUCLEAR WARHEAD TESTS, such as this 1951 blast in Nevada, may be replaced with supercomputer simulations.

level," the ASCI program plan asserts, because "these applications will integrate 3-D capability, finer spatial resolution and more accurate and robust physics."

Paine and others question that necessity. "Do we really need three machines?" he asks. "After all, the labs, using their existing computers and software, have certified that the nuclear stockpile is currently safe. ASCI presumes that we will detect problems never seen before that require much higher simulation capabilities to resolve. That is unsubstantiated. In fact, the data suggest that weapons become safer with age." They also grow less likely to detonate on command, however.

Robert B. Laughlin, a professor at Stanford University who has worked on bomb-related physics at Lawrence Livermore National Laboratory since 1981, worries that "computer programs can only simulate the stuff you know. Suppose you left a personal computer out in the rain for a year. Is there a program that can tell you whether it will still run? Of course not—it all depends on what happened to it." Likewise with nuclear warheads, he says: "Changes happen over time that you are not sure how to measure. Some matter, some don't. The problem is the things you didn't think to put in the simulation."



LAWRENCE LIVERMORE NATIONAL LABORATORY

SIMULATION OF METAL EXPOSED TO SHOCK WAVES, showing the growth of gaps, is a key element of the DOE stockpile stewardship.

Indeed, skeptics note, some previous attempts to simulate very complex systems—such as the behavior of oil surfactants, the Ariane 5 rocket and plasma fusion reactors—failed to forecast the outcome of field tests, at great cost to those who relied on the simulations. The software codes developed since the 1950s to predict whether bombs will mushroom or fizzle "are full of adjustable parameters that have been fit to [underground test] data," Laughlin reports. "If the new codes don't match the old ones that correctly predicted experiment results"—and Laughlin bets that they won't—"the designers will simply throw them out."

To minimize the uncertainty in its models, the DOE is looking to academic engineers for help. In December the agency offered to sponsor two to five university research centers with up to $5 million a year and supercomputer access for each. "The goal isn't to get them to do our job," says Richard W. Watson, who is managing the program at Lawrence Livermore, "but to establish in the scientific community confidence in simulation as a valid third arm of science alongside theory and experiment." Although researchers will be allowed to publish all their work—none will be classified—the DOE is asking specifically for projects that focus on areas, such as material stress and the interior of stars, that are not too distant from its weapons work. (Most academic institutions generally forbid their staff from conducting weapons and other classified research on university time.)

Most schools have responded enthusiastically—of 10 contacted for this article, all planned to submit preliminary proposals. Some of the eagerness may reflect an imminent consolidation of National Science Foundation funding to the four federal supercomputing centers. "If one center were cut off, ASCI would be there," concedes Malvin H. Kalos, director of the supercomputer center at Cornell University. But many scientists welcome the intellectual challenge as well. "This is exciting because the scale of simulation they want is mind-blowing," comments Arvind, a professor of computer science at the Massachusetts Institute of Technology. Stitching chemical models together with physical and mechanical models to simulate, from first principles, an entire combustion chamber or star (or H-bomb) "will require a lot of difficult fundamental research. But these are absolutely tractable problems," he says. "This is not at all like Star Wars. Even if we cannot achieve the ultimate goal, every inch of the way we will be learning things that will have dramatic positive side effects."

On the whole, according to Howard K. Birnbaum of the University of Illinois, ASCI is "a great advance over stewardship based on physical testing of weapons. Will these new computational approaches be used to design new weapons?" he asks. "Perhaps they will. But it is unrealistic to expect that these will achieve 'weapons' status based on simulation alone."

There is debate on that point—and its implications for the test ban. "The labs, for example, have used their existing computers to modify the B-61 bomb to fit a new case that will burrow into the ground before detonating," Paine points out. "They are going to put this into the stockpile without ever testing it." Pakistan or India, he suggests, could be forgiven for suspecting that the five major nuclear powers, which asserted for years that testing was critical to maintaining deterrence, have now advanced beyond the need for nuclear tests. All the more reason, perhaps, for them to oppose the treaty.

Finally, there is the matter of proliferation. "With underground testing, the U.S. could keep the lid on most of the technical information," Paine notes. Information technology, in contrast, flows more easily from one country to another. Fortunately, observes Srinivas Aluru of New Mexico State University, "it is virtually impossible to create meaningful simulation systems without access to data" from real explosions. "But if the Manhattan Project taught us anything, it is that no technology remains a secret very long," says Michael Veiluva of the Western States Legal Foundation. "In 20 or 30 years, when five or 10 industrial states may have access to this technology, one can envision a world in which nobody is exploding nuclear bombs but in which lots of states are designing and testing new weapons, with horrific verification problems." Perhaps that safety question should be simulated as well.

—W. Wayt Gibbs in San Francisco

NEUROBIOLOGY

SUICIDE PREVENTION

Biochemistry offers some new clues

A number of known factors can, under certain circumstances, compel someone to attempt suicide. Mental illness, family history and life events often contribute significantly. Mere opportunity, too, increases the risk: for every firearm death attributed to self-protection, there are some 37 suicides. Even so, individual suicides are exceedingly difficult to predict. Indeed, a recent survey showed that although roughly half of all suicide victims visit clinicians during the 90 days preceding their death, only a quarter receive any psychiatric treatment.

To remedy that situation—and prevent tens of thousands of deaths each year—neuroscientists are now actively searching for the biological triggers behind suicidal behavior. So far their findings point to mixed-up chemical messengers in the prefrontal cortex, an area of the brain involved in processing emotions and inhibitions. "New research indicates that suicide is not a normal response to severe distress," says J. John Mann of Columbia University and the New York State Psychiatric Institute, "but [is] the response of a person with a vulnerability to act on powerful feelings."

Mann has focused his studies on the neurotransmitter serotonin. Scientists have long known that monkeys with depleted serotonin metabolites in their spinal fluid tend to be more impulsive and aggressive. In 1976 it was first demonstrated that depressed suicide attempters had similarly low levels. More recently, Mann and his colleague Kevin M. Malone reported that these levels are in fact lowest in people who make the most lethal attempts to end their life. From these facts, the researchers guess that serotonin signaling in the brains of suicidal individuals is inadequate.

Testing that idea is somewhat difficult. "The technology for looking at serotonin activity directly in the living brain is still under development," Mann says.

FIELD NOTES

Amphibians On-line

It's no secret why conferences are typically held in places like New Orleans or Sun Valley. In between the long talks, people want to wander around the French Quarter or take a few runs down the slope. So, of course, I'm curious to check out the "Field Trips" listing in the guide to the third annual meeting of the North American Amphibian Monitoring Project (NAAMP). I'm a bit shocked to see "Exotic Dancers" as an option, but I take a peek anyway. Dancing frogs? Where am I?

This winter the NAAMP conference was held in cyberspace—at http://www.im.nbs.gov/naamp3/naamp3.html, to be precise. Meetings began in November 1996 and ended in mid-February 1997. In addition to the unusual field trips (another favorite: a virtual voyage to see and hear the frogs of Kenya's Arabuko-Sokoke Forest at http://www.calacademy.org/research/herpetology/frogs/list.html), the conference offered some 50 papers on topics that included aquatic sampling techniques and frog-calling surveys.

Sam Droege of the U.S. Geological Service Biological Resources Division headed the online conference—seemingly the first one of this size to have been held on the World Wide Web. Droege is pleased with the response. "We have reached a much wider audience than [we did in] our previous meetings," he writes by e-mail. "Folks can attend when they like, can look closely at the data and statements made, can respond publicly (or privately) to the author if they disagree or want further details." Papers from the meeting will be archived on the Web site, but the discussion groups will become inactive after February 14.

DEFORMED AMPHIBIANS have been seen more frequently in the past year.

MINNESOTA POLLUTION CONTROL AGENCY

Despite the various humorous diversions, much of the business conducted was quite serious: several reports presented findings of exceptionally high numbers of malformed amphibians. David M. Hoppe of the University of Minnesota at Morris points to what he calls a "recent, rapid-onset phenomenon" of limb deformities—which include missing or extra legs and digits. In his paper "Historical Observations and Recent Species Diversity of Deformed Anurans in Minnesota," Hoppe notes that in the course of handling thousands of frogs between 1975 and 1995, he saw only two with visible limb defects; in 1996 alone he saw more than 200. Hoppe speculates that an environmental agent in the water where the creatures breed could be the cause.

Stanley K. Sessions of Hartwick College has also encountered an unusually high frequency of amphibian limb abnormalities, in particular, among Pacific tree frogs and long-toed salamanders in northern California. In his NAAMP paper, Sessions argues that parasitic flatworms known as trematodes triggered the limb defects. He also comments that the infestation by trematodes could be linked to human-caused environmental problems.

Just as reporters do at any conference, I interview some of the participants. Sessions e-mails me from Costa Rica, where he is currently doing fieldwork. He has mixed feelings about the cyberconference—although he is pleased with how easy and inexpensive it was to participate, he has been disappointed by a lack of interaction with other scientists during the meeting. "A cyberconference such as this one is no substitute for a conventional conference, because the important face-to-face social interactions are not happening," he writes. So, alas, the next NAAMP conference will be more conventional, without any dancing frogs.

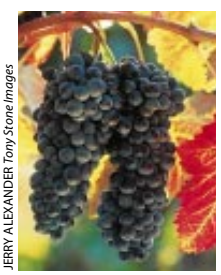
—Sasha Nemecek

IN BRIEF

Clues from Scleroderma
New results have shed light on why the body sometimes attacks its own tissues: Antony Rosen and colleagues at Johns Hopkins University developed novel means for tracking the biochemistry behind scleroderma, an autoimmune disorder that damages the arteries, joints and internal organs. They found that toxic oxygen products, caused by an irregular blood supply, break apart common tissue molecules when high levels of metals are present. The fragmented molecules then present unfamiliar facades to the immune system, which produces antibodies against them.

Rapid-Fire Gamma Rays
Four gamma-ray bursts, recorded by NASA instruments over two days last October, have shot down several key theories. Astrophysicists long thought that whatever caused the high-energy events, which usually occur at random throughout the sky, might well be destroyed in the making. But this new series appeared too quickly, and too close together, to support that idea.

Grape Expectations
Scientists grappling for ways to prevent cancer have found new hope in the humble grape. John M. Pezzuto and his colleagues at the University of Illinois found that resveratrol, an abundant compound in grape skins, can block an enzyme called cyclooxygenase, which catalyzes the conversion of substances that stimulate tumor growth.


JERRY ALEXANDER *Tony Stone Images*

Cautioned by Chaos
Ecologists are learning a little mathematics of late. A group led by R. A. Desharnais of California State University at Los Angeles used chaos theory to build a model of population dynamics among flour beetles. The model forecast chaotic fluctuations in the beetle's numbers after a rise in adult mortality—a transition later confirmed in laboratory trials. Based on this finding, the authors caution ecologists managing large populations: the slightest intervention can topple a population from stability.


ABC AJANSI *Gamma Liaison*

***SUICIDE** is currently the ninth leading cause of death among adults and third among adolescents.*

He has, however, devised an approximation technique: he made positron emission tomographic (PET) scans of patients shortly after they took the serotonin-releasing compound fenfluramine. In healthy adults the drug increased metabolic activity in the prefrontal cortex. But as expected, this change was minimal in depressed patients.

Mann's colleague Victoria Arango has found additional evidence linking diminished serotonin activity to suicide. It is impossible to measure serotonin levels directly after death because the compound quickly dissipates. So Arango prepared slides of prefrontal cortex—taken from depressed and alcoholic suicide victims—and counted the number of serotonin receptors. Most samples, compared with control subjects, contained more receptors. This was no great surprise. Such a change could represent the body's own efforts to compensate for naturally weak serotonin signals; the more antennae each neuron puts forth, the better its chances for clear communications.

"In alcoholics, however, we found some unexpected results," Arango says. These samples revealed a dearth of serotonin receptors. The shortage may be genetic or developmental and so help predispose someone to alcoholism. Or it may just be yet another of alcohol's many toxic effects, Arango suggests. Whatever the cause, alcoholics, it appears, lack the ability to compensate for weak serotonin signals—a fact that could help explain why suicide rates in this group are astonishingly high. Some 18 percent of alcoholics take their own life, compared with 15 percent of depressed or manic-depressive people and 10 percent of schizophrenics.

Other biochemical abnormalities appear in suicide victims as well. Mary Pacheco of the University of Alabama at Birmingham has developed an assay for studying secondary-messenger systems in postmortem tissues. These systems relay information from a cell's surface to its nucleus, where an appropriate response is generated. "If this communication system does not work well, behavioral responses to the environment, such as emotion and learning, may be affected," Pacheco states.

She found that in depressed suicide victims, one such system, the phosphoinositide system, was impaired by some 30 percent. Further investigation showed that the problem lay in a class of proteins, called G-proteins, that are activated by cell receptors and that are capable of rousing the phosphoinositide system. "If we can find out why the G-protein does not work correctly, it might enable us to develop better therapeutic agents for treating depression," Pacheco adds. Certainly, many people hope she is right. *—Kristin Leutwyler*

NUCLEAR WASTE

NOT IN MY BACKYARD

Could ocean mud trap nuclear waste from old Russian subs?

Disclosures by Russia that it had dumped 16 nuclear reactors from ships and submarines into the Arctic's Kara Sea shocked Western sensibilities a few years ago. And although it never purposefully plunged nuclear reactors into the Pacific, the Soviet navy had routinely disposed of radioactive liquids in those waters. Interestingly, researchers have detected little pollution from these former practices, showing the ocean's resiliency and, perhaps, unique capacity for absorbing radioactive wastes.

Not only do ocean waters dilute such

contaminants, but the fine-grained sediments that accumulate on the bottom of the sea can hold fast to certain radioactive elements, effectively isolating them. That phenomenon has, for example, helped to lessen the environmental injury caused by a B-52 bomber that crashed onto floating ice off Greenland in 1968, dispersing plutonium into shallow coastal waters. Scott W. Fowler and his colleagues at the International Atomic Energy Agency in Monte Carlo summarized the results of years of careful assessment of that accident in a 1994 report: "These studies demonstrated that plutonium…was rapidly bound by the sediments, thus becoming effectively retained in the benthic ecosystem." They noted that "no significant increases in plutonium concentrations were found in either the overlying waters, zooplankton, pelagic fish, sea birds, marine mammals, or the indigenous population."

Thus, it would seem that more careful ocean disposal, if conducted safely, might help ease Russia's radioactive burden. In addition to the many problems threatening Arctic sites, the Pacific naval bases near Vladivostok and on the Kamchatka Peninsula hold radioactive waste in the form of some 50 decommissioned submarines. Since 1993 (the year they first gave a candid account of their dumping activities), the Russians have ceased injecting low-level liquid waste into the Pacific. But with the continuing economic crisis, work on decommissioning submarines and disposing of their wastes proceeds excruciatingly slowly. Less than half the nuclear submarines retired from service in the Soviet Pacific fleet have had their nuclear fuel removed. Fewer still have had their reactor compartments cut out so that the

MIR AGENCY

DECOMMISSIONED RUSSIAN SUBMARINES, many containing nuclear reactors, sit idly in ports, awaiting dismantling.

Slippery When Wet

Some of the very first molecular-scale images of the surface of ice are helping to explain why it is so slick. Michel Van Hove and his colleagues at Lawrence Berkeley National Laboratory used low-energy electron diffraction to depict a thin film of ice deposited on platinum at –183 degrees Celsius. In the resulting image, they found that about half the surface molecules were seemingly invisible.

SOENAR CHAMID *Tony Stone Worldwide*

This absence, Van Hove suggests, occurs because the outermost molecules vibrate more quickly than those underneath—thus keeping the ice's slippery top coat in a constantly moving, quasiliquid state.

Spinning Bits

In the unending quest to build quantum computers, scientists have again come one step closer, creating means for storing information using multiple-pulse magnetic resonance techniques. The method stores bits in atomic spins. Earlier tactics—which included storing bits by way of trapped ions or quantum dots—proved hard in practice: the slightest perturbation brought about decoherence, destroying the data. This new suggestion, put forth by Neil A. Gershenfeld of the Massachusetts Institute of Technology and I. L. Chuang of the University of California at Santa Barbara, however, seems to sidestep those problems.

Breathing an Earful

Zoologists have wondered for some time why, like the blind leading the blind, earless frogs sing. The tiny, yellow creatures, called Panamanian golden frogs, lack both a middle and external ear. So to test the frogs' hearing, Thomas Hetherington and his colleagues at Ohio State University set up speakers in the wild. The frogs turned toward the speakers and actually called out in reply. Hetherington suspects that the animals' lungs, which are close to the skin, act like eardrums—a hint, perhaps, into the evolution of hearing in vertebrates.

Continued on page 24

remaining metal can be used for scrap. Most vessels float tied up in port, patiently awaiting dismantling.

According to Bruce F. Molnia, chief of environmental activities at the U.S. Geological Survey, the only promise of progress in the area comes from a joint Russian-Japanese effort to build a holding barge equipped to concentrate the copious low-level radioactive liquids generated by these submarines. That maneuver should lessen the volume that needs to be stored, but it does not address the fundamental question of what ultimately to do with the resulting radioactive brine. The future disposition of spent fuel and reactor cores is also of great concern, as is the permanent storage of reactor compartments.

Although speedy reprocessing might help alleviate the immediate problems near Vladivostok (reprocessing is done far to the west), it would only create a different set of headaches elsewhere, including toxic solutions loaded with radioactive fission products. One wonders how these liquids would be disposed of.

British and French reprocessing plants resorted to releasing their radioactive effluent into coastal waters, and a recognizable plume containing those contaminants now stretches into the North Atlantic. In fact, measurements in the Kara Sea show the effects of nuclear fuel reprocessing in western Europe (and of atmospheric weapons testing). But, curiously, they do not indicate any regional pollution caused by Russia's nuclear dumping there.

If muddy sediments have indeed helped trap radioactive materials from the reactors discarded in these shallow waters, the notion of using deeper parts of the seabed for long-term disposal of nuclear wastes would seem that much more reasonable. That concept, which calls for encapsulating nuclear wastes and burying them in deep-sea muds, was effectively dropped from worldwide consideration when the U.S. decided to bury its waste on land, naming Yucca Mountain in Nevada as the site for a future nuclear waste repository. But the idea is still alive in the minds of some scientists. Charles D. Hollister of the Woods Hole Oceanographic Institution has been especially vocal in his support for continued study of this option.

One way to evaluate how deep-sea muds sequester radioactive wastes, Hollister contends, is to investigate the effects of certain maritime disasters. At a recent meeting of the American Geophysical Union, he suggested that the accidental sinking of a Soviet ballistic missile submarine in 1986 offers "a very exciting experimental opportunity." After suffering an explosion at sea, that vessel plummeted to the bottom of the deep Atlantic carrying two reactors and 34 nuclear warheads with it. Exploring the wreckage site could determine if mud can indeed trap radioactive substances.

Hollister is not currently advocating the disposal of nuclear waste in the ocean. "It should be illegal to do it until we've studied it," he stated flatly to his audience. But it is clear that he believes parts of the seabed could well serve as nuclear repositories. "It isn't a warm, fuzzy feeling you get about it," he quipped as he expressed his long-held view that burying unwanted nuclear materials in deep-sea muds "is probably the safest thing we can do with them." But with defunct subs and their radioactive wastes continuing to pile up close to town, some residents of Vladivostok might just agree. —*David Schneider*

In Brief, *continued from page 21*

Supersonic Silencer

Dimitri Papamoschou of the University of California at Irvine has invented a technique to eliminate Mach waves, a major source of the exhaust noise created by high-performance jet engines.

TONY STONE WORLDWIDE

This noise has prevented widespread use of supersonic passenger aircraft. Current designs for minimizing noise call for metal shrouds. In contrast, the new method uses no mechanical devices; instead the exhaust is mixed with a flow of air molecules to create a virtual shroud. The flow muffles excessive sounds and, unlike the metal shrouds, has little impact on the engine's overall performance.

FOLLOW-UP

Fasten Your Seat Belts

A panel assembled by the National Research Council has advised designers of the international space station to take extra precaution against a range of road hazards, including falling rocks, meteoroids and other space debris. Because this 460-ton space Winnebago will be larger than a football field when it is completed and spend some 15 years in orbit, it is very likely to encounter collisions with the debris, the panel of experts says. Shields—made primarily from giant aluminum bumpers—will protect those modules housing astronauts and critical equipment. (See June 1996, page 64.)

Bug Off

Plants, it appears, can act on the fly—and, well, on other foraging pests. P. W. Pare and James H. Tumlinson of the U.S. Department of Agriculture used radioactive carbon for tracking how cotton plants fend off feeding beet armyworms. They found that, induced by substances in the bug's spit, damaged cotton leaves could synthesize from scratch several volatile compounds known to attract the beet armyworm's enemies. Previously, researchers thought that plants manufactured such repellents from premade ingredients stored in their leaves. (See March 1993, page 100.) *—Kristin Leutwyler*

SA

EVOLUTIONARY BIOLOGY

WHERE DO TURTLES GO?

Turtles may not be the "living fossils" they were thought to be

The first time that paleontologist Olivier Rieppel presented his findings on turtles, before 200 people at a meeting last year sponsored by the Society of Vertebrate Paleontology, a presenter prefaced his talk with, "And now everybody may hiss as much as you like." Venomous commentary did not ensue, but a bit of a murmur must have lingered as Rieppel announced that he believed turtles had been classified in the wrong branch of the reptile family tree.

Rieppel, from the Field Museum in Chicago, and Ph.D. student Michael deBraga of Erindale College in Ontario, knew they were proposing a maverick theory. Turtles had long been deemed to be "living fossils," the only surviving member of a primitive reptile subclass, the anapsids, which originated some 325 million years ago in the Paleozoic era. Now these two researchers were proposing that turtles belonged to the modern reptilian lot—the diapsids, which first emerged about 230 million years ago in the Triassic and include present-day lizards, snakes and crocodiles.

The team came to that conclusion using cladistics, a generally well accepted way of figuring evolutionary relations. It relies on the muddy task of identifying so-called homologous characteristics shared by certain groups. But they decided to challenge the long-held belief that anapsid and diapsid skulls are the ultimate defining characteristics. So unlike earlier cladistic modeling of turtles, Rieppel and deBraga examined numerous features and included taxa from outside the Paleozoic. DeBraga says, "We decided to look at everything…[to give turtles] a whole new approach, and lo and behold look at what happens."

Their work hinged on computer analyses of huge sets of data. Although more data would seem to buttress the validity of their work, it intensified the predicament of deciding which characteristics are appropriate. Among the 168 characteristics studied, what really convinced Rieppel that turtles are diapsids were their ankles. He says the morphological similarity among the ankles of turtles, lizards and the tuatara, a lizard from New Zealand, is too strong to be denied.

Although some of the morphological evidence presented is quite sound, Rieppel and deBraga hear some hissing. Gene Gaffney, curator of vertebrate paleontology at the American Museum of Natural History (and orator of the snide opening statement before Rieppel's talk), believes the "evidence presented was somewhat skewed." He notes that some of the characteristics used in the study—bone ossification, for one—are not particularly reliable for all amniotes (reptiles, birds, mammals). Other critics assert that comparing different groups can spawn erroneous, or at least highly ques-

GENE GAFFNEY

MOST PRIMITIVE KNOWN TURTLE, **Proganochelys quenstedti** *(shown as a skeleton cast), may not be so primitive after all, according to a controversial new analysis.*

tionable, theories. Such was the case in the 1800s, when the theory of hematothermia arose. It stated that birds and mammals are closely related because they are both warm-blooded, even though the overwhelming evidence suggests that birds are more reptilian.

What particularly distresses some researchers about the turtle debate is that it takes only a few additional characteristics in the data matrix to move turtles again, back into anapsids. Rieppel counters by insisting that evolutionary trees tend to become unstable when they become too heavy with characteristics.

Although their work may not have received the sanctification of colleagues, neither has it been discounted. Other animals may be misplaced and thus may force a reworking, or at least a rethinking, of various evolutionary paths. Never mind the hissing, at least they're talking. —*Erica Garcia*

LINGUISTICS

A MATTER OF LANGUAGE

The popular debate over Ebonics belies decades of linguistic research

On December 18 the board of education in Oakland, Calif., unanimously adopted a policy stating that most of the 26,000 black students in its district do not speak English as their primary language but rather speak "West and Niger-Congo African Language Systems," which the directive also calls "Ebonics." "Numerous validated scholarly studies," the policy asserts, have demonstrated that "African Language Systems are genetically based and not a dialect of English." (In January the board deleted the phrase "genetically based" from its policy.)

The policy does not order schools to teach Ebonics—until recently, a rarely used term for the variety of English spoken by many urban blacks in the U.S. Linguists more commonly refer to the variety as black English vernacular (BEV). Oakland's policy does insist, however, that teachers should understand BEV and use it to help black students learn educated English.

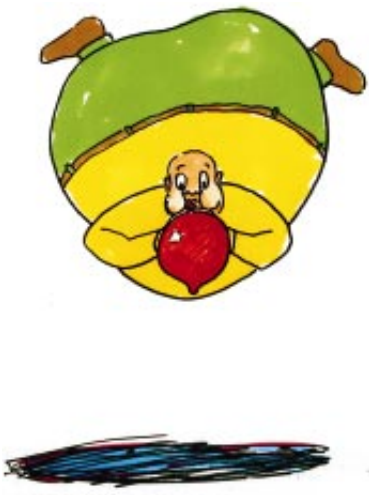
Oakland's decision, and the firestorm of controversy it generated in the media, left many linguists pleased that the issue was being discussed yet dismayed that so much of the debate seemed to ignore linguistic research. "Black English is clearly the most heavily investigated variety of English over the past 30 years," notes Walt Wolfram, a linguist at North Carolina State University. "In fact," adds Guy Bailey, a linguist at the

ANTI GRAVITY

Body Blow

As Julius Caesar might have put it, all of the galling things that can happen to the human body can be divided into three parts. There are the ordinary adversities, when the body falls victim to common disease or accident. Then there are the vapid calamities, such as when the body hoists a few and decides to take a midnight stroll along some train tracks, in which case the body itself may be divided into three parts. Finally, there exist those rare misadventures that would have forced Hamlet to up his estimate to 1,001 for the number of shocks the body's flesh is heir to. The story of the young man and the balloons belongs in this last category.

"A 24-year-old previously healthy, nonsmoker presented with a 48-hour history of a sensation of crackling under the skin," wrote attending physician Stuart Elborn, then at the University Hospital of Wales, in a recent issue of the *British Medical Journal*. His examination turned up pockets of air trapped under the skin on the man's shoulders, chest, neck, abdomen, back, arms, legs and, providing a built-in whoopie-cushion effect, derriere.



MICHAEL CRAWFORD

Because people seldom spontaneously change into flotation devices, Elborn asked the man if he had done anything unusual. He learned that two days earlier his buoyant patient had inflated some 20 balloons in about an hour. "We were pretty sure what was going on when we heard that," Elborn says. "To develop subcutaneous air collections, you need to have a leak from your lung for some reason." And that reason was the Valsalva.

Valsalva is not where Scandinavian heroes go when they die. It is, in fact, a medical maneuver in which a subject takes in a deep breath, then tries to exhale forcefully without first opening the glottis. An interesting thing about the Valsalva is that it is quite commonly performed. Blowing up balloons happens to be an excellent way to do it. And careless Valsalving can burst some of the lung's alveoli, the tiny air sacs where gas exchange actually occurs. "It seems that most seem to stop after four or five," Elborn says, "whereas he blew up 20. He probably started leaking air maybe after three or four and then by continuing to inflate balloons managed to push out a large volume of air into the skin."

Other activities can cause this inflated sense of self. Air trapped under the skin is well documented among saxophone players, whose aggressive style probably makes them more susceptible than other wind musicians, according to Elborn. Marijuana smokers attempting to hold in the fumes unwittingly do the Valsalva. Those at greatest risk for the kind of bloat the balloon blower experienced would thus be pot-smoking sax players. (Meanwhile President Bill Clinton has backed members of Congress who are attempting to protect the people of Arizona and California, the electorate in both states having approved legalization of marijuana for medical purposes. These citizens almost certainly voted in complete ignorance of the potential danger of turning into life rafts.)

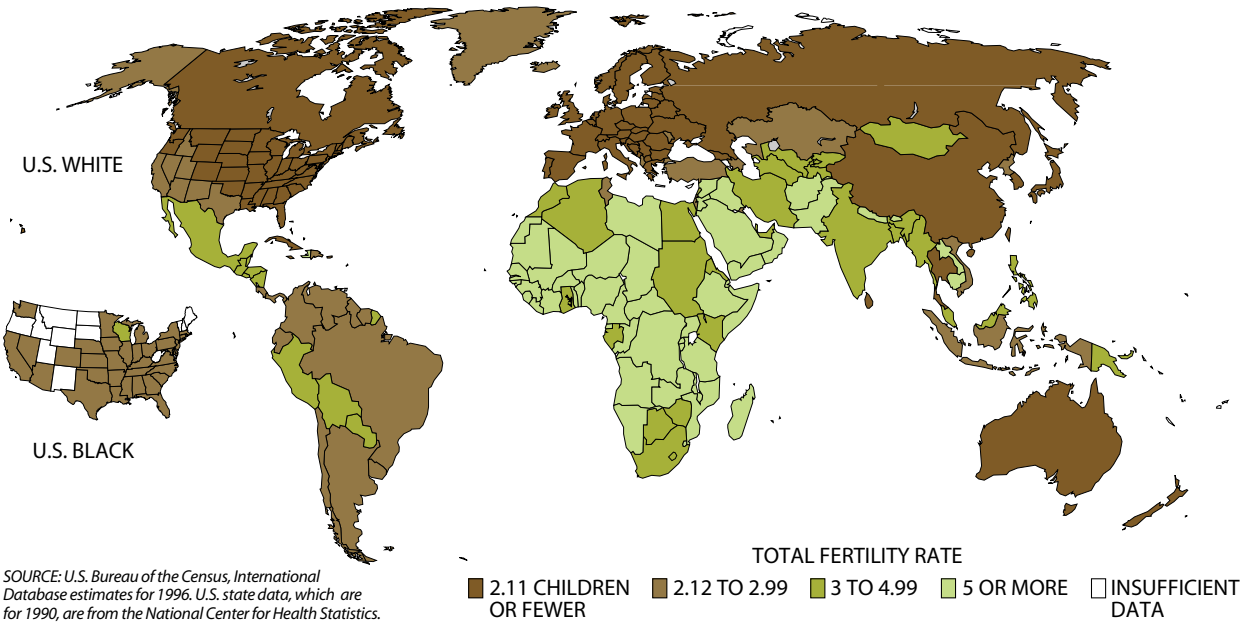
Back in Wales, 10 days after visiting the hospital, the intrepid balloonist had completely deflated, the trapped air having diffused into capillaries with no lasting ill effects. His experience, however, is a warning for us all. "Clearly, if you have any pain or discomfort when you're blowing up a balloon," counsels Elborn, who has since moved to the Belfast City Hospital, "you should stop. It might be better to use a pump." —*Steve Mirsky*

University of Nevada at Las Vegas, "much of our basic understanding of how languages change and develop comes from our study of black English."

That study has produced a rough consensus on a few points about BEV. One is that, contrary to the Oakland school board's assertion, it is not a separate language. "Languages are best defined by their speakers," says Salikoko S. Mufwene of the University of Chicago. "And almost all blacks will tell you that they speak English." Linguists also agree that, contrary to some critics' assertions, BEV is not slang. "Slang refers to a specialized lexicon of words that are exclusive, that replace other words in function and that tend to have a short life cycle," Wolfram says. "Groovy" is slang, but "he done gone" is not. "Like southern English or Appalachian English—or

BY THE NUMBERS

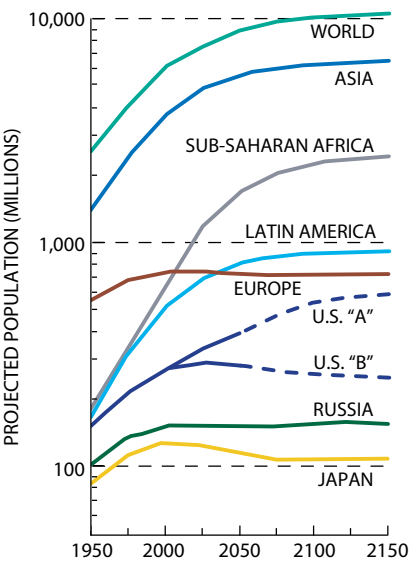
Global Fertility and Population



SOURCE: U.S. Bureau of the Census, International Database estimates for 1996. U.S. state data, which are for 1990, are from the National Center for Health Statistics.

Historically, fertility has varied widely, but beginning in 19th-century Europe and America, it has generally declined as parents came to favor smaller families. According to the latest United Nations projections, this trend will continue, stabilizing the world population early in the 23rd century at somewhat under 11 billion, compared with about 5.8 billion today.

The map shows the total fertility rate, which indicates the total number of children the average woman will bear in a lifetime based on the experience of all women in a given year, in this case, 1996. A rate of less than 2.11 children per woman will eventually result in a declining population for a country, assuming no immigration. (The extra 0.11 allows for deaths of children before they reach reproductive age.) A dip below this rate does not lead to a declining population until about seven decades or so later, when all those living at the time the replacement level is reached have died. Such a case is illustrated by Japan, which arrived at the replacement level in the 1950s, well before other industrial nations. The Japanese population will probably level off or decline in the second decade of the next century.



SOURCE: U.S. data are based on Census Bureau series projections through 2050. Data for all other areas are from Eduard Bos et al., World Population Projections, 1994–95 Edition. (Johns Hopkins University Press for the World Bank, 1994.)

At the opposite end is sub-Saharan Africa, the poorest region on the globe. The population here may not stabilize until early in the 23rd century, when it could reach over two billion. India could achieve a stationary population of more than 1.5 billion by the late 22nd century, making it more populous than China, which has stringent limitations on reproduction. The populations of Pakistan, Nigeria and Ethiopia could stabilize at more than one third of a billion each, whereas those of Mexico, Vietnam, Iran, Zaire and the Philippines could reach well over 150 million before leveling off.

Projecting population far into the future naturally involves guesswork, and this applies particularly to the U.S. because of uncertainties about the future course of immigration—right now the highest in the world—and the unpredictability of nonwhite and Hispanic fertility, which are currently well above replacement levels. The U.S. could conceivably reach a population of more than half a billion by the 22nd century (*U.S.* "A" *in graph*) or, by lowering fertility and restricting immigration, achieve a population at or below the current level (*U.S.* "B"). —*Rodger Doyle*

RODGER DOYLE

standard English, which really means educated English," Mufwene says, "BEV is a dialect."

More important than its label, noted a resolution passed in January by the Linguistics Society of America, is the fact that BEV is as systematic as any other dialect. "In fact, it has some nuances that standard English does not express well," Mufwene says. "Many people think African-Americans don't conjugate the verb 'be,' for example. That is a mistake; they simply use the word 'be' differently. If I say, 'Larry sick,' that means he is sick now. But 'Larry be sick' means he is usually in the state of sickness. So in BEV you cannot say, 'Larry be sick now'—that is a contradiction."

Historical research also suggests that many of the features that differentiate black English from mainstream English developed not from ancestral African roots but from contact with other American populations. "There are features of black speech that do certainly go back to a creole [a new language formed by the mixture of two others]. The absence of 'be,' as in 'they workin',' appears in most Caribbean creoles. But the use of 'be' plus a verb to connote habitual behavior doesn't appear in records of black English before World War II," Bailey reports. "The same is true of 'had' plus past tense used as a simple past tense, such as 'Yesterday I had told him I was coming.' "

Linguists differ on whether BEV is still diverging from the mainstream. "For every feature you see that appears to be diverging, there are others that are converging," Wolfram says. "Kids used to say, 'Whassup?' Now they say, 'What up?' which demonstrates that they know the educated form is 'What is up?' " observes John Baugh, a linguist at Stanford University. "It is a form of linguistic defiance." Evidence suggests that among blacks in the South, however, the nonstandard deletion of unstressed syllables—saying "member" for "remember"—appears to be waning.

So despite the technical errors in Oakland's policy, many linguists agree with Bailey, who says "it gets at a real issue. I grew up in southern Alabama and was the first person in my mother's family to go to high school. When I went to college and started speaking educated English, there was a sense in which I was seen as betraying my culture. To successfully educate people from uneducated backgrounds, you have to understand that they are going to pay a price for speaking differently. Telling them that they are just wrong is not the best way."

—W. Wayt Gibbs in San Francisco

RON RIESTERER *Oakland Tribune*/AP Photo

EBONICS, LINGUISTICALLY A DIALECT, could help instruct students in using standard English.

PROFILE: RONALD L. GRAHAM

Juggling Act

Ronald L. Graham, chief scientist at AT&T Labs–Research, begins with two balls, flipping them into the air with one hand while casually chatting with a visitor. He grabs another ball off a counter, and another, while noting that the world record for juggling is nine balls. He can do six consistently, seven "playing around." Nodding at a photograph on the wall showing himself juggling 12 balls, he reveals that it is an illusion generated by his daughter, Ché, a photographer who specializes in digital doctoring.

Settling into a chair to give himself more vertical room, Graham juggles five balls, occasionally shifting the pattern, his hands a blur. His ground-level office here in Murray Hill, N.J.—adorned with a tabletop rock garden through which a minuscule stream burbles, a sheet of Chinese ideograms, a print of M. C. Escher's *Night into Day*—has too low a ceiling for six.

As Graham is fond of saying, "Juggling is a metaphor." Each of these white silicone balls could refer to a different aspect of his life, except that an accurate representation would require far too many balls. As a manager at AT&T Labs–Research, which he joined 35 years ago when it was still called Bell Laboratories, he has nurtured some of the top mathematicians and computer scientists in the world. His work in number theory and other realms of mathematics earned him the prestigious Polya Prize in 1972 and membership in the National Academy of Sciences in 1985.

He carries a crushing load of other professional commitments. He is a part-time professor at Rutgers University and gives lectures and seminars around the world. He is highly active in the American Mathematical Society and the National Academy of Sciences, and he sits on the editorial board of 40—yes, 40—mathematics and computer journals. He served during the past two years on a high-profile National Research Council committee on cryptography, which last December issued a 750-page report recommending less restrictive U.S. regulation of encryption.

Graham's nonmathematical feats are equally diverse. He is an expert juggler and gymnast, who at the age of 61 can still do a triple somersault on a trampoline and a one-armed handstand on a swiveling pedestal. Over the past few decades he has mastered Ping-Pong (he is the former champion of Bell Labs), bowling (he has two perfect games under his belt) and Mandarin (he says he can pass himself off as Chinese in telephone conversations).

Cabinets just outside Graham's office are crammed with skill-challenging tchotchkes: an adult-size pogo stick, a unicycle, a spherical chess game, a box of so-called aperiodic tiles that, when properly fitted together, can cover an infinite plane with patterns that never quite repeat themselves. Graham pulls out a mutant basketball whose asymmetrical center of gravity makes it difficult to spin on a finger. "It's a constant battle," he murmurs as he gets the ball up and whirling. Graham makes it look easy.

Indeed, Graham's most impressive feat may be that he does not come across as the type-AAA person that at some level he must be. Tall, slim and sandy-haired, with a ready smile and a soft, tenor-pitched voice, he is the essence of easy-goingness. In conversation, he meanders from topic to topic, segueing seamlessly from the implications of Gödel's theorem to the psychological perils of gymnastics to the secret of his successes. The best way to crack a complex problem, he confides, whether a triple somersault or a conundrum in graph theory—is to "break it down into component parts, learn each of the parts and learn how the parts go together."

Only rarely does Graham offer a glimpse of the forces that compel him. The death last September of one of his closest friends, the legendary Hungarian mathematician Paul Erdös (pronounced AIR-dish), has made him more cognizant of how little time he has to learn new skills, solve new problems. He has considered making a memento mori, he says, out of a piece of graph paper with 100 squares on a side, 10,000 squares in all: "Every day you come in, make an X in that square." He draws an X in the air and then pauses, as if pondering an invisible sheet before him. Chances are, he adds, that he would not finish filling in the sheet.

KAREN KUEHN *Matrix*

"JUGGLING IS A METAPHOR," says AT&T mathematician Ronald L. Graham.

Graham's history demonstrates that mathematicians can sprout even from the most apparently infertile soil. He was born in Taft, Calif., 100 miles northwest of Los Angeles, where his father worked in the oil fields. Young Ron's family kept moving back and forth across the country as his father switched from one job to another, mostly in shipyards.

Although he never stayed longer than two years at any one school, Graham nonetheless displayed a prodigious appetite and aptitude for mathematics and science. When he was 15 years old, he won a Ford Foundation scholarship to the University of Chicago, which had a program for gifted youths. On the small side for contact sports, he enrolled in a school program called Acrotheater, which taught students gymnastics, juggling and trampolining. (Graham is now 6′2″, "huge" for gymnastics.) "We did shows throughout the year at high schools to show what a fun place the University of Chicago really is," he says.

After Graham had spent three years at Chicago, his father, worried that the university was too leftist, convinced him to transfer to a "nice, all-American school," the University of California at Berkeley. Graham enrolled there as an electrical engineering major, but after only one year, concerned that he might be drafted, he enlisted in the U.S. Air Force.

Shipped to Alaska, he worked as a communications specialist at night and attended classes full-time at the University of Alaska at Fairbanks during the day. On fulfilling his tour of duty, he returned to Berkeley and obtained a graduate degree in mathematics. In 1962 he joined Bell Laboratories, where he quickly rose through the managerial ranks while still pursuing his own research.

One of Graham's abiding mathematical interests is Ramsey theory, conceived almost 70 years ago by the British mathematician Frank P. Ramsey. "Complete disorder is impossible: that's the guiding philosophy of Ramsey theory," Graham says. "In any large, apparently disordered structures there are smaller, more well behaved substructures."

Problems in Ramsey theory are sometimes posed as "party puzzles." How many people must be invited to a party to ensure that a given number all know one another or are all mutual strangers? Finding the so-called Ramsey number becomes extraordinarily difficult as the number of guests increases. In 1993 two mathematicians established that the Ramsey number for a party with at least four mutual acquaintances or five mutual strangers is 25; the proof required a calculation that consumed the equivalent of 11 years of computation by a workstation.

It is still unclear whether Ramsey theory will prove to be useful (even to Martha Stewart). But areas of mathematics that seem utterly impractical, Graham points out, often turn out to have significant applications. Number theory, which was the subject of Graham's Ph.D. thesis and was once the "purest of the pure," is now a vital part of cryptography. Many encryption schemes exploit the fact that although multiplying two 100-digit numbers is relatively easy (at least for a computer), factoring one is mind-numbingly hard.

On the other hand, Graham adds, "it may be that just around the corner there's some great new idea" that would make factoring large numbers easy. Some experts think quantum computing, in which the bizarre properties of the quantum realm are harnessed to accomplish feats beyond the capability of conventional computers, may represent such a breakthrough. "That's one of my main jobs right now, to help foster this very far-out speculative thinking," Graham remarks.

The most forceful fosterer of Graham's thinking was Erdös, whom Graham calls "one of the great problem posers of all time." They met in 1963, and their first joint paper appeared in 1972. Graham maintained an "Erdös room" in his house for his mentor, who never had a family or steady job but traveled around the world staying with friends.

A 1979 paper by Graham helped to popularize the concept of an "Erdös number," which reflects a mathematician's degree of separation from Erdös. Those who have co-authored papers with Erdös have the Erdös number one, those who have co-authored papers with a member of this group but not Erdös himself have the number two, and so on. To Graham's surprise, a similar game has recently flourished on the Internet, in which people try to name the movies connecting the actor Kevin Bacon to other show-business personalities.

KAREN KUEHN *Matrix*

GRAHAM fosters "very far-out" thinking at AT&T.

Graham has little difficulty switching from mathematics to other activities, in part because mathematics is connected with so much of what he does. For example, many of the 3,000 members of the International Jugglers Association, of which Graham once served as president, are involved with math or computers, and juggling has inspired some ingenious mathematics [see "The Science of Juggling," by Peter J. Beek and Arthur Lewbel; Scientific American, November 1995].

Moreover, Graham's closest collaborator lately is Fan Chung, a professor of mathematics at the University of Pennsylvania whom he married in 1983. (A previous marriage produced Graham's two children, Ché and Marc.) The two recently tackled a problem related to the routing of calls through a telephone network. An ideal way to prevent calls from converging on the same route and thus exceeding its capacity is to assign calls to routes at random, but achieving true randomness is tricky. Chung and Graham have shown that most of the benefits of randomness can be obtained with "quasirandom" methods that are much easier to design and deploy.

Graham and his wife also just improved on a conjecture first posed by Erdös and a colleague back in 1935. The conjecture held that the number of points on a plane required to generate a convex polygon with n sides is a hideously complicated function of $n + 1$, or $f(n) + 1$. "We got rid of the plus one," Graham says happily. —*John Horgan*

BIOTECHNOLOGY

MEMORIES ARE MADE OF…

Pharmaceutical aids to remembering and forgetting

To be healthy, a human being needs a memory that works well—but not too well. The fading remembrances of a patient with Alzheimer's disease slowly erode the victim's personal identity. A traumatized war veteran, in contrast, is shattered by too vivid a recall as he cowers when a car backfires nearby.

Biologists have been zeroing in on molecular events that underlie the creation of memories. Developments are suggesting how drugs might be designed to enhance or suppress learning and remembering. Cortex Pharmaceuticals in Irvine, Calif., has already found a molecule that seems to improve the performance of volunteers in memory tests. The founders of Helicon Therapeutics in Cold Spring Harbor, N.Y., have discovered that a protein found in many animals seems to be a crucial player in forming long-term memories. The company plans to screen for drugs that will enhance or suppress the protein's action.

Cortex calls its drug candidate Ampalex. The compound emerged from a search for substances that boost a process referred to as long-term potentiation, which neuroscientists believe is an important part of the mechanism that records memories. Junctions known as synapses transmit signals between neurons in the brain when activity on one side of the junction exceeds a threshold. Long-term potentiation is the tendency of a busy synapse to lower its threshold, making it more likely to transmit a signal in the future and so strengthening the connection.

Gary Lynch of the University of California at Irvine noticed a few years ago that aniracetam, a drug used in Europe and Japan to treat memory problems, boosted long-term potentiation in certain neurons, ones that bear signal receptors of a recently discovered type called AMPA. The drug seems to modify the AMPA receptors' behavior. He teamed up with chemist Gary Rogers, then at the University of California at Santa Barbara, who soon created molecules termed ampakines that had an even stronger effect. Cortex started to investigate the molecules and in 1994 chose one, Ampalex, to develop as a drug.

Cortex is aiming first to treat memory loss caused by Alzheimer's disease. In preliminary experiments in Europe the drug boosted the scores of volunteers in standard tests measuring how well people remember. With the drug, two thirds of the elderly volunteers quadrupled their scores, to levels typical for people younger than 35 years. The drug did not obviously affect mood or general excitability. In the U.S., the National Institute of Neurological Disease and Stroke is planning to launch a trial of Ampalex in Alzheimer's patients early this year.

Helicon Therapeutics, currently being established, will be making drug candidates aimed at different brain molecules. The initial target is a protein known as CREB. Tim Tully and Jerry C. P. Yin of Cold Spring Harbor Laboratory, the company's founders, have shown that the level of CREB in fruit flies' brains has a striking effect on their ability to learn and remember.

Tully and Yin measured how well flies remembered to avoid an odor that had been delivered along with an electric shock. Flies genetically engineered to produce more CREB than normal remember the odor for a week—an eternity for a fly—after a single training session, although an ordinary fly needs several sessions. Flies producing less CREB than normal, in contrast, cannot form long-lasting memories, although their short-term recollections are unaffected. Alcino J. Silva, also at Cold Spring Harbor, has shown that CREB-deficient mice likewise have a particular type of long-term memory impairment.

Tully has evidence that CREB activity allows cells in the brain to make proteins, which are presumably necessary to strengthen synapses. He and his colleagues are now trying to find the site where CREB operates. They published in December in *Science* results showing that a fruit fly's ability to learn can be abolished by subtle genetic alterations at a crucial location in the fly's brain. The resulting biochemical changes are likely to influence CREB.

Tully and Yin have developed proprietary techniques to search for drugs that boost CREB's effects. "Our long-range goal is to become the memory company," Tully declares. He sees lucrative future markets not only for drugs that might boost a failing memory but also for pharmaceuticals that, administered after a traumatic event, might prevent

ROBERT PROCHNOW

TEACHING MACHINE *for fruit flies allows Tim Tully of Cold Spring Harbor Laboratory to measure the insects' ability to remember odors.*

crippling long-term recollections from arising.

Additional memory drugs might emerge from other work that has started to pin down the processes of memory in mammals. Recently researchers led by Susumu Tonegawa of the Massachusetts Institute of Technology have shown that for mice to form memories about places, particular neuronal receptors that permit long-term potentiation (and that could plausibly affect CREB activity) have to be functioning in the hippocampus of the brain. That area has long been believed to be vital for memory.

Observers expect that the breakthroughs in genetic engineering that allowed the recent crop of results will soon lead to a barrage of new information about remembering. Commercially, Cortex and Helicon so far have the arena pretty much to themselves. They are unlikely to keep it that way for long.

—Tim Beardsley in Washington, D.C.

POLICY

CHINA SYNDROME

China's eugenics law makes trouble for science and business

DAN HABIB *Impact Visuals*

CHINA'S LARGE POPULATION is genetically more uniform than that of many nations, and good records are kept, making the country ideal for studying genetic illnesses. But ethical questions loom.

Eugenics produced some of the worst horrors of the century, so geneticists get jumpy when their expertise is used to coerce. Scientists are now trying to decide how to respond to a law that came into force in China in 1995 and seems unabashedly eugenic.

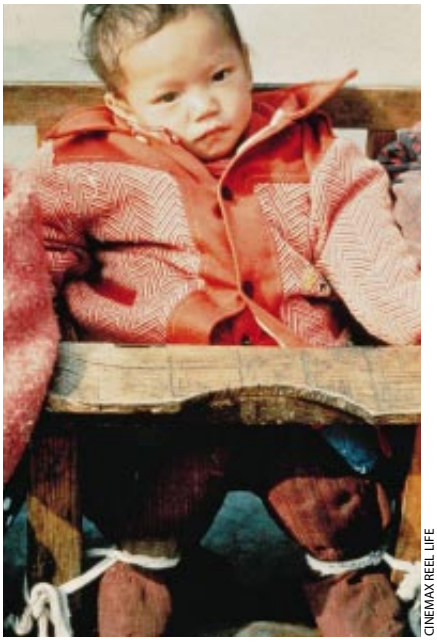
In most of the world, choosing to have a baby is a private matter for two people. The Chinese Law on Maternal and Infant Health Care, however, stipulates that if a married couple in childbearing years suffers from a genetic disease "of a serious nature," the couple "shall take measures in accordance with…medical advice." Other provisions make plain what measures might be appropriate. Couples with unspecified genetic diseases "considered to be inappropriate for childbearing" may be married only if both agree to practice long-term contraception or to be sterilized.

How to register disapproval has divided Western geneticists. The U.K.'s Genetical Society, mindful of past abuses ranging from compulsory sterilizations in North America to genocide elsewhere, has decided to boycott the 1998 International Congress of Genetics in Beijing. The action is "a strong U.K. move to distance itself from China," says David Sherratt of the University of Oxford, president of the society. Moreover, an international group of human geneticists, with the support of some Chinese scientists, last fall urged the government of China to delay implementing the law until geneticists have discussed the issues. Some additional societies have also expressed concern, and the American Society of Human Genetics is studying the questions raised.

Opinions vary on the value of scientific ostracism. Some say a semiboycott by scientists helped to end apartheid in South Africa. Others counter that a boycott of the International Congress of Genetics in Moscow in 1978 achieved nothing. In any event, the protests over China's eugenics law have not affected commerce. The French biotechnology company Genset is launching a joint venture with the Chinese Academy of Medical Sciences to carry out surveys in China for genes contributing to common diseases. Genset will use what it learns to develop novel therapies. Pascal Brandys, the company's president, replies to critics by noting that the blood samples his company collects will be anonymous. All donors give informed consent, Brandys says. Sequana Therapeutics in La Jolla, Calif., is also gene hunting in China. A company official says it, too, employs Western-style ethical safeguards when collecting samples.

Promises of good behavior provide only partial reassurance to those who want to protest. But many geneticists believe they can best help by strengthening scientific exchanges with China. The International Genetics Federation plans to engage the country diplomatically by holding a symposium about eugenics at the Beijing meeting. The Chinese Academy of Sciences's Institute of Genetics is content with the arrangement, notes Robert Haynes of York University in Toronto, who is planning the session. "I think those British geneticists are shooting themselves in the foot with regard to their future esteem in China," Haynes says.

He points out that it is unclear how the Chinese law is being implemented. In a country where millions of female children vanish—presumably killed—and many children with developmental abnormalities are left to die, the law might represent an improvement, Haynes suggests. The eugenic provisions specify no penalties, and the law does, for example, prohibit the abortion of fetuses simply because they happen to be female. John Drake of the National Institute of Environmental Health Sciences in North Carolina, who chairs an advisory committee to the federation, says he believes the law is intended to be advisory: "Few Westerners have an appreciation of the magnitude of the population problem



CINEMAX REEL LIFE

INFANT GIRLS
fill China's orphanages and may face grim conditions, as seen in* The Dying Rooms, *a 1996 Cinemax documentary.

China is trying to come to grips with."

Complexities abound, but the Chinese government is not making things easier. It has shown no inclination to revise the law, and it has not repudiated a statement attributed in 1994 to Chen Mingzhang, minister of public health, that seems to confirm the critics' worst fears. Chen reportedly said births of "inferior quality" are serious among "the old revolutionary base" and "ethnic minorities" as well as the poor and those near "the frontier." With public spokespeople like that, China probably does not need any more enemies.

—Tim Beardsley in Washington, D.C.

ASTRONOMY

A MIRROR, CHEAPLY

Computer power opens a new era of low-budget astronomy

Who would build a giant telescope that cannot move up and down? A consortium led by the University of Texas at Austin and Pennsylvania State University, that's who. The contradiction between observers' ever more ambitious plans and harsh fiscal realities encouraged the universities to back the Hobby-Eberly Telescope (HET) at the McDonald Observatory in Texas. The telescope's stripped-down design offers high performance at a bargain price. Its light-gathering mirror stretches 11 meters across, the world's largest, but its $13.5-million construction budget is a mere fraction of that of other giant telescopes.

HET was dreamed up in the recession years of the early 1980s by Lawrence W. Ramsey and Daniel Weedman of Penn State. In their quest for efficiency, they reconsidered almost everything that one typically associates with a telescope—including the ability to point in any direction. The telescope's gaze is permanently tipped 35 degrees from vertical, although it can rotate on its base. A small, movable focusing instrument above the main mirror tracks astronomical images across the sky. Reduced mobility means a much simpler, cheaper telescope. "We're getting 70 percent of the sky for 15 percent of the price," Ramsey says.

HET's innovations extend to the way it is being built and managed. Under the guidance of project manager Thomas A. Sebring, "first light"—the inaugural testing of the telescope—took place last December 10, just three years after groundbreaking. When it begins regular operations in the fall of this year, HET will work around a flexible "cue schedule," in which an observer's time might be split into discrete blocks over several nights, thereby maximizing the efficiency with which it shifts its gaze from object to object. Electronic light detectors will seamlessly store the light from the disparate viewing sessions. Even the low-key publicity that has surrounded the project is related to its lean management: "The publicity team is the project team, and we've been busy building the telescope," Ramsey explains.

The result is a bargain compared with the similarly sized Keck I telescope on Mauna Kea in Hawaii, which cost nearly $100 million. Ramsey is quick to point out that Keck is a far more capable and flexible device. But there is no shortage of tasks waiting for HET. The telescope will peer into the central regions of active galaxies and quasars, where giant black holes seem to be stirring gas into a white-hot frenzy. It will also help measure the distances and composition of the most remote quasars and galaxy clusters, and it will aid in the search for planets around other stars.

Other astronomers are likewise discovering the economic benefits of automation and narrowed goals. The Jet Propulsion Laboratory in Pasadena, Calif., and the U.S. Air Force have collaborated on a new electronic camera, the Near-Earth Asteroid Tracking System; for a modest $1 million, the system is producing a vastly improved survey of the asteroids and comets that venture disconcertingly close to the earth. Another innovative project, the $500,000 Katzman Automated Imaging Telescope at the University of California at Berkeley, conducts computer-controlled surveys for supernova explosions in remote galaxies, which will help determine the age and fate of the universe.

Astronomers, it seems, are learning from corporate downsizing. "The idea of HET is exploiting niches," Ramsey notes. "You can do everything and pay a lot of money, or do some things and pay a lot less."

—Corey S. Powell

THOMAS A. SEBRING

HOBBY-EBERLY TELESCOPE
demonstrates that big science need not be big-budget science.

MATERIALS SCIENCE

BETTER RED THAN DEAD

An inexpensive new test instantly spots harmful E. coli

In the eternal struggle between humans and microbes, certain toxic strains of *Escherichia coli* are the special forces of the bacteria world. Swift and potentially deadly, they produce toxins that cause intense intestinal distress, severe dehydration and internal bleeding. No treatment has been proved consistently effective against the disease, public health officials say. And at present, no specific, convenient test is routinely used to detect the bacteria, which kill as many as 200 people every year in the U.S. alone. To test for the bacteria, samples that have been taken from food or from a patient who may be afflicted must be cultured for 24 or more hours, after which the harmful organisms can be detected with microscopes or special dyes.

An invention at Lawrence Berkeley National Laboratory promises to change all that. Researchers in the lab's Biomolecular Materials Program have created an advanced thin-film biomaterial that functions as a litmus test for the bacteria. The plastic strips, which researchers say could be produced for less than a penny apiece, instantly change from blue to red in the presence of any toxic strain of *E. coli.* "It could change the rules of the game," asserts Jeffery Kahn, a laboratory spokesperson.

Toxic *E. coli* bacteria are particularly dangerous to young children and the elderly, possibly because their immune systems are less robust. The most recent publicized outbreak of the bacteria, in Scotland last December, caused 12 deaths and several hundred cases of illness. A massive episode in Japan last summer killed a number of schoolchildren and affected some 9,000 others. Such publicized outbreaks, however, may actually be only a small subset of a much greater epidemic whose victims generally do not realize what has afflicted them, some public health officials believe. According to a recent estimate by the Centers for Disease Control and Prevention, *E. coli* 0157:H7—the most common toxic *E. coli* strain by far—may be responsible for at least 20,000 cases of illness annually in the U.S. Various studies have found that harmful *E. coli* strains may be present in anywhere from 0.1 to 3.7 percent of the raw meat sold in the U.S.

These strains secrete a toxin that binds to a type of protein molecule, known as a receptor, on the surface of the cells that line the wall of the intestine. This toxin damages the cells and eventually leads to intestinal bleeding. It can then enter the bloodstream and, in the most serious cases, damage the kidney.

To build their *E. coli* detector, the Berkeley group, led by Raymond Stevens, duplicated the intestinal cell-surface receptor molecule and joined it to an underlying "backbone." This backbone, which had been developed previously at the lab by Mark Bednarski and Deborah Charych, is a long chain of linked lipid molecules that together constitute what is known as a polydiacetylene film, which happens to be blue. But the binding of *E. coli* toxin to the other part of the molecule (the cell-surface receptor) breaks the links joining the lipids to one another, changing the color of the film to a reddish magenta.

The sensitivity of the test scheme is limited mainly by the ability of the human eye to distinguish color shades. Most people can easily see a color change triggered by *E. coli* concentrations in the low parts-per-million range, Stevens says. Such sensitivity is ample for most practical applications, but much greater sensitivity could be obtained by using a spectrophotometer to detect color change, he adds. Such a configuration might be used in a meat-processing plant or some other industrial setting.

The test film could be manufactured inexpensively enough to be incorporated into packaging materials—the wrap used for meat or the lids of jars or cans—without adding significantly to their cost, according to Stevens. And as of early January, a number of firms had already expressed interest in licensing the Berkeley lab's patents and turning the film into a commercially available product. "The phone has been ringing off the hook," Stevens reports.

In the meantime, the Berkeley group has begun exploring other uses for the technology. With the appropriate receptor molecules, the films could be used to detect almost any kind of harmful microbe, from those in biological weapons to influenza viruses. In fact, a flu detector has already been fabricated and did detect the virus in saliva from an infected student, Stevens notes. Discussions are under way with the U.S. Army about products to detect botulinum toxin and anthrax, two common biological agents. —*Glenn Zorpette*

PAUL FUSCO *Magnum*

GROUND BEEF,
being packed here for a fast-food hamburger chain, is one of the typical carriers of harmful strains of* E. coli *bacteria.

CYBER VIEW

Where the Money Is

In the past year only a trickle of money on the World Wide Web has actually made its way toward consumer goods such as books, flowers and airline tickets. But the Web has actually produced a bona fide financial hit—intranets. These systems are networks that are generally accessible only to select users and that rely on the rules of the Internet that permit computers to "talk" to one another. Unlike their rambunctious, flashy Internet cousins, intranets (and extranets, or networks extended to branches and business partners) are the emerging bourgeoisie—stable, productive money earners, the economic bedrock of cyberspace.

Convinced that they will increase profits, U.S. companies are ready to pay for the Web technology to create them. The market for intranets is estimated to reach at least $9 billion by 2000 or perhaps even more: Zona Research, a consulting firm in Redwood City, Calif., thinks annual spending on intranets will exceed $13 billion by 1999. Netscape, Sun Microsystems and Lotus/IBM are already competing fiercely for this enormous market, and so, too, looming over them all, is the Godzilla of Redmond, Wash., Microsoft.

Intranets have earned their status by efficiently performing many unglamorous but useful tasks: publishing job postings and searchable versions of technical reports, managing supply chains and distribution channels, letting workers check on matters ranging from their health plan to the daily specials in the cafeteria.

Although they are today's signature business phenomenon, intranets began so modestly that until two years ago they did not even have their own name. According to Katie Hafner and Matthew Lyon's history of the origins of the Internet (*Where Wizards Stay Up Late,* Simon & Schuster, 1996), in the mid-1980s "internet" with a small "i" was the term for any network using the standard suite of Internet TCP/IP parameters. (TCP, for transmission control protocol, breaks up and reassembles messages on the Net; IP, for Internet protocol, controls the structure of transmitted data and defines the addressing mechanism used to deliver them.) With an initial capital, Internet stood for the public, federally subsidized network made up of linked networks running TCP/IP.

The Internet/internet spelling was still the distinction in late 1995, when writer Brent Schlender visited Eric Schmidt, chief technology officer at Sun Microsystems. Schlender thought "intranet" was a less confusing term, and his colleague Alison Sprout later tried the new word out in print in *Fortune*.

Web-based intranets emerged humbly, typically as simple publishing tools in human resources departments, home of the myriad documents needed by virtually everyone within a company. The sites proved useful—they saved paper and reduced time spent handling routine telephone calls. Indeed, such intranets earned enviable returns on investments; one study by Internal Data Corporation in Framingham, Mass., found that Netscape intranets produced returns of more than 1,000 percent.

DAVID SUTER

Meanwhile, within companies, many people had started to build their own internal Web sites. If 1996 began as the year that everyone put up home pages but didn't know what to do with them, it ended with many firms realizing that the value of their internal Web sites went beyond the personnel department: they let business partners or a sales force keep in touch and workers share information and collaborate effectively. In short, they boosted productivity.

"The Web is not something that a corporation has to decide to use," says Bill Raduchel, Sun Microsystems's chief information officer. "Once you have a TCP/IP network, a handful of people can create a Web site. Kids create them; people see how good they are. The sites compound and expand. Of the 2,000-plus Web sites within Sun, only one was created by the company," he notes.

By the end of 1996, Netscape had repositioned itself as an intranet infrastructure company, ready for what CEO Jim Barksdale called the next wave for the Net: groupware. Intranets are inherently collaborative, and groupware—software that many users can run at the same time—takes advantage of this characteristic. Network users could simultaneously view complex data or employ hypertext links in their e-mail so that they could seamlessly send their 401(k) forms back to human resources.

Groupware is emerging as the key battleground of the intranet wars between Netscape, Microsoft and Lotus. Lotus pioneered groupware when it introduced its highly regarded Notes software in 1989. In the past two years, though, Lotus has migrated to an IP base and is now Web-enabled. Through a browser, intranet users can sample Notes's complex, elegant features: identical, perfectly updated files for all those who open the folder (multiple servers present the same data); threaded discussions; and work-flow applications, which not only track packages, for instance, but also automatically inform the right people when a package goes astray.

Best of all, if you don't want to own a full-service intranet, you can rent one. Lotus, for example, will supply a virtual intranet for those who want to organize an international meeting or draw up a contract. Just choose the groupware functions you want—say, document sharing. Within the hour, according to Steven Brand, a director at Lotus, participants can check into their password-protected URL (uniform resource locator—a Web address) and go to work commenting and revising at their convenience. Lotus plans to sell the groupware wholesale to Internet service providers, who, Brand says, will charge about $10 to $30 a month for each user. At the least, intranets are going to lead to far fewer documents shipped overnight.

"Late and in entirely unexpected ways, IP inside corporations is finally going to deliver what people had hoped for all along from the Internet," comments Paul Saffo of the Institute for the Future, a think tank in Menlo Park, Calif. "The promised goods—intellectual capital. The IP will be the vortex around which all this happens." —*Anne Eisenberg*

SOHO Reveals the Secrets of the Sun

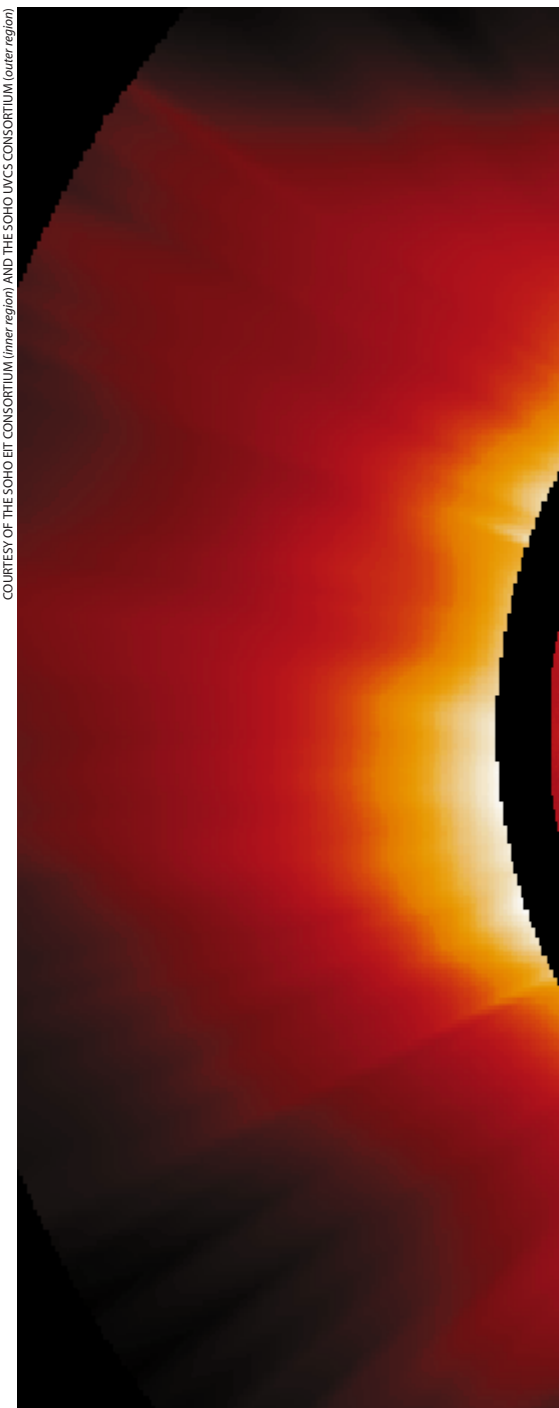
A powerful new spacecraft, the Solar and Heliospheric Observatory, or SOHO, is now monitoring the sun around the clock, providing new clues about our nearest star

by Kenneth R. Lang

From afar, the sun does not look very complex. To the casual observer, it is just a smooth, uniform ball of gas. Close inspection, however, shows that the star is in constant turmoil—a fact that fuels many fundamental mysteries. For instance, scientists do not understand how the sun generates its magnetic fields, which are responsible for most solar activity, including unpredictable explosions that cause magnetic storms and power blackouts here on the earth. Nor do they know why this magnetism is concentrated into so-called sunspots, dark islands on the sun's surface that are as large as the earth and thousands of times more magnetic. Furthermore, physicists cannot explain why the sun's magnetic activity varies dramatically, waning and intensifying again every 11 years or so.

To solve such puzzles—and better predict the sun's impact on our planet—the European Space Agency and the National Aeronautics and Space Administration launched the two-ton Solar and Heliospheric Observatory (SOHO, for short) on December 2, 1995. The spacecraft reached its permanent strategic position—which is called the inner Lagrangian point and is about 1 percent of the way to the sun—on February 14, 1996. There SOHO is balanced between the pull of the earth's gravity and the sun's gravity and so orbits the sun together with the earth. Earlier spacecraft studying the sun orbited the earth, which would regularly obstruct their view. In contrast, SOHO monitors the sun continuously: 12 instruments examine the sun in unprecedented detail. They downlink several thousand images a day through NASA's Deep Space Network antennae to SOHO's Experimenters' Operations Facility at the NASA Goddard Space Flight Center in Greenbelt, Md.

At the Experimenters' Operations Facility, solar physicists from around the world work together, watching the sun night and day from a room without windows. Many of the unique images they receive move nearly instantaneously to the SOHO home page on the World Wide Web (http://sohowww.nascom.nasa.gov). When these pictures first began to arrive, the sun was at the very bottom of its 11-year activity cycle. But SOHO carries enough fuel to continue operating for a decade or more. Thus, it will keep watch over the sun through all its tempestuous seasons—from its current lull in magnetic activity to its next maximum, which should take place at the end of the century. Already, though, SOHO has offered some astounding findings.



COURTESY OF THE SOHO EIT CONSORTIUM (*inner region*) AND THE SOHO UVCS CONSORTIUM (*outer region*)

Exploring Unseen Depths

To understand the sun's cycles, we must look deep inside the star, to where its magnetism is generated. One way to explore these unseen depths is by tracing the in-and-out, heaving motions of the sun's outermost visible surface, named the photosphere from the Greek word *photos,* meaning "light." These oscillations, which can be tens of kilometers high and travel a few hundred meters per second, arise from sounds that course through the solar interior. The sounds are trapped inside the sun; they cannot propagate through the near vacuum of space. (Even if they could reach the earth, they are too low for human hearing.) Nevertheless, when these sounds strike the sun's surface and rebound back down, they disturb the gas-

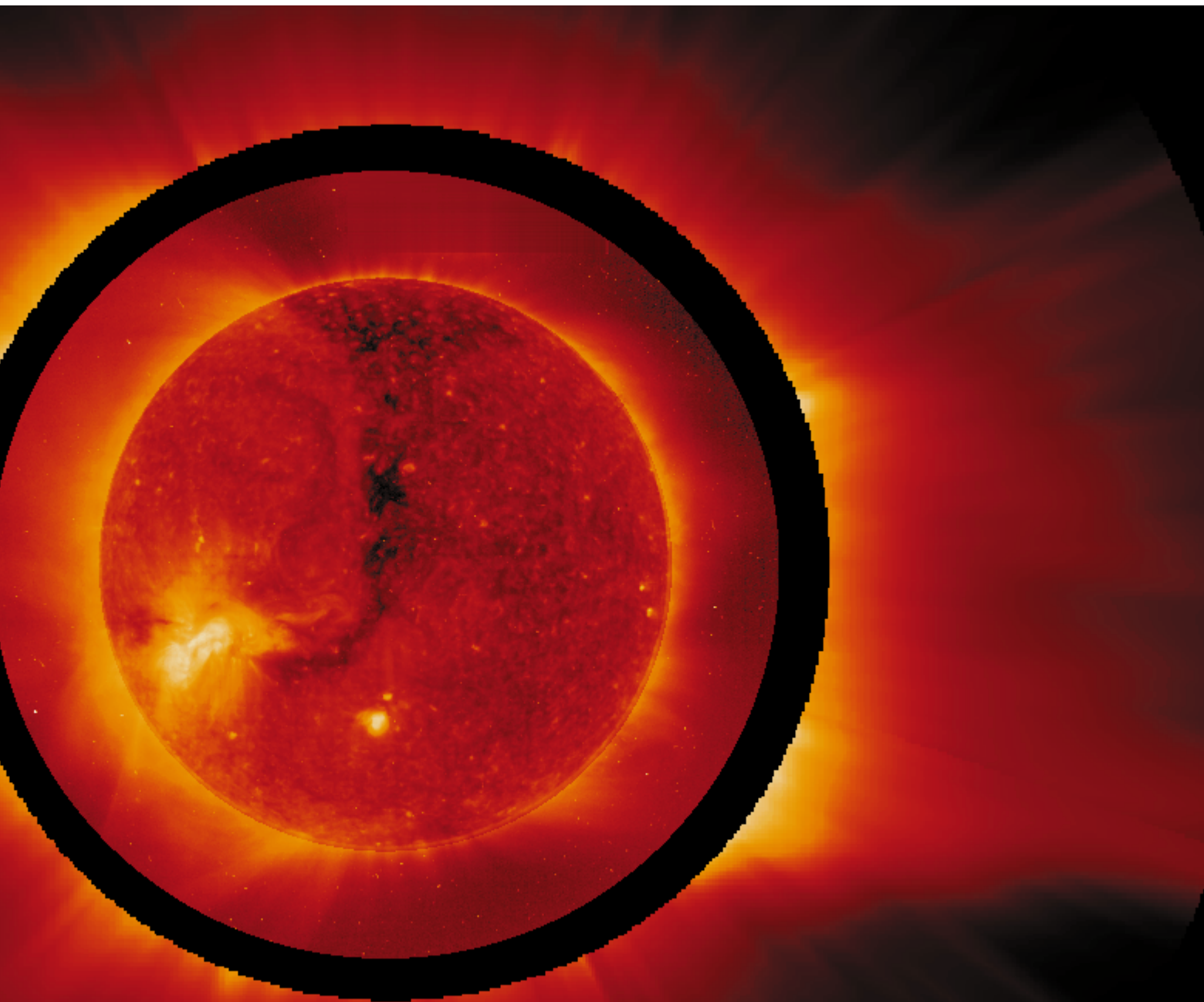
es there, causing them to rise and fall, slowly and rhythmically, with a period of about five minutes.

The throbbing motions these sounds create are imperceptible to the naked eye, but SOHO instruments routinely pick them out. Two devices, the Michelson Doppler Imager (MDI) and the Global Oscillations at Low Frequencies (GOLF), detect surface oscillation speeds with remarkable precision—to better than one millimeter per second. A third device tracks another change the sound waves cause: as these vibrations interfere with gases in light-emitting regions of the sun, the entire orb flickers like a giant strobe. SOHO's Variability of solar IRradiance and Gravity Oscillations (VIRGO) device records these intensity changes, which are but minute fractions of the sun's average brightness.

The surface oscillations are the combined effect of about 10 million separate notes—each of which has a unique path of propagation and samples a well-defined section inside the sun. So to trace the star's physical landscape all the way through—from its churning convection zone, the outer 28.7 percent (by radius), into its radiative zone and core—we must determine the precise pitch of all the notes.

The dominant factor affecting each sound is its speed, which in turn depends on the temperature and composition of the solar regions through which it passes. SOHO scientists compute the expected sound speed using a numerical model.

COMPOSITE IMAGE, taken by two SOHO instruments and joined at the black circle, reveals the sun's outer atmosphere from the base of the corona to millions of kilometers above the solar surface. Raylike structures appear in the ultraviolet light emitted by oxygen ions flowing away from the sun to form the solar wind (*outside the black circle*). The solar wind with the highest speed originates in coronal holes, which appear as dark regions at the north pole (*top*) and across the solar disk (*inside the black circle*).

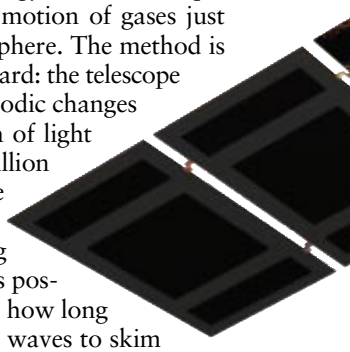


They then use relatively small discrepancies between their computer calculations and the observed sound speed to fine-tune the model and establish the sun's radial variation in temperature, density and composition.

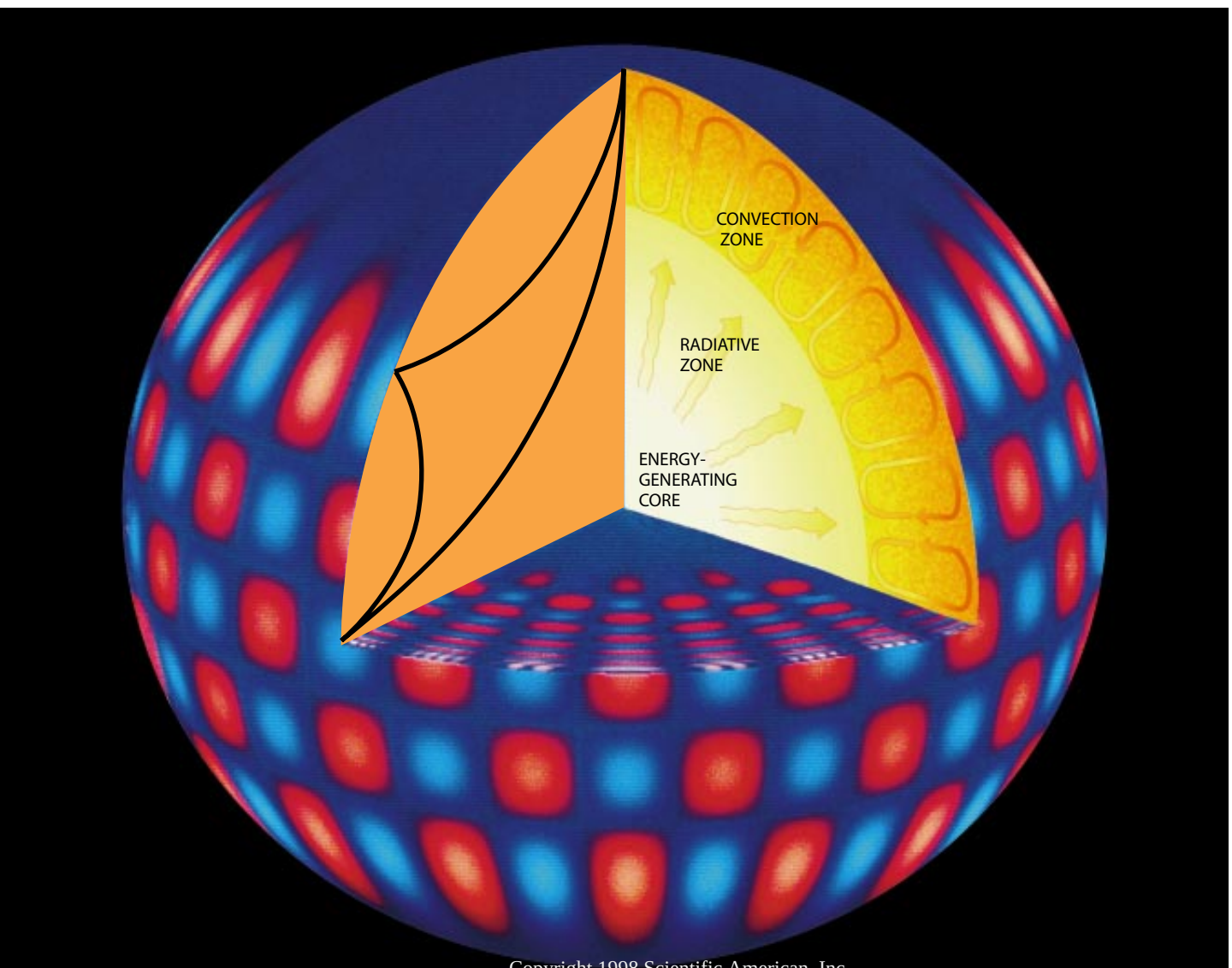
At present, theoretical expectations and observations made with the MDI telescope are in close agreement, showing a maximum difference of only 0.2 percent. Where these discrepancies occur is, in fact, significant. They suggest that material is mixing at the boundary of the energy-generating core and also just below the convection zone.

For more than three centuries, astronomers have known from watching sunspots that the photosphere rotates faster at the equator than at higher latitudes and that the speed decreases evenly toward each pole. SOHO data confirm that this differential pattern persists through the convection zone. Furthermore, the rotation speed becomes uniform from pole to pole about a third of the way down. Thus, the rotation velocity changes sharply at the base of the convection zone. There the outer parts of the radiative interior, which rotates at one speed, meet the overlying convection zone, which spins faster in its equatorial middle. We now suspect that this thin base layer of rotational shear may be the source of the sun's magnetism.

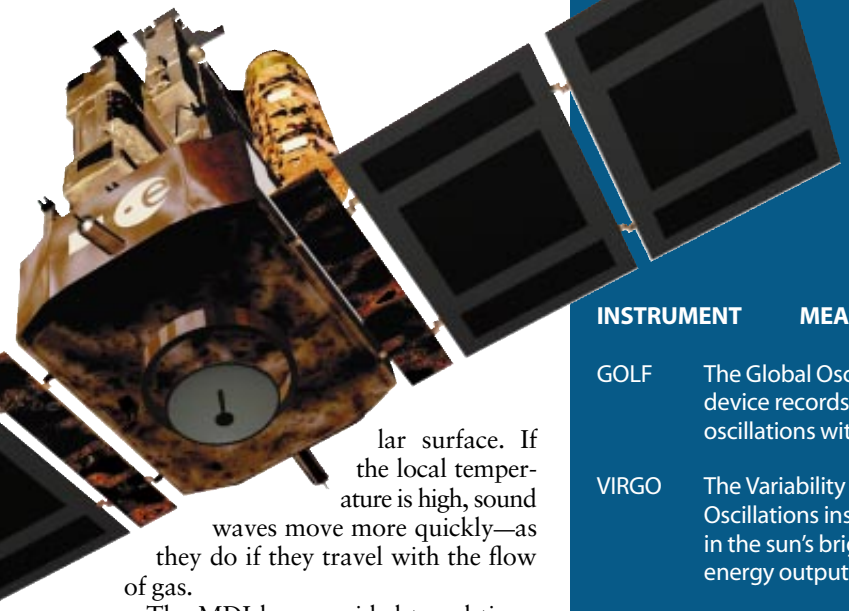
The MDI telescope on board SOHO has also helped probe the sun's outer shells. Because its lenses are positioned well above the earth's obscuring atmosphere, it can continuously resolve fine detail that cannot always be seen from the ground. For this reason, it has proved particularly useful in time-distance helioseismology, a new technique for revealing the motion of gases just below the photosphere. The method is quite straightforward: the telescope records small periodic changes in the wavelength of light emitted from a million points across the sun every minute. By keeping track of them, it is possible to determine how long it takes for sound waves to skim through the sun's outer layers. This travel time tells of both the temperature and gas flows along the internal path connecting two points on the visible so-



SOUND WAVES, represented here by black lines inside the cutaway section, resonate throughout the sun. They are produced by hot gas churning in the convection zone, which lies above the radiative zone and the sun's core. As sound waves travel toward the sun's center, they gain speed and are refracted back out. At the same time, the sun's surface reflects waves traveling outward back in. Thus, the entire star throbs, with regions pulsing in (*red spots*) and out (*blue spots*).



COURTESY OF JACK HARVEY *National Optical Astronomy Observatories;* CROSS SECTIONS BY MICHAEL GOODMAN



lar surface. If the local temperature is high, sound waves move more quickly—as they do if they travel with the flow of gas.

The MDI has provided travel times for sounds crossing thousands of paths, linking myriad surface points. And SOHO scientists have used these data to chart the three-dimensional internal structure and dynamics of the sun, much in the same way that a computed tomographic (CT) scan creates an image of the inside of the brain. They fed the SOHO data to supercomputers to work out temperatures and flow directions along these intersecting paths. After a solid week of number crunching, the machines generated the first maps showing convective flow velocities inside a star. These flows are not global motions, such as rotations, but rather small-scale ones that seem to be independent of one another. Even so, their speed reaches one kilometer per second—which is faster than a supersonic jet airplane.

To get a look at these flows diving down through the convection zone, the MDI team computed travel times for sounds moving some 8,000 kilometers down into the sun. The researchers found that, as expected, this tumultuous region resembles a pot of boiling water: hot material rises through it, and cooler gases sink. Many of these flows are, however, unexpectedly shallow. The team also investigated horizontal motions at a depth of about 1,400 kilometers and compared them with an overlying magnetic image, also taken by the MDI instrument. They found that strong magnetic concentrations tend to lie in regions where the subsurface gas flow converges. Thus, the churning gas probably forces magnetic fields together and concentrates them, thereby overcoming the outward magnetic pressure that ought to make such localized concentrations expand and disperse.

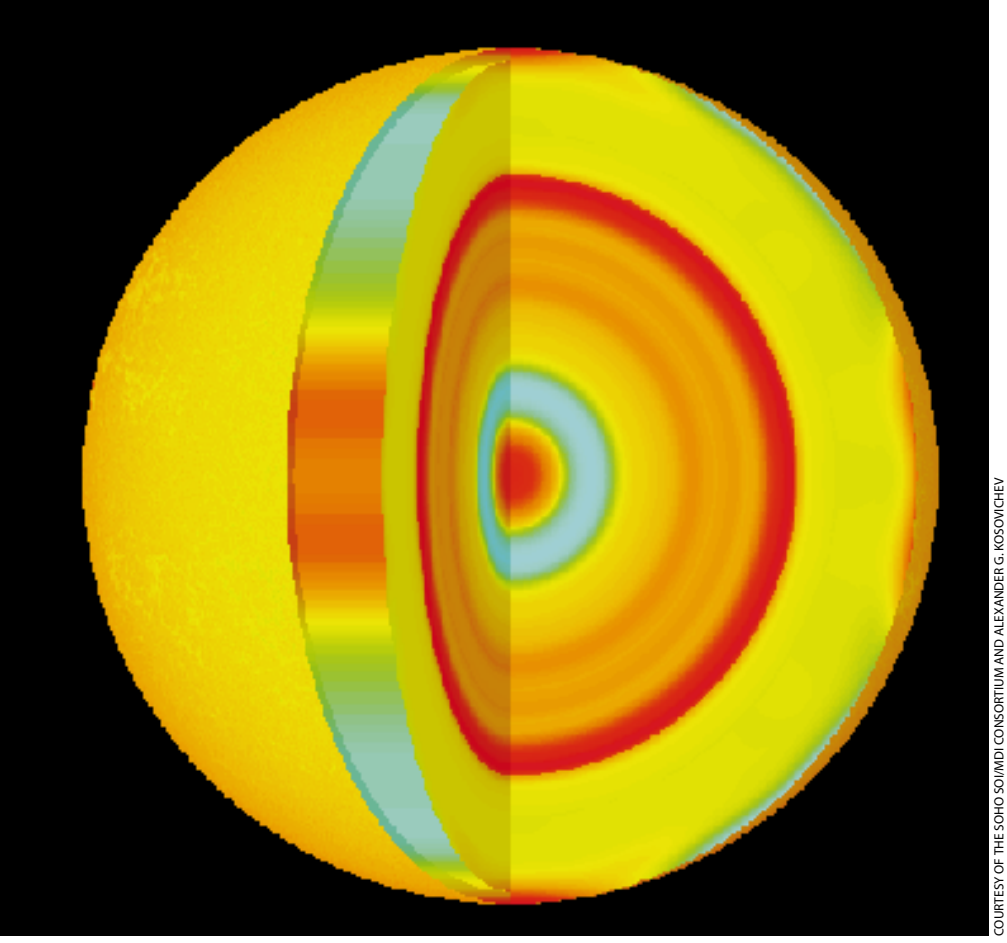
SOHO is also helping scientists ex-

SOURCES: EUROPEAN SPACE AGENCY AND NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SOHO's Instruments

Researchers around the world are studying the sun using 12 instruments on board SOHO. Three devices probe the sun's interior; six measure the solar atmosphere; and three keep track of the star's far-reaching winds.

INSTRUMENT	MEASUREMENT	PRINCIPAL INVESTIGATOR
GOLF	The Global Oscillations at Low Frequencies device records the velocity of global oscillations within the sun	Alan H. Gabriel, Institut d'Astrophysique Spatiale, France
VIRGO	The Variability of solar IRradiance and Gravity Oscillations instrument measures fluctuations in the sun's brightness, as well as its precise energy output	Claus Fröhlich, Physico-Meteorological Observatory Davos and World Radiation Center, Switzerland
SOI/MDI	The Solar Oscillations Investigation/ Michelson Doppler Imager measures the velocity of oscillations, produced by sounds trapped inside the sun	Philip H. Scherrer, Stanford University, U.S.
SUMER	The Solar Ultraviolet Measurements of Emitted Radiation instrument gives data about the temperatures, densities and velocities of various gases in the chromosphere and corona	Klaus Wilhelm, Max Planck Institute for Aeronomy, Germany
CDS	The Coronal Diagnostic Spectrometer records the temperature and density of gases in the corona	Richard A. Harrison, Rutherford Appleton Laboratory, U.K.
EIT	The Extreme-ultraviolet Imaging Telescope provides full-disk images of the chromosphere and the corona	Jean-Pierre Delaboudinière, Institut d'Astrophysique Spatiale
UVCS	The UltraViolet Coronagraph Spectrometer measures the temperatures and velocities of hydrogen atoms, oxygen and other ions in the corona	John L. Kohl, Smithsonian Astrophysical Observatory, U.S.
LASCO	The Large Angle Spectroscopic COronograph provides images that reveal the corona's activity, mass, momentum and energy	Guenter E. Brueckner, Naval Research Laboratory, U.S.
SWAN	The Solar Wind ANisotropies device monitors latitudinal and temporal variations in the solar wind	Jean-Loup Bertaux, Service d'Aéronomie, France
CELIAS	The Charge, ELement and Isotope Analysis System quantifies the mass, charge, composition and energy distribution of particles in the solar wind	Peter Bochsler, University of Bern, Switzerland
COSTEP	The COmprehensive SupraThermal and Energetic Particle analyzer determines the energy distribution of protons, helium ions and electrons	Horst Kunow, University of Kiel, Germany
ERNE	The Energetic and Relativistic Nuclei and Electron experiment measures the energy distribution and isotopic composition of protons, other ions and electrons	Jarmo Torsti, University of Turku, Finland



COURTESY OF THE SOHO SOI/MDI CONSORTIUM AND ALEXANDER G. KOSOVICHEV

SOUND SPEEDS within the sun give some indication of the density and temperature in different regions. Red areas correspond to faster sound speeds relative to a standard solar model (*yellow*). Similarly, blue areas denote slower sound speeds. The drop in sound speed at the boundary of the sun's core may result from some unstable burning process mixing the material there. The rise in sound speed just below the convection zone may reflect turbulence, caused by variations in the rate at which different parts of the sun rotate. The latitudinal variations near the surface (*shown left of center*) probably mark temperature differences.

plain the solar atmosphere, or corona. The sun's sharp outer rim is illusory. It merely marks the level beyond which solar gas becomes transparent. The invisible corona extends beyond the planets and presents one of the most puzzling paradoxes of solar physics: it is unexpectedly hot, reaching temperatures of more than one million kelvins just above the photosphere; the sun's visible surface is only 5,780 kelvins. Heat simply should not flow outward from a cooler to a hotter region. It violates the second law of thermodynamics and all common sense as well. Thus, there must be some mechanism transporting energy from the photosphere, or below, out to the corona. Both kinetic and magnetic energy can flow from cold to hot regions. So writhing gases and shifting magnetic fields may be accountable.

For studying the corona and identifying its elusive heating mechanism, physicists look at ultraviolet (UV), extreme ultraviolet (EUV) and x-ray radiation. This is because hot material—such as that within the corona—emits most of its energy at these wavelengths. Also, the photosphere is too cool to emit intense radiation at these wavelengths, so it appears dark under the hot gas. Unfortunately, UV, EUV and x-rays are partially or totally absorbed by the earth's atmosphere, and so they must be observed through telescopes in space. SOHO is now measuring radiation at UV and EUV wavelengths using four instruments: the Extreme-ultraviolet Imaging Telescope (EIT), the Solar Ultraviolet Measurements of Emitted Radiation (SUMER), the Coronal Diagnostic Spectrometer (CDS) and the UltraViolet Coronagraph Spectrometer (UVCS).

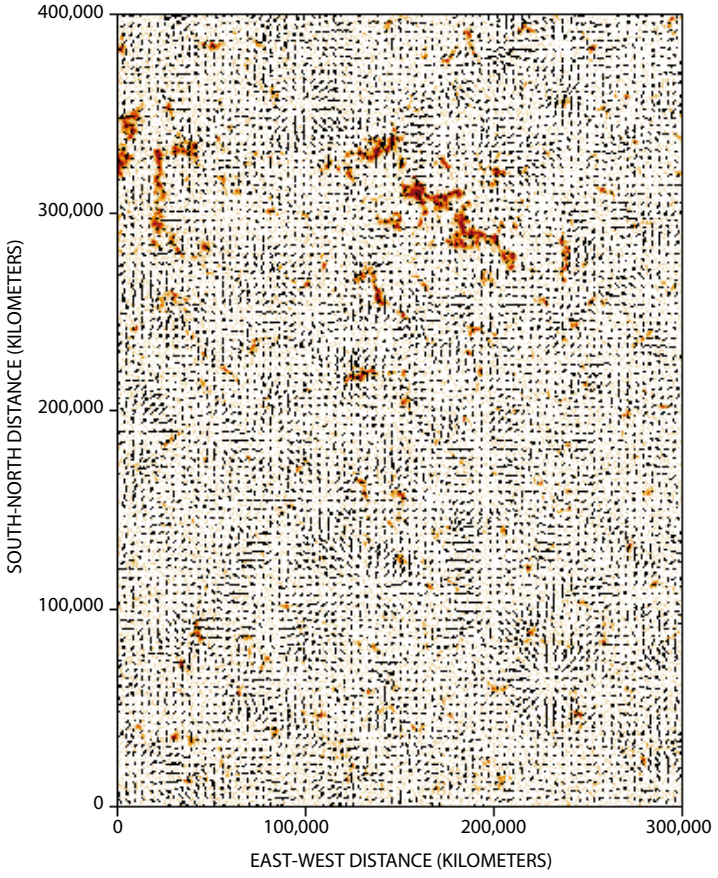
To map out structures across the solar disk, ranging in temperature from 6,000 to two million kelvins, SOHO makes use of spectral lines. These lines appear when the sun's radiation intensity is displayed as a function of wavelength. The various SOHO instruments locate regions having a specific temperature by tuning into spectral lines emitted by the ions formed there. Atoms in a hotter gas lose more electrons through collisions, and so they become more highly ionized. Because these different ions emit spectral lines at different wavelengths, they serve as a kind of thermometer. We can also infer the speed of the material moving in these regions from the Doppler wavelength changes of the spectral lines SOHO records.

Ultraviolet radiation has recently revealed that the sun is a vigorous, violent place even when its 11-year activity cycle is in an apparent slump—and this fact may help explain why the corona is so hot. The whole sun seems to sparkle in the UV light emitted by localized bright spots. According to SOHO measurements, these ubiquitous hot spots are formed at a temperature of a million kelvins, and they seem to originate in small, magnetic loops of hot gas found all over the sun, including both its north and south poles. Some of these spots explode and hurl material outward at speeds of hundreds of kilometers per second. SOHO scientists are now studying these bright spots to see if they play an important role in the elusive coronal heating mechanism.

To explore changes at higher levels in the sun's atmosphere, SOHO relies on its UVCS and its Large Angle Spectroscopic COronagraph (LASCO). Both instruments use occulting disks to block the photosphere's underlying glare. LASCO detects visible sunlight scattered by electrons in the corona. Initially it revealed a simple corona—one that was highly symmetrical and stable. This corona, viewed during the sun's magnetic lull, exhibited pronounced holes in the north and south. (Coronal holes are extended, low-density, low-temperature regions where EUV and x-ray emissions are abnormally low or absent.)

In contrast, the equatorial regions were ringed by straight, flat streamers of outflowing matter. The sun's magnetic field shapes these streamers. At their base, electrified matter is densely concentrated within magnetized loops rooted in the photosphere. Farther out in the corona, the streamers narrow and stretch tens of millions of kilometers into space. These extensions confine material at temperatures of about two million kelvins within their elongated magnetic boundaries, creating a belt of hot gas that extends around the sun.

The streamers live up to their name:



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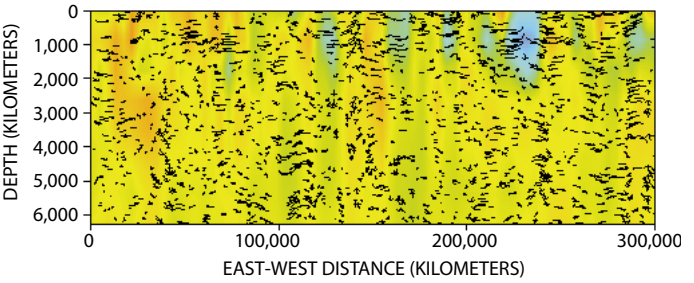


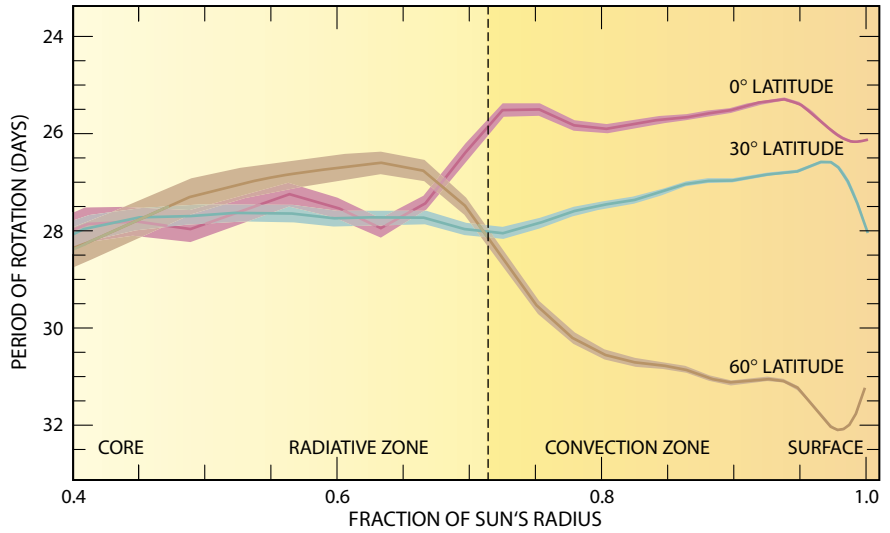
MATERIAL FLOWS through the sun both vertically and horizontally, and its movement and temperature can be inferred using SOHO's Michelson Doppler Imager. The vertical cut (*above*) shows flow and temperature changes in the outer 1 percent (the top 8,000 kilometers) of the sun. Color shading indicates changes from cool temperatures (*blue*) to hot ones (*red*). The horizontal cut (*left*) is at a depth of 1,400 kilometers; it is compared with surface magnetic fields (*dark concentrations*). In both cases, the arrows indicate the direction and relative speeds of the material, which reach a maximum velocity of one kilometer per second.

material seems to flow continuously along their open magnetic fields. Occasionally the coronagraphs record dense concentrations of material moving through an otherwise unchanging streamer—like seeing leaves floating on a moving stream. And sometimes tremendous eruptions, called coronal mass ejections, punctuate the steady outward flow. These ejections hurl billions of tons of million-degree gases into interplanetary space at speeds of hundreds of kilometers per second. This material often reaches the earth in only two or three days. To almost everyone's astonishment, LASCO found equatorial ejections emitted within hours of each other from opposite sides of the sun.

The coronagraphs have only a side view of the sun and so can barely see material moving to or from the earth. But based on what we can see, we guess that these ejections are global disturbances, extending all the way around the sun. In fact, unexpectedly wide regions of the sun seem to convulse when the star releases coronal mass ejections, at least during the minimum in the 11-year activity cycle. And the coronagraph has detected that a few days before the ejections, the streamer belt gets brighter, suggesting that more material is accruing there. The pressure and tension of this added material probably build until the streamer belt blows open in the form of an ejection. The entire process is most likely related to a large-scale global reorganization of the sun's magnetic field.

Solar Winds and Beyond

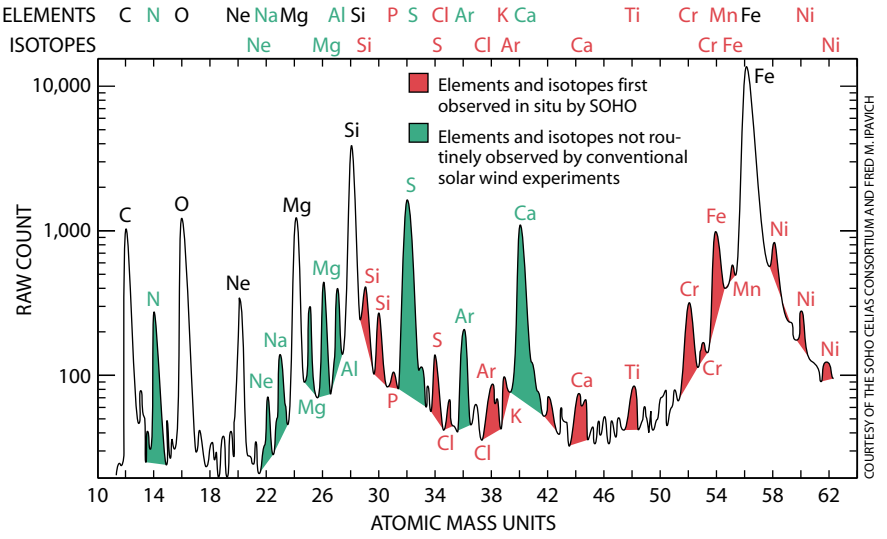
The sun's hot and stormy atmosphere is forever expanding in all directions, filling the solar system with a ceaseless flow—called the solar wind—that contains electrons, ions and magnetic fields. The million-degree corona creates an outward pressure that overcomes the sun's gravitational attraction, enabling this perpetual outward flow. The wind accelerates as it moves away from the sun, like water overflowing a dam. As the corona disperses, it must be replaced



MICHAEL GOODMAN AFTER THE SOHO SOI/MDI CONSORTIUM AND ALEXANDER G. KOSOVICHEV

INTERNAL ROTATION rate of the sun at latitudes of zero, 30 and 60 degrees has been inferred using data from the Michelson Doppler Imager. Down to the base of the convection zone, the polar regions spin more slowly than the equatorial ones do. Beyond that, uniform rotation appears to be the norm, although scientists have not yet determined rotation rates within the sun's core.

SOLAR WIND carries many elements. SOHO instruments have now distinguished sulfur, argon and calcium from such neighboring species as silicon and iron. So, too, nitrogen, carbon and oxygen are all easily identified. SOHO is also detecting rare elements, including phosphorus, chlorine, potassium, titanium, chromium, manganese and nickel.



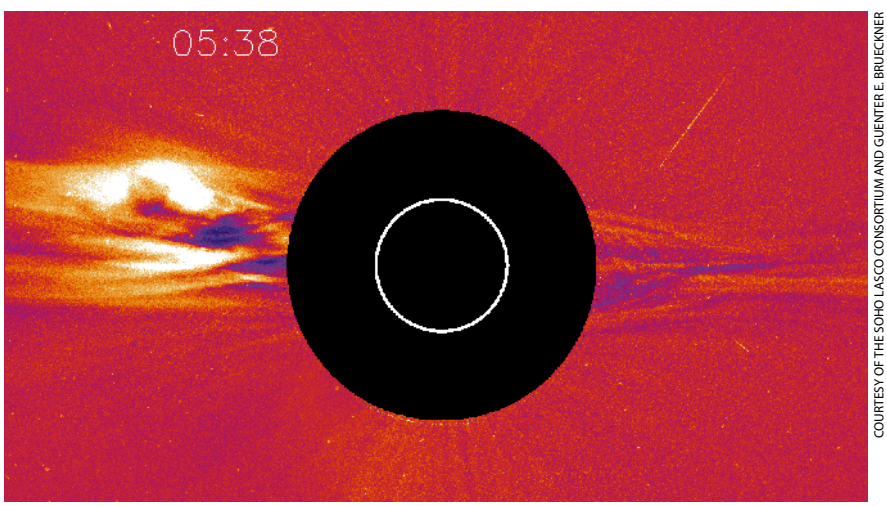
by gases welling up from below to feed the wind. Earlier spacecraft measurements, as well as those from Ulysses (launched in 1990), showed that the wind has a fast and a slow component. The fast one moves at about 800 kilometers per second; the slow one travels at half that speed.

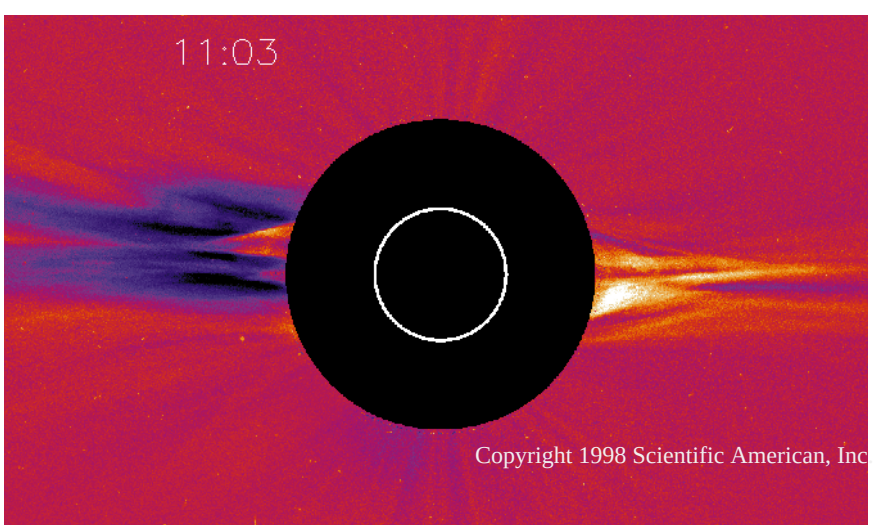
No one knows exactly where the slow-speed component originates or what gives the high-speed component its additional push, but SOHO should provide the answers. The slow component is associated with equatorial regions of the sun, now being scrutinized by LASCO and UVCS. The high-speed component pours forth from the polar coronal holes. (Open magnetic fields there allow charged particles to escape the sun's gravitational and magnetic grasp.) SOHO is now investigating whether polar plumes—tall structures rooted in the photosphere that extend into the coronal holes—help to generate this high-speed solar wind.

SOHO's UVCS has examined the spectral emission of hydrogen and heavily charged oxygen ions in the regions where the corona is heated and the solar wind accelerates. And these spectral-line profiles have produced surprising results, revealing a marked difference in the agitation speeds at which hydrogen and oxygen ions move. In polar coronal holes, where the fast solar wind originates, the heavier oxygen is far more agitated, with about 60 times more energy of motion; above two solar radii from the sun's center, oxygen has the higher agitation speed, approaching 500 kilometers per second. Hydrogen, on the other hand, moves at only 250 kilometers per second. In contrast, within equatorial regions, where the slow-speed wind begins, the lighter hydrogen moves faster than the oxygen, as one would expect from a heat-driven wind.

Researchers are now trying to determine why the more massive oxygen ions move at greater speeds in coronal holes. Information about the heating and acceleration processes is probably retained within the low-density coronal holes, wherein ions rarely collide with electrons. Frequent collisions in high-density streamers might erase any signature of the relevant processes.

Another instrument on board SOHO, the Solar Wind ANisotropies (SWAN), examines interstellar hydrogen atoms sweeping through our solar system from elsewhere. The sun's ultraviolet radiation illuminates this hydrogen, much

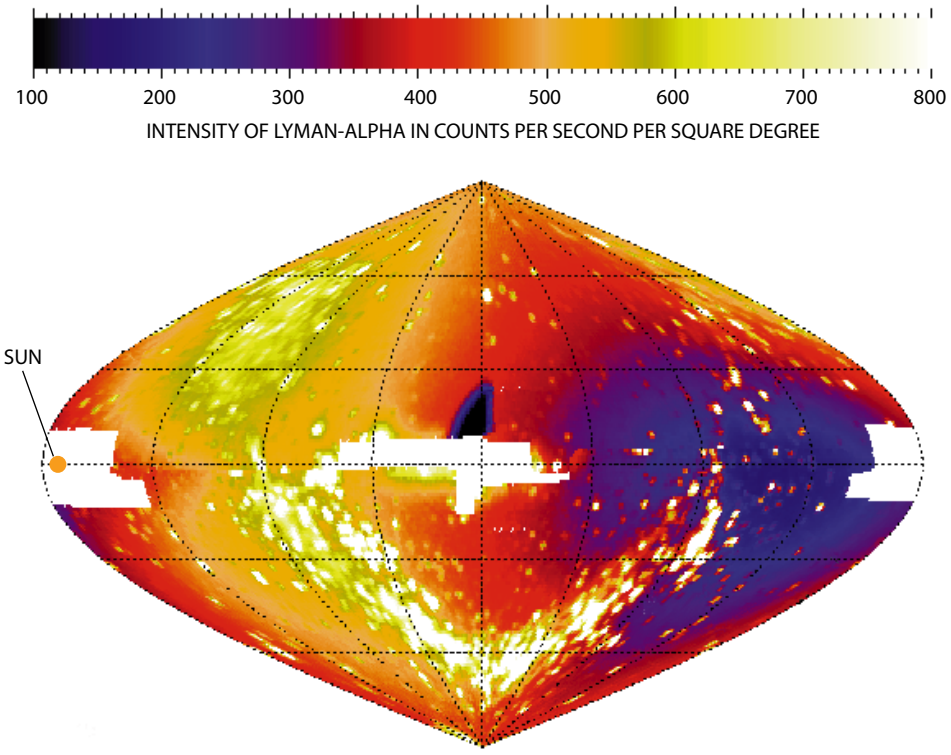




COURTESY OF THE SOHO LASCO CONSORTIUM AND GUENTER E. BRUECKNER

CORONAL MASS EJECTIONS (*white*), occurring on the east and west sides of the sun, were recorded within hours on the same day by one of SOHO's coronagraphs. The black occulting disk blocks the glare of the sun, whose visible edge is represented here by the white circle.

the way that a street lamp lights a foggy mist at night. The solar wind particles tear the hydrogen atoms apart. For this reason, where the wind passes through the interstellar hydrogen cloud, it creates a dark cavity in its wake. The ultraviolet glow detected by this instrument therefore outlines the shape of the sun's wind. So far these measurements indicate that the solar wind is more intense in the equatorial plane of the sun than over the north or south poles.



COURTESY OF THE SOHO SWAN CONSORTIUM AND JEAN-LOUP BERTAUX

INTERSTELLAR HYDROGEN glows in the ultraviolet light of the Lyman-alpha spectral line at a wavelength of 1,216 angstroms. An interstellar cloud of gas emits the diffuse regions, and hot stars produce the bright dots. The sun travels through the cloud at a velocity of 26 kilometers per second, and the solar wind creates an asymmetry in the diffuse UV glow.

Here on Earth

As our civilization becomes increasingly dependent on sophisticated systems in space, it becomes more vulnerable to sun-driven space weather. In addition to magnetic storms and power surges, forceful coronal mass ejections can trigger intense auroras in the polar skies and damage or destroy earth-orbiting satellites. Other intense eruptions, known as solar flares, hurl out energetic particles that can endanger astronauts and destroy satellite electronics. If we knew the solar magnetic changes preceding these violent events, then SOHO could provide the early warning needed to protect us from their effects.

Indeed, parked just outside the earth, SOHO can sample threatening particles before they get to us. SOHO's Charge, ELement and Isotope Analysis System (CELIAS) currently measures the abundance of rare elements and isotopes that were previously not observable. By comparing these, we can reach certain conclusions about conditions in the sun's atmosphere, where the solar wind originates. Two other instruments, the COmprehensive SupraThermal and Energetic Particle (COSTEP) analyzer and the Energetic and Relativistic Nuclei and Electron experiment (ERNE), have already obtained direct in situ measurements of very energetic electrons, protons and helium nuclei approaching the earth. They traced them back to violent eruptions detected by the EIT at the sun. Such events will surely become more numerous as we enter the next maximum in solar activity. And then SOHO will be able to follow such eruptions as they begin below the sun's visible surface and travel through the sun's atmosphere to affect the earth and the rest of the solar system.

SOHO has obtained marvelous results to date. It has revealed features on the mysterious sun never seen before or never seen so clearly. It has provided new insights into fundamental unsolved problems, all the way from the sun's interior to the earth and out to the farthest reaches of the solar wind. Some of its instruments are now poised to resolve several other mysteries. Two of them, the GOLF and VIRGO instruments, will soon have looked at the solar oscillations long enough, and deep enough, to determine the temperature and rotation at the sun's center. Moreover, during the next few years, our home star's inner turmoil and related magnetic activity—which can directly affect our daily lives—will increase. SOHO should then offer even greater scientific returns, determining how its threatening eruptions and hot, gusty winds originate and perhaps predicting conditions in the sun's atmosphere. SA

The Author

KENNETH R. LANG is professor of astronomy at Tufts University. His recent illustrated book, *Sun, Earth and Sky,* describes all aspects of the sun and its interactions with the earth. Lang has also written more than 150 professional articles and four additional books, which have been translated into seven languages. Among them is the classic reference *Astrophysical Formulae.*

Further Reading

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THE SOHO MISSION. Edited by Bernhard Fleck, Vicente Domingo and Arthur I. Poland. Special section of *Solar Physics,* Vol. 162, Nos. 1–2; 1995.
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UNSOLVED MYSTERIES OF THE SUN, Parts 1–2. Kenneth R. Lang in *Sky and Telescope,* Vol. 92, No. 2, pages 38–42; August 1996; and Vol. 92, No. 3, pages 24–28; September 1996.
SOHO images can be obtained (and freely used with appropriate acknowledgment) from the World Wide Web at http://sohowww.nascom.nasa.gov/

SPECIAL REPORT

THE INTERNET:
Fulfilling the Promise

THE INTERNET:
BRINGING ORDER FROM CHAOS

The Internet, as everybody with a modem now knows, has fallen victim to its own success. In a few short years, it has gone from being the communications province of scientists and engineers to a primary route of information exchange for everyone from financial analysts to fashion designers. So much clutter and traffic snarl the computer networks that the Clinton administration has announced its intention to build a new, separate system—the Internet II—just so that scientists can get some work done again.

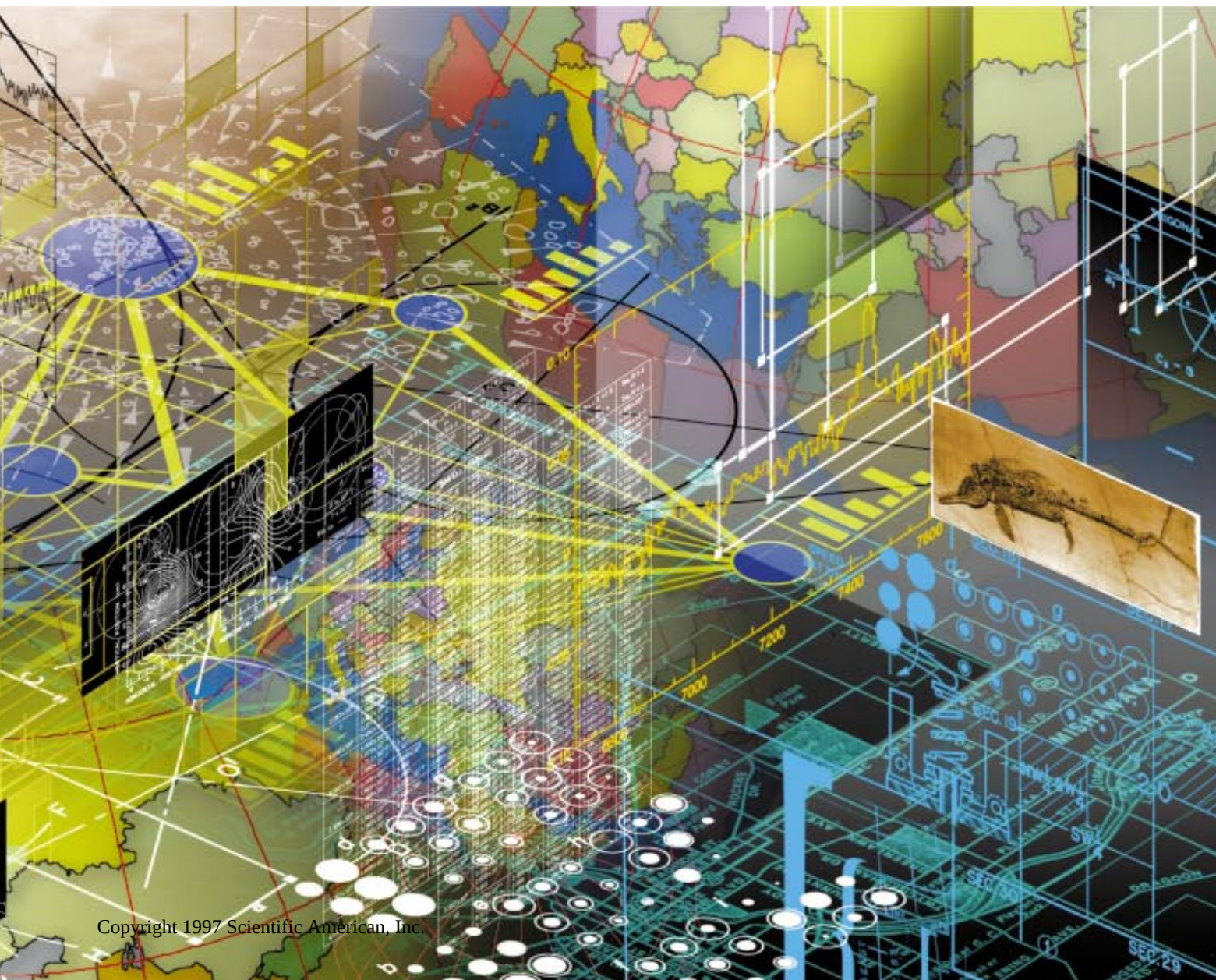
Putting the Net to work for the rest of us will be the real challenge in the years ahead. Electronic mail and even videoconferencing are already entrenched, but those applications do not cut to the heart of what the World Wide Web and the rest of the Internet constitute a gigantic storehouses of raw information and analysis, the database of all databases. Worries about the future of the Net usually center on the delays and access limitations caused by its overburdened hardware infrastructure. Those may be no more than growing pains, however. The more serious, longer-range obstacle is that much of the information on the Internet is quirky, transient and chaotically "shelved."

In the pages that follow, noted technologists tackle ques-

tions about how to organize knowledge on the Internet with the aim of making it more genuinely useful. From a variety of standpoints, they consider how to simplify finding the information we desire (yes, there is life beyond today's search engines). They discuss the best ways to format and display data, so that everyone (including the blind) has maximum access to them, in as many ways as can be imagined. The creative technological solutions that they propose may not be the approaches that are finally adopted, but their ideas will certainly provoke further awareness and constructive thinking about the problems. (More on all these themes can be found on *Scientific American*'s Web site at http://www.sciam.com)

Bringing a measure of organization and structure to an inherently fluid medium like the Web may help realize the 18th-century French encyclopedists' vision of gathering together all the world's knowledge in one place. Two centuries later Vannevar Bush, the U.S. director of the Office of Scientific Research and Development during World War II, proposed the memex, a desk containing a microfilm reader and stores of film that would serve as the equivalent of an entire research library. The memex would allow different items in the microfilm collection to be linked together and annotated by the reader. Bush's ideas influenced Ted Nelson, who conceived of the hypertext system that was ultimately fashioned by others into the Web. The same intellectual dynamism is on view in the articles in this special report.

The authors, perhaps members of a new generation of encyclopedists, sketch a technological pathway that might take the Internet a step toward realizing the utopian vision of an all-encompassing repository of human knowledge. In this conception, the Internet will become a place where the musings of Homer, Shakespeare and Lao-tzu will reside just a mouse click away from school lunch menus and agendas for the next city council meeting—a permanent record of all human activity, from the high-minded to the mundane. *—The Editors*

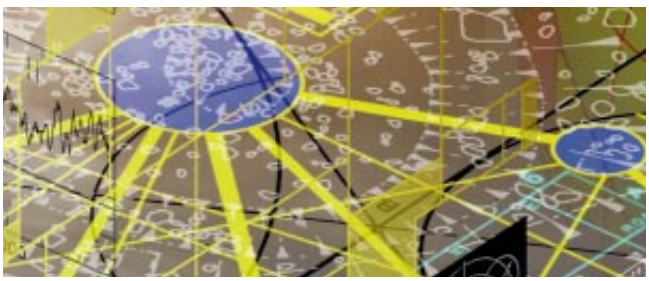


JEFF BRICE

SEARCHING THE INTERNET

Combining the skills of the librarian and the computer scientist may help organize the anarchy of the Internet

by Clifford Lynch



JEFF BRICE

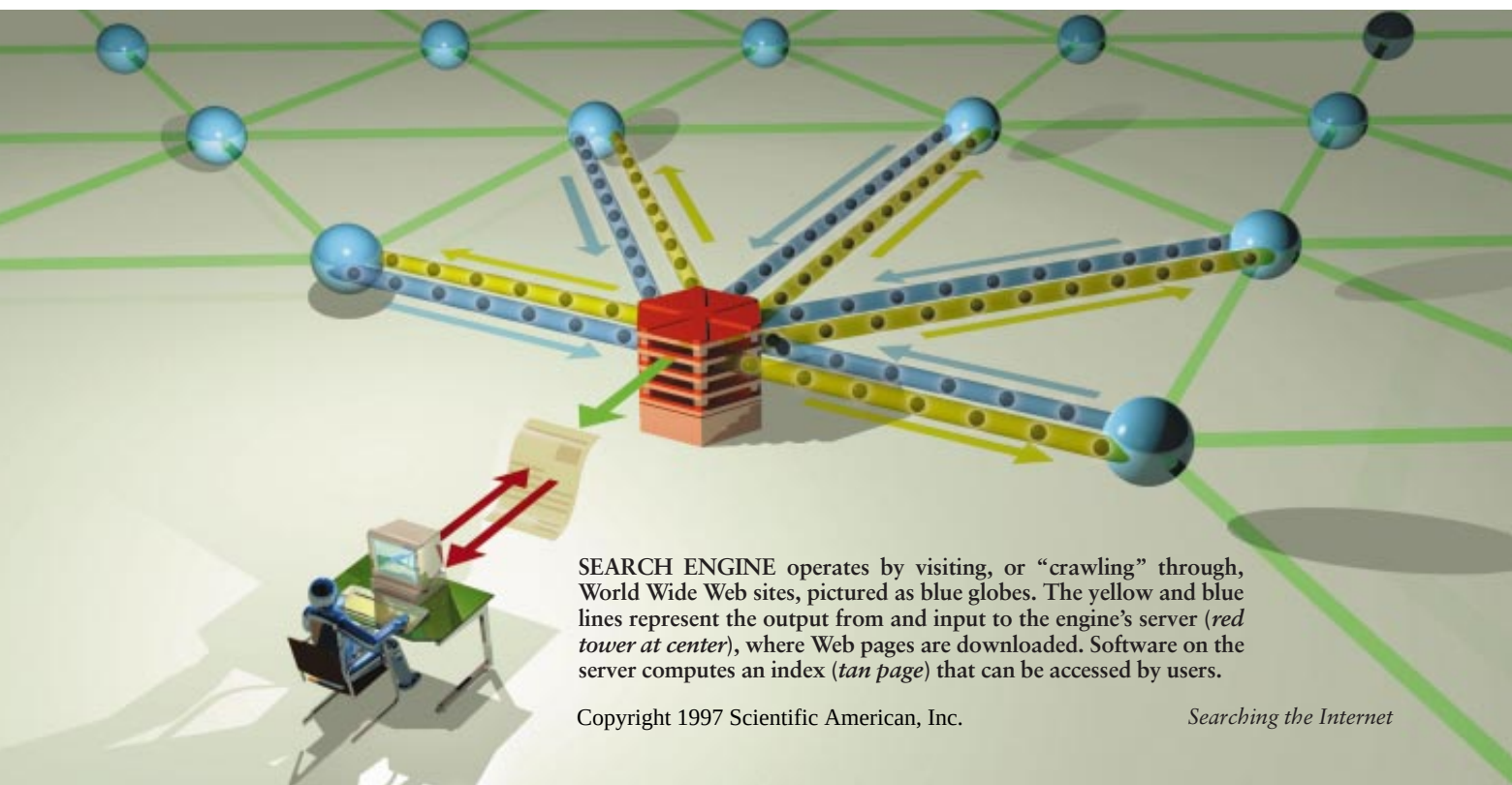
One sometimes hears the Internet characterized as the world's library for the digital age. This description does not stand up under even casual examination. The Internet—and particularly its collection of multimedia resources known as the World Wide Web—was not designed to support the organized publication and retrieval of information, as libraries are. It has evolved into what might be thought of as a chaotic repository for the collective output of the world's digital "printing presses." This storehouse of information contains not only books and papers but raw scientific data, menus, meeting minutes, advertisements, video and audio recordings, and transcripts of interactive conversations. The ephemeral mixes everywhere with works of lasting importance.

In short, the Net is not a digital library. But if it is to continue to grow and thrive as a new means of communication, something very much like traditional library services will be needed to organize, access and preserve networked information. Even then, the Net will not resemble a traditional library, because its contents are more widely dispersed than a standard collection. Consequently, the librarian's classification and selection skills must be complemented by the computer scientist's ability to automate the task of indexing and storing information. Only a synthesis of the differing perspectives brought by both professions will allow this new medium to remain viable.

At the moment, computer technology bears most of the responsibility for organizing information on the Internet. In theory, software that automatically classifies and indexes collections of digital data can address the glut of information on the Net—and the inability of human indexers and bibliographers to cope with it. Automating information access has the advantage of directly exploiting the rapidly dropping costs of computers and avoiding the high expense and delays of human indexing.

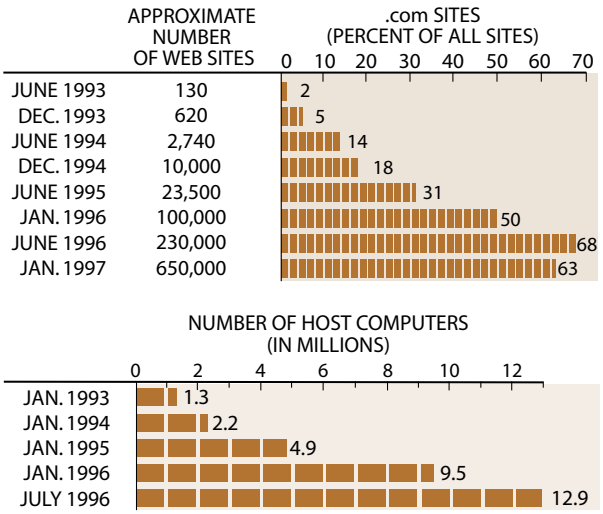
But, as anyone who has ever sought information on the Web knows, these automated tools categorize information differently than people do. In one sense, the job performed by the various indexing and cataloguing tools known as search engines is highly democratic. Machine-based approaches provide uniform

BRYAN CHRISTIE



SEARCH ENGINE operates by visiting, or "crawling" through, World Wide Web sites, pictured as blue globes. The yellow and blue lines represent the output from and input to the engine's server (*red tower at center*), where Web pages are downloaded. Software on the server computes an index (*tan page*) that can be accessed by users.

and equal access to all the information on the Net. In practice, this electronic egalitarianism can prove a mixed blessing. Web "surfers" who type in a search request are often overwhelmed by thousands of responses. The search results frequently contain references to irrelevant Web sites while leaving out others that hold important material.



GROWTH AND CHANGE on the Internet are reflected in the burgeoning number of Web sites, host computers and commercial, or ".com," sites.

Crawling the Web

The nature of electronic indexing can be understood by examining the way Web search engines, such as Lycos or Digital Equipment Corporation's AltaVista, construct indexes and find information requested by a user. Periodically, they dispatch programs (sometimes referred to as Web crawlers, spiders or indexing robots) to every site they can identify on the Web—each site being a set of documents, called pages, that can be accessed over the network. The Web crawlers download and then examine these pages and extract indexing information that can be used to describe them. This process—details of which vary among search engines—may include simply locating most of the words that appear in Web pages or performing sophisticated analyses to identify key words and phrases. These data are then stored in the search engine's database, along with an address, termed a uniform resource locator (URL), that represents where the file resides. A user then deploys a browser, such as the familiar Netscape, to submit queries to the search engine's database. The query produces a list of Web resources, the URLs that can be clicked on to connect to the sites identified by the search.

Existing search engines service millions of queries a day. Yet it has become clear that they are less than ideal for retrieving an ever growing body of information on the Web. In contrast to human indexers, automated programs have difficulty identifying characteristics of a document such as its overall theme or its genre—whether it is a poem or a play, or even an advertisement.

The Web, moreover, still lacks standards that would facilitate automated indexing. As a result, documents on the Web are not structured so that programs can reliably extract the routine information that a human indexer might find through a cursory inspection: author, date of publication, length of text and subject matter. (This information is known as metadata.) A Web crawler might turn up the desired article authored by Jane Doe. But it might also find thousands of other articles in which such a common name is mentioned in the text or in a bibliographic reference.

Publishers sometimes abuse the indiscriminate character of automated indexing. A Web site can bias the selection process to attract attention to itself by repeating within a document a word, such as "sex," that is known to be queried often. The reason: a search engine will display first the URLs for the documents that mention a search term most frequently. In contrast, humans can easily see around simpleminded tricks.

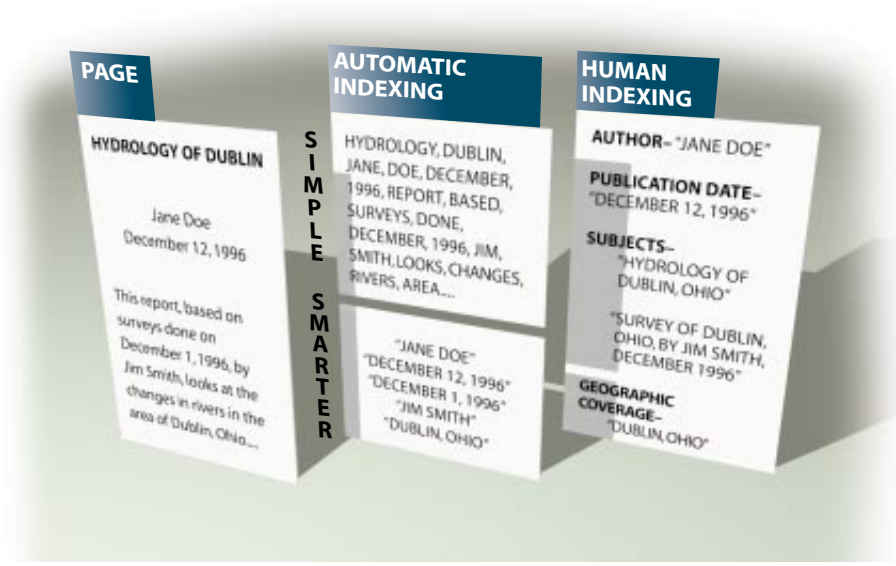
The professional indexer can describe the components of individual pages of all sorts (from text to video) and can clarify how those parts fit together into a database of information. Civil War photographs, for example, might form part of a collection that also includes period music and soldier diaries. A human indexer can describe a site's rules for the collection and retention of programs in, say, an archive that stores Macintosh software. Analyses of a site's purpose, history and policies are beyond the capabilities of a crawler program.

Another drawback of automated indexing is that most search engines recognize text only. The intense interest in the Web, though, has come about because of the medium's ability to display images, whether graphics or video clips. Some research has moved forward toward finding colors or patterns within images [*see box on next two pages*]. But no program can deduce the underlying meaning and cultural significance of an image (for example, that a group of men dining represents the Last Supper).

At the same time, the way information is structured on the Web is changing so that it often cannot be examined by Web crawlers. Many Web pages are no longer static files that can be analyzed and indexed by such programs. In many cases, the information displayed in a document is computed by the Web site during a search in response to the user's request. The site might assemble a map, a table and a text document from different areas of its database, a disparate collection of information that conforms to the user's query. A newspaper's Web site, for instance, might allow a reader to specify that only stories on the oil-equipment business be displayed in a personalized version of the paper. The database of stories from which this document is put together could not be searched by a Web crawler that visits the site.

A growing body of research has attempted to address some of the problems involved with automated classification methods. One approach seeks to attach metadata to files so that indexing systems can collect this information. The most advanced effort is the Dublin Core Metadata program and an affiliated endeavor, the Warwick Framework—the first named after a workshop in Dublin, Ohio, the other for a colloquy in Warwick, England. The workshops have defined a set of metadata elements that are simpler than those in traditional library cataloguing and have also created methods for incorporating them within pages on the Web.

Categorization of metadata might range from title or author to type of document (text or video, for instance). Either automated indexing software or humans may derive the metadata, which can then be attached to a Web page for retrieval by a crawler. Precise and de-



BRYAN CHRISTIE

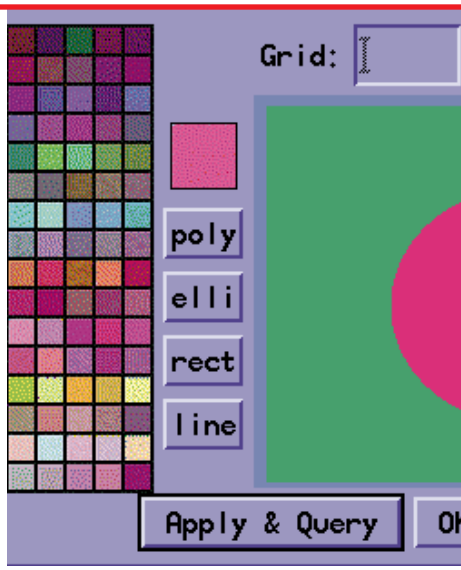
AUTOMATED INDEXING, used by Web crawler software, analyzes a page (*left panel*) by designating most words as indexing terms (*top center*) or by grouping words into simple phrases (*bottom center*). Human indexing (*right*) gives additional context about the subject of a page.

tailed human annotations can provide a more in-depth characterization of a page than can an automated indexing program alone.

Where costs can be justified, human indexers have begun the laborious task of compiling bibliographies of some Web sites. The Yahoo database, a commercial venture, classifies sites by broad subject area. And a research project at the University of Michigan is one of

Finding Pictures on the Web

by Gary Stix, *staff writer*



The Internet came into its own a few years ago, when the World Wide Web arrived with its dazzling array of photography, animation, graphics, sound and video that ranged in subject matter from high art to the patently lewd. Despite the multimedia barrage, finding things on the hundreds of thousands of Web sites still mostly requires searching indexes for words and numbers.

Someone who types the words "French flag" into the popular search engine AltaVista might retrieve the requested graphic, as long as it were captioned by those two identifying words. But what if someone could visualize a blue, white and red banner but did not know its country of origin?

Ideally, a search engine should allow the user to draw or scan in a rectangle with vertical thirds that are colored blue, white and red—and then find any matching images stored on myriad Web sites. In the past few years, techniques that combine key-word indexing with image analysis have begun to pave the way for the first image search engines.

Although these prototypes suggest possibilities for the indexing of visual information, they also demonstrate the crudeness of existing tools and the continuing reliance on text to track down imagery. One project, called WebSEEk, based at Columbia University, illustrates the workings of an image search engine. WebSEEk begins by downloading files found by trolling the Web. It then attempts to locate file names containing acronyms, such as GIF or MPEG, that designate graphics or video content. It also looks for words in the names that might identify the subject of the files. When the software finds an image, it analyzes the prevalence of different colors and where they are located. Using this information, it can distinguish among photographs, graphics and black-and-white or gray images. The software also compresses each picture so that it can be represented as an icon, a miniature image for display alongside other icons. For a video, it will extract key frames from different scenes.

A user begins a search by selecting a category from a menu—"cats," for example. WebSEEk provides a sampling of icons for the "cats" category. To narrow the search, the user can click on any icons that show black cats. Using its previously generated color analysis, the search engine looks for matches of images that have a similar color profile. The presentation of the next set of icons may show black cats—but also some marmalade cats sitting on black cushions. A visitor to WebSEEk can refine a search by adding or excluding certain colors from an image when initiating subsequent queries. Leaving out yellows or oranges might get rid of the odd marmalade. More simply, when presented with a series of icons, the user can also specify those images that do not contain black cats in order to guide the program away from mistaken choices. So far WebSEEk has downloaded and indexed more than 650,000 pictures from tens of thousands of Web sites.

Other image-searching projects include efforts at the University of Chicago, the University of California at San Diego, Carnegie Mellon University, the Massachusetts Institute of Technology's Media Lab and the University of California at Berkeley. A number of commercial companies, including IBM and Virage, have crafted software that can be used for searching corporate networks or databases. And two companies—Excalibur Technologies and Interpix Software—have collaborated to supply software to the Web-based indexing concerns Yahoo and Infoseek.

One of the oldest image searchers, IBM's Query by Image Content (QBIC), produces more sophisticated matching of image features than, say, WebSEEk can. It is able not only to pick out the col-

several efforts to develop more formal descriptions of sites that contain material of scholarly interest.

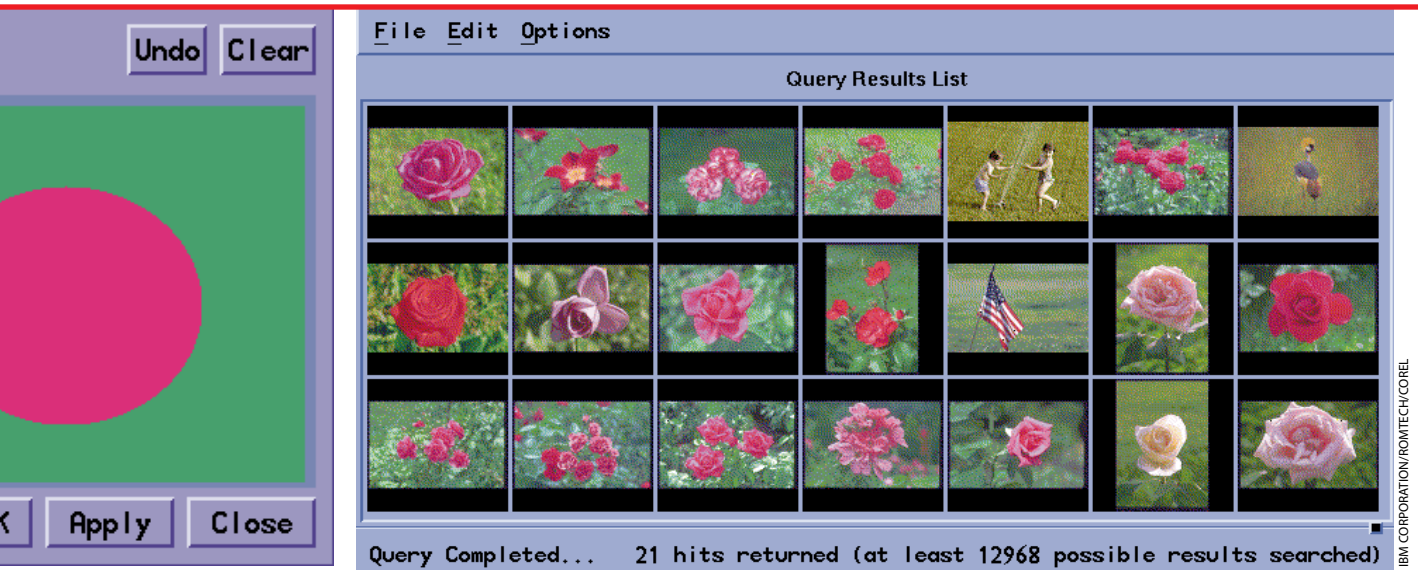
Not Just a Library

The extent to which either human classification skills or automated indexing and searching strategies are needed will depend on the people who use the Internet and on the business prospects for publishers. For many communities of scholars, the model of an organized collection—a digital library—still remains relevant. For other groups, an uncontrolled, democratic medium may provide the best vehicle for information dissemination. Some users, from financial analysts to spies, want comprehensive access to raw databases of information, free of any controls or editing. For them, standard search engines provide real benefits because they forgo any selective filtering of data.

The diversity of materials on the Net goes far beyond the scope of the traditional library. A library does not provide quality rankings of the works in a collection. Because of the greater volume of networked information, Net users want guidance about where to spend the limited amount of time they have to research a subject. They may need to know the three "best" documents for a given purpose. They want this information without paying the costs of employing humans to critique the myriad Web sites. One solution that again calls for human involvement is to share judgments about what is worthwhile. Software-based rating systems have begun to let users describe the quality of particular Web sites [see "Filtering Information on the Internet," by Paul Resnick, page 62].

Software tools search the Internet and also separate the good from the bad. New programs may be needed, though, to ease the burden of feeding the crawlers that repeatedly scan Web sites. Some Web site managers have reported that their computers are spending enormous amounts of time in providing crawlers with information to index, instead of servicing the people they hope to attract with their offerings.

To address this issue, Mike Schwartz



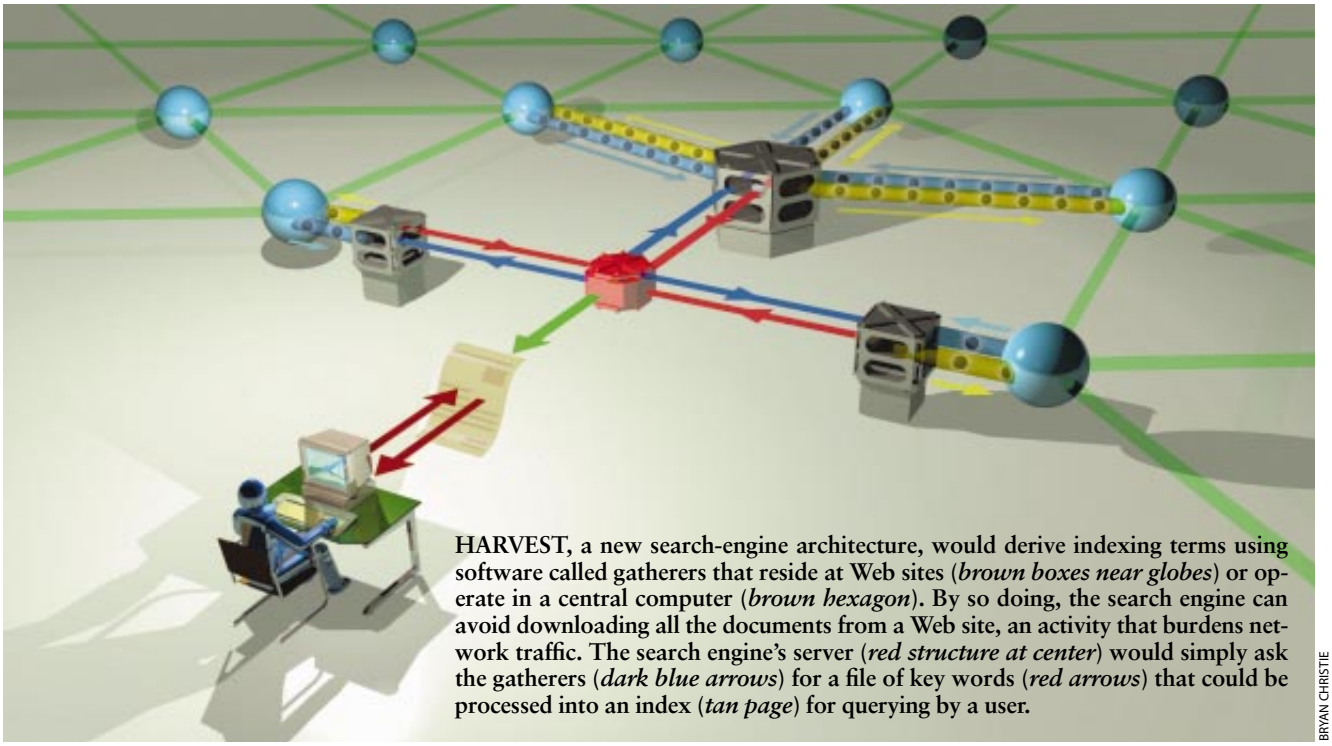
IBM CORPORATION/ROMTECH/COREL

ors in an image but also to gauge texture by several measures—contrast (the black and white of zebra stripes), coarseness (stones versus pebbles) and directionality (linear fence posts versus omnidirectional flower petals). QBIC also has a limited ability to search for shapes within an image. Specifying a pink dot on a green background turns up flowers and other photographs with similar shapes and colors, as shown above. Possible applications range from the selection of wallpaper patterns to enabling police to identify gang members by clothing type.

All these programs do nothing more than match one visual feature with another. They still require a human observer—or accompanying text—to confirm whether an object is a cat or a cushion. For more than a decade, the artificial-intelligence community has labored, with mixed success, on nudging computers to ascertain directly the identity of objects within an image, whether they are cats or national flags. This approach correlates the shapes in a picture with geometric models of real-world objects. The program can then deduce that a pink or brown cylinder, say, is a human arm.

One example is software that looks for naked people, a program that is the work of David A. Forsyth of Berkeley and Margaret M. Fleck of the University of Iowa. The software begins by analyzing the color and texture of a photograph. When it finds matches for flesh colors, it runs an algorithm that looks for cylindrical areas that might correspond to an arm or leg. It then seeks other flesh-colored cylinders, positioned at certain angles, which might confirm the presence of limbs. In a test last fall, the program picked out 43 percent of the 565 naked people among a group of 4,854 images, a high percentage for this type of complex image analysis. It registered, moreover, only a 4 percent false positive rate among the 4,289 images that did not contain naked bodies. The nudes were downloaded from the Web; the other photographs came primarily from commercial databases.

The challenges of computer vision will most likely remain for a decade or so to come. Searches capable of distinguishing clearly among nudes, marmalades and national flags are still an unrealized dream. As time goes on, though, researchers would like to give the programs that collect information from the Internet the ability to understand what they see.



HARVEST, a new search-engine architecture, would derive indexing terms using software called gatherers that reside at Web sites (*brown boxes near globes*) or operate in a central computer (*brown hexagon*). By so doing, the search engine can avoid downloading all the documents from a Web site, an activity that burdens network traffic. The search engine's server (*red structure at center*) would simply ask the gatherers (*dark blue arrows*) for a file of key words (*red arrows*) that could be processed into an index (*tan page*) for querying by a user.

BRYAN CHRISTIE

and his colleagues at the University of Colorado at Boulder developed software, called Harvest, that lets a Web site compile indexing data for the pages it holds and to ship the information on request to the Web sites for the various search engines. In so doing, Harvest's automated indexing program, or gatherer, can avoid having a Web crawler export the entire contents of a given site across the network.

Crawler programs bring a copy of each page back to their home sites to extract the terms that make up an index, a process that consumes a great deal of network capacity (bandwidth). The gatherer, instead, sends only a file of indexing terms. Moreover, it exports only information about those pages that have been altered since they were last accessed, thus alleviating the load on the network and the computers tied to it.

Gatherers might also serve a different function. They may give publishers a framework to restrict the information that gets exported from their Web sites. This degree of control is needed because the Web has begun to evolve beyond a distribution medium for free information. Increasingly, it facilitates access to proprietary information that is furnished for a fee. This material may not be open for the perusal of Web crawlers. Gatherers, though, could distribute only the information that publishers wish to make available, such as links to summaries or samples of the information stored at a site.

As the Net matures, the decision to opt for a given information collection method will depend mostly on users. For which users will it then come to resemble a library, with a structured approach to building collections? And for whom will it remain anarchic, with access supplied by automated systems?

Users willing to pay a fee to underwrite the work of authors, publishers, indexers and reviewers can sustain the tradition of the library. In cases where information is furnished without charge or is advertiser supported, low-cost computer-based indexing will most likely dominate—the same unstructured environment that characterizes much of the contemporary Internet. Thus, social and economic issues, rather than technological ones, will exert the greatest influence in shaping the future of information retrieval on the Internet. SA

The Author

CLIFFORD LYNCH is director of library automation at the University of California's Office of the President, where he oversees MELVYL, one of the largest public-access information retrieval systems. Lynch, who received a doctorate in computer science from the University of California, Berkeley, also teaches at Berkeley's School of Information Management and Systems. He is a past president of the American Society for Information Science and a fellow of the American Association for the Advancement of Science. He leads the Architectures and Standards Working Group for the Coalition for Network Information.

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JEFF BRICE

GOING DIGITAL

Electronic libraries will make today's Internet pale by comparison. But building them will not be easy

by Michael Lesk

Smack in the middle of Paris, hugging the bank of the Seine, four enormous high-rises stand ready, with 395 kilometers of shelf space, to receive up to 22 million books. The French national library's new Tolbiac tower complex may be both the last and the first of its kind. Last because most major cities can no longer afford to construct such ambitious public works. But first because the Bibliothèque Nationale de France will complete its move with a pièce de résistance: hundreds of computer workstations providing ready electronic access to the full text of 110,000 volumes covering much of French history and culture.

All over the world, libraries have begun the Herculean task of making faithful digital copies of the books, images and recordings that preserve the intellectual effort of humankind. For armchair scholars, the work promises to bring such a wealth of information to the desktop that the present Internet may seem amateurish in retrospect. But many technical, economic and legal obstacles still make that promise an uncertain one.

Librarians see three clear benefits to going digital. First, it helps them preserve rare and fragile objects without denying access to those who wish to study them. The British Library, for example, holds the only medieval manuscript of *Beowulf* in London. Only qualified scholars were allowed to see it until Kevin S. Kiernan of the University of Kentucky scanned the manuscript with three different light sources (revealing details not normally apparent to the naked eye) and put the images up on the Internet for anyone to peruse. Tokyo's National Diet Library is similarly creating highly detailed digital photographs of 1,236 woodblock prints, scrolls and other materials it considers national treasures so that researchers can scrutinize them without handling the originals.

A second benefit is convenience. Once books are converted to digital form, patrons can retrieve them in seconds rather than minutes. Several people can simultaneously read the same book or view the same picture. Clerks are spared the chore of reshelving. And libraries could conceivably use the Internet to lend their virtual collections to those who are unable to visit in person.

The third advantage of electronic copies is that they occupy millimeters of space on a magnetic disk rather than meters on a shelf. Expanding library buildings is increasingly costly. The University of California at Berkeley recently spent $46 million on an underground addition to house 1.5 million books—an average cost of $30 per volume. The price of disk storage, in contrast, has fallen to about $2 per 300-page publication and continues to drop.

Technological Trade-offs

Not all these benefits can be enjoyed at once. Each of the several technologies libraries can choose from to digitize their holdings imposes certain trade-offs between preservation, convenience and cost. Scanning pages into digital pictures, for example, is the cheapest. Anne Kenney of Cornell University found in 1992 that 19th-century books could be transformed into page images for $30 to $40 per volume, with most of that cost going to pay the wages of scanner operators. Kodak's PhotoCD

AGENCE FRANCE-PRESSE

MICHEL GANGNE *Agence France-Presse*

TOLBIAC TOWERS, the giant new home of France's national library in central Paris (*seen at left*), have shelf space for 22 million books. But 100,000 of the library's volumes, stored digitally as page images, will require almost no space and will be instantly accessible via workstations placed throughout the complex.

technology, which automates the process of digitizing photographic negatives, can lower this cost considerably. Using PhotoCD, Harvard University was able to convert 80,000 posters from its Judaica holdings at a rate of 1,000 a day and a cost of just $2 each. Because libraries are perennially strapped for funds, most of the objects currently scheduled for conversion—including 91 percent of the French national library's electronic books and five million items that the Library of Congress intends to digitize by the year 2000—will be scanned.

Scanning is also a good choice for the purposes of preservation. It captures the look of a book and any notes scribbled in its margins. And highly detailed nontextual items can be converted into high-resolution images. To be sure, this can produce unwieldy files. Ensuring a legible image of a map 15 by 31 inches with printing only 0.05 inch high, for example, requires scanning it as a 4,500-by-9,300-pixel, 125-megabyte file—large enough to choke a desktop computer. But more powerful machines and new image formats that can be rendered at lower resolutions when desired should eventually remove this obstacle.

The main drawback of scanning is that it produces only digital images, which, like the typeset pages of books, are good only for viewing. There is as yet no easy way to find a particular quote or passage buried within a scanned book. Pictures of text cannot easily be e-mailed to a friend or pasted into a book report. And for visually impaired users, images of books are no more accessible than the books themselves [see "Websurfing without a Monitor," by T. V. Raman, page 73].

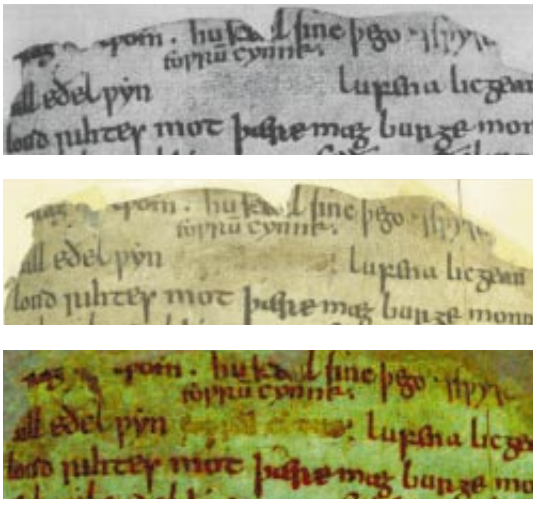
For many purposes, electronic text—of the kind that can be manipulated and indexed by word processors—would be much more convenient than the scanned images. The least expensive way to convert printed matter into electronic text is to use optical character-recognition (OCR) software. These programs, which use pattern-matching techniques to extract words letter by letter from scanned images, have indeed grown considerably cheaper and slightly more accurate in recent years. The leading programs can now identify more than 99 percent of the characters in standard test images correctly—but this still means that they produce a dozen or more errors on every page. That many mistakes may be acceptable if the converted text will be used only for indexing and not for reading. Otherwise, the errors must be corrected by hand, a labor-intensive process that costs as much or more than scanning.

The Andrew W. Mellon Foundation has been using the latter approach in its Journal Storage Project to digitize 10 popular economics and history journals. Although the project pays 39 cents a page—the equivalent of $120 for a 300-page book—for scanning, OCR and correction, the foundation believes it will easily recoup this expense through reduced cataloging and storage costs. (As text files, books take up only one tenth the disk space they occupy as page image files.) Plus, the investment will allow readers to identify interesting articles much faster.

Of course, any archive that aspires to replace paper publications must include the drawings and photographs present in the original works. But illustrations confuse OCR programs. Fortunately, other software has recently been developed that can automatically identify illustrations so that they can be preserved as images and placed at appropriate points in the electronic text. The technique, used by the American Chemical Society to extract almost 400,000 figures and diagrams from 428,000 pages of chemistry journals, relies on the fact that text darkens the page in a regular, predictable way, whereas drawings tend to be lighter and irregular [*see illustration on next page*].

The slowest way to get a book into a computer is to type it in. It is also the most expensive method, even though there are now companies in Asia, employing thousands of low-wage typists, that can handle enormous jobs. Keying, especially when performed by those who do not understand the language they are copying, does generally capture misspellings and idiosyncrasies in the original that are often inadvertently "corrected" by OCR. And for formatted texts, such as the *Oxford English Dictionary,* with its many different fonts cueing subtle details of information, retyping is the only reliable way to convert the text to digital form. But keying is prohibitively expensive for all but the most important works: ordinary 300-page texts run $600; encoding the document's format in Hypertext Markup Language (HTML, the computer language used on the World Wide Web) or one of its many cousins can cost $900—30 times as much as simply scanning the pages.

Today nearly all the new material bought by libraries originates in a computer somewhere. Increasingly, libraries are able to license large quantities of material on CD-ROM or some other machine-readable form, thus avoiding the need for conversion altogether. The Institute of Electrical and Electronics Engineers (IEEE), for example, encodes all the 62 journals it publishes in markup language for on-line viewing. Because patrons generally use the newer items at a library much more frequently than its older holdings, I expect that by 2000, half the material accessed in most ma-



BY PERMISSION OF THE BRITISH LIBRARY

SCANS OF *BEOWULF* illuminated by daylight (*top*), backlighting (*middle*) and ultraviolet light (*bottom*), now available on the Internet, reveal details not immediately apparent in the original, which is held safely in the British Library in London.

By 2000, half the material accessed in major libraries will be digital.

jor libraries will be digital. Yet it will probably take another decade beyond that before half the libraries' materials will be available in digital formats.

Hazards in the Road Ahead

This transition poses some risks. In the 1980s, when many libraries computerized their catalogues, librarians found that after a third or so of the book records were on-line, users tended to ignore the rest. Similarly, as the books themselves move on-line, any library that does not provide on-line access to old material will find those books orphaned. For all its potential to improve scholarship, the electronic library may for a time have the opposite effect.

The uncertainty over copyright issues for digital works also raises thorny problems. When IBM prepared a CD-ROM for the 500th anniversary of Columbus's famous voyage, the company reportedly had to spend $1 million to obtain the necessary copyright permissions. So far most libraries have dodged the administrative headaches by converting only materials published before 1920 (and thus out of copyright). The Library of Congress, for instance, has digitized thousands of Civil War photographs, Continental Congress documents and speeches from World War I—but not *Gone with the Wind*. When Cornell University chose to convert key agricultural literature from 1850 to 1950 for the benefit of developing nations, it carefully avoided all copyrighted books.

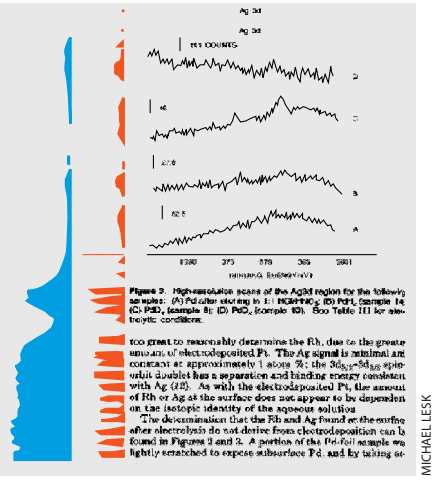
Unless libraries are allowed to share digital copies of works as easily as they share actual copies, visitors to a library 20 years hence may find everything on-line except a strange pile of books published from 1920 to 1990, a kind of Sargasso Sea of publishing relegated to the stacks. The restrictions may make it difficult to raise the millions of dollars needed for conversion projects. *Gone with the Wind* was checked out many more times last year than any World War I oration; digitizing the most popular holdings first is a good way to drum up popular support.

Failing that, institutions could team up to share their virtual collections over the Internet, splitting the costs of creating them. But political and organizational questions—How much service should libraries provide to people who are far away? How can the burden of buying and storing material be shared fairly by different institutions?—have so far thwarted attempts at cooperation.

Once these obstacles are cleared, and millions of books, pictures and recordings have been digitized, will our children be able to find, view, search and print them? Physically durable devices are not an answer; the problem is technological obsolescence [see "Ensuring the Longevity of Digital Documents," by Jeff Rothenberg; SCIENTIFIC AMERICAN, January 1995]. Every few years, librarians will have to move their collections to new formats on new devices. Copying files from one device to another should pose little difficulty—bits are bits. Software formats are more plentiful and changeable, however, so it is easier to fall behind.

Moreover, some formats simply cannot be translated into others without losing information. The increasing acceptance of standard formats for images and formatted text helps. But some of the standards, such as SGML (Standardized General Markup Language) for text, are so loosely defined that no single program can easily display all the files that adhere to it.

Libraries are not the only information repositories going digital. The choices and issues they face also apply to government agencies such as the National Aeronautics and Space Administration and the National Archives, to businesses scanning blueprints and health care records—even to the Mormons as they digitize birth and marriage records around the world. Conversion efforts will take decades and cost billions. But just as we now hear Bach fugues played on the piano as well as the harpsichord, read Shakespeare's plays on paper as well as recite them aloud, and watch Charlie Chaplin on videotape as well as film, in time we will use networked computers to enjoy the wealth of human creativity more easily, affordably and gently than ever before. SA



MICHAEL LESK

SEPARATION OF IMAGES from text in scanned pages is performed automatically by software developed for the American Chemical Society. The program examines the density of black pixels in each vertical stripe down the page to identify column boundaries. Next, it measures the pixel density of horizontal scan lines (*orange*) and mathematically derives the regular spacing between lines of text. Then the software computes an autocorrelation function (*blue*) that yields high values for evenly spaced text and much lower values for illustrations. By selecting regions that fall below a certain threshold, the system reliably isolates images.

The Author

MICHAEL LESK is a chief research scientist at Bellcore in Morristown, N.J. He is best known for work in electronic libraries, including the CORE project for chemical information, and for writing some Unix system utilities, such as those for table printing (tbl) and intersystem mail (uucp). Lesk is a Fellow of the ACM and a visiting professor of computer science at University College London. During 1987 he was Senior Visiting Fellow of the British Library.

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JEFF BRICE

FILTERING INFORMATION ON THE INTERNET

Look for the labels to decide if unknown software and World Wide Web sites are safe and interesting

by Paul Resnick

The Internet is often called a global village, suggesting a huge but close-knit community that shares common values and experiences. The metaphor is misleading. Many cultures coexist on the Internet and at times clash. In its public spaces, people interact commercially and socially with strangers as well as with acquaintances and friends. The city is a more apt metaphor, with its suggestion of unlimited opportunities and myriad dangers.

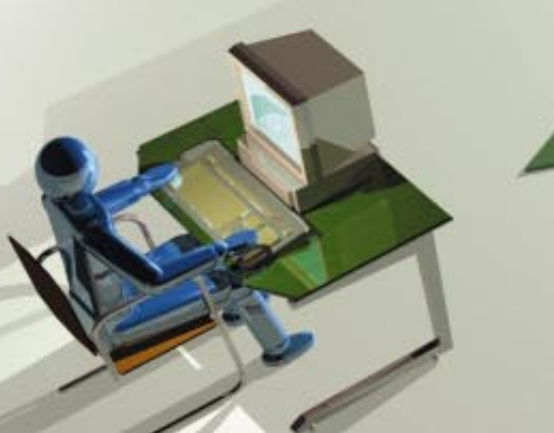
To steer clear of the most obviously offensive, dangerous or just boring neighborhoods, users can employ some mechanical filtering techniques that identify easily definable risks. One technique is to analyze the contents of on-line material. Thus, virus-detection software searches for code fragments that it knows are common in virus programs. Services such as AltaVista and Lycos can either highlight or exclude World Wide Web documents containing particular words. My colleagues and I have been at work on another filtering technique based on electronic labels that can be added to Web sites to describe digital works. These labels can convey characteristics that require human judgment—whether the Web page is funny or offensive—as well as information not readily apparent from the words and graphics, such as the Web site's policies about the use or resale of personal data.

The Massachusetts Institute of Technology's World Wide Web Consortium has developed a set of technical standards called PICS (Platform for Internet Content Selection) so that people can electronically distribute descriptions of digital works in a simple, computer-readable form. Computers can process these labels in the background, automatically shielding users from undesirable material or directing their attention to sites of particular interest. The original impetus for PICS was to allow parents and teachers to screen materials they felt were inappropriate for children using the Net. Rather than censoring what is distributed, as the Communications Decency Act and other legislative initiatives have tried to do, PICS enables users to control what they receive.

What's in a Label?

PICS labels can describe any aspect of a document or a Web site. The first labels identified items that might run afoul of local indecency laws. For example, the Recreational Software Advisory Council (RSAC) adapted its computer-game rating system for the Internet. Each RSACi (the "i" stands for "Internet") label has four numbers, indicating levels of violence, nudity, sex and potentially offensive language. Another organization, SafeSurf, has developed a vocabulary with nine separate scales. Labels can reflect other concerns beyond indecency, however. A privacy vocabulary, for example, could describe Web sites' information practices, such as what personal information they collect and whether they resell it. Similarly, an intellectual-property vocabulary could describe the conditions under which an item could be viewed or reproduced [see "Trusted Systems," by Mark Stefik, page 78]. And various Web-indexing organizations could develop labels that indicate the subject categories or the reliability of information from a site.

Labels could even help protect computers from exposure to viruses. It has become increasingly popular to download small fragments of computer code, bug fixes and even entire applications from Internet sites. People generally trust



FILTERING SYSTEM for the World Wide Web allows individuals to decide for themselves what they want to see. Users specify safety and content requirements (*a*), which label-processing software (*b*) then consults to determine whether to block access to certain pages (marked with a stop sign). Labels can be affixed by the Web site's author (*c*), or a rating agency can store its labels in a separate database (*d*).

that the software they download will not introduce a virus; they could add a margin of safety by checking for labels that vouch for the software's safety. The vocabulary for such labels might indicate which virus checks have been run on the software or the level of confidence in the code's safety.

In the physical world, labels can be attached to the things they describe, or they can be distributed separately. For example, the new cars in an automobile showroom display stickers describing features and prices, but potential customers can also consult independent listings such as consumer-interest magazines. Similarly, PICS labels can be attached or detached. An information provider that wishes to offer descriptions of its own materials can directly embed labels in Web documents or send them along with items retrieved from the Web. Independent third parties can describe materials as well. For instance, the Simon Wiesenthal Center, which tracks the activities of neo-Nazi groups, could publish PICS labels that identify Web pages containing neo-Nazi propaganda. These labels would be stored on a separate server; not everyone who visits the neo-Nazi pages would see the Wiesenthal Center labels, but those who were interested could instruct their software to check automatically for the labels.

Software can be configured not merely to make its users aware of labels but to act on them directly. Several Web software packages, including CyberPatrol and Microsoft's Internet Explorer, already use the PICS standard to control users' access to sites. Such software can make its decisions based on any PICS-compatible vocabulary. A user who plugs in the RSACi vocabulary can set the maximum acceptable levels of language, nudity, sex and violence. A user who plugs in a software-safety vocabulary can decide precisely which virus checks are required.

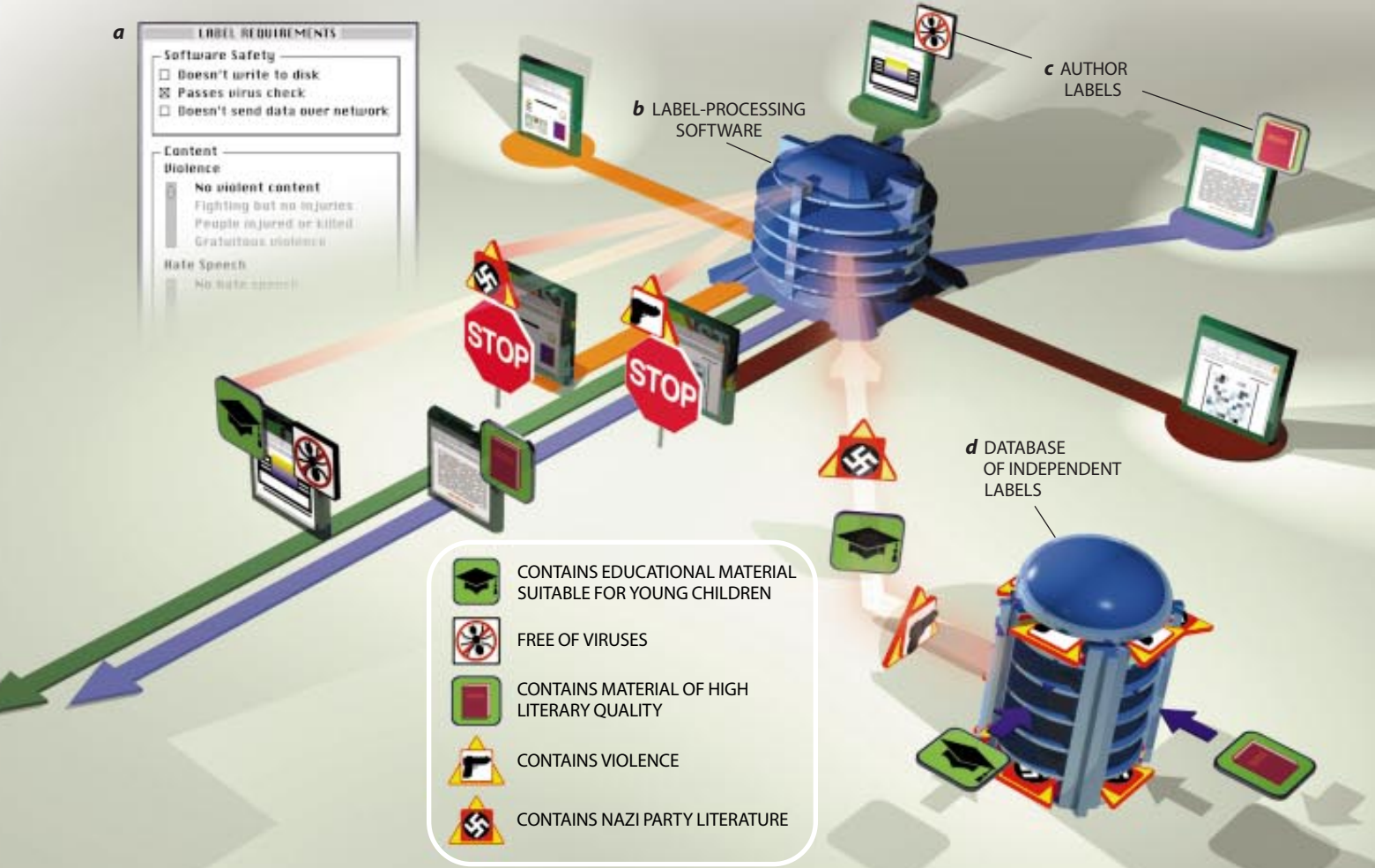
In addition to blocking unwanted materials, label processing can assist in finding desirable materials. If a user expresses a preference for works of high literary quality, a search engine might be able to suggest links to items labeled that way. Or if the user prefers that personal data not be collected or sold, a Web server can offer a version of its service that does not depend on collecting personal information.

Establishing Trust

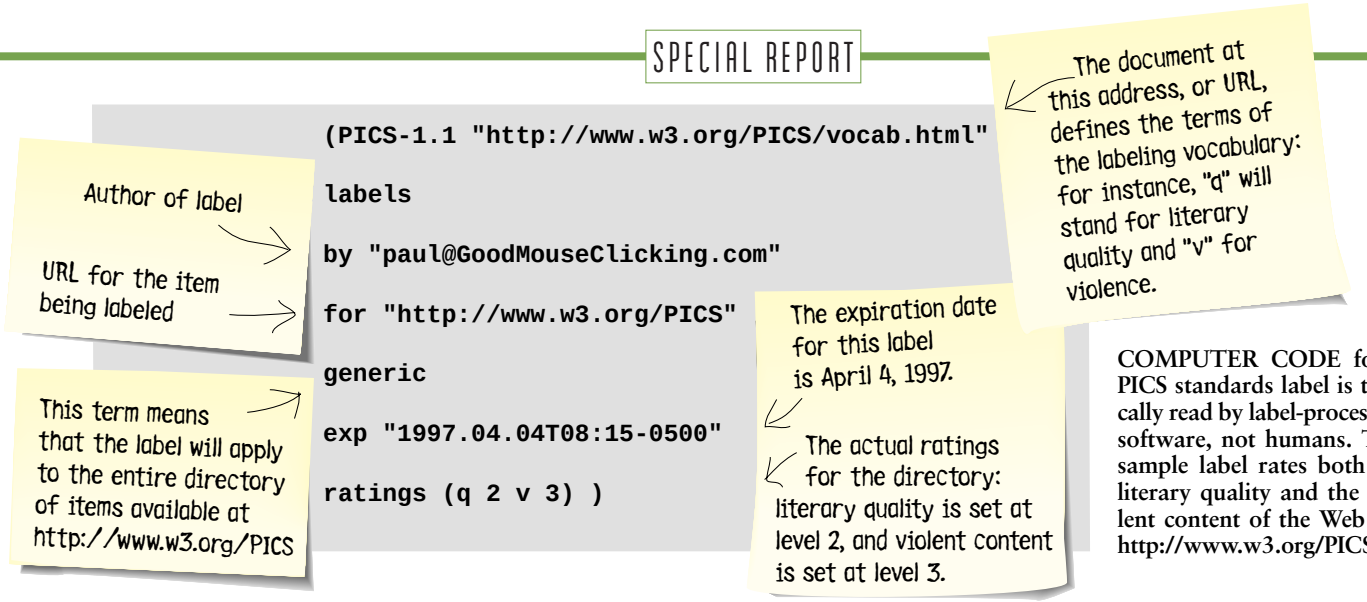
Not every label is trustworthy. The creator of a virus can easily distribute a misleading label claiming that the software is safe. Checking for labels merely converts the question of whether to trust a piece of software to one of trusting the labels. One solution is to use cryptographic techniques that can determine whether a document has been changed since its label was created and to ensure that the label really is the work of its purported author.

That solution, however, simply changes the question again, from one of trusting a label to one of trusting the label's author. Alice may trust Bill's labels if she has worked with him for years or if he runs a major software company whose reputation is at stake. Or she might trust an auditing organization of some kind to vouch for Bill.

BRYAN CHRISTIE



Filtering Information on the Internet



JENNIFER C. CHRISTIANSEN

COMPUTER CODE for a PICS standards label is typically read by label-processing software, not humans. This sample label rates both the literary quality and the violent content of the Web site http://www.w3.org/PICS

Of course, some labels address matters of personal taste rather than points of fact. Users may find themselves not trusting certain labels, simply because they disagree with the opinions behind them. To get around this problem, systems such as GroupLens and Firefly recommend books, articles, videos or musical selections based on the ratings of like-minded people. People rate items with which they are familiar, and the software compares those ratings with opinions registered by other users. In making recommendations, the software assigns the highest priority to items approved by people who agreed with the user's evaluations of other materials. People need not know who agreed with them; they can participate anonymously, preserving the privacy of their evaluations and reading habits.

Widespread reliance on labeling raises a number of social concerns. The most obvious are the questions of who decides how to label sites and what labels are acceptable. Ideally, anyone could label a site, and everyone could establish individual filtering rules. But there is a concern that authorities could assign labels to sites or dictate criteria for sites to label themselves. In an example from a different medium, the television industry, under pressure from the U.S. government, has begun to rate its shows for age appropriateness.

Mandatory self-labeling need not lead to censorship, so long as individuals can decide which labels to ignore. But people may not always have this power. Improved individual control removes one rationale for central control but does not prevent its imposition. Singapore and China, for instance, are experimenting with national "firewalls"—combinations of software and hardware that block their citizens' access to certain newsgroups and Web sites.

Another concern is that even without central censorship, any widely adopted vocabulary will encourage people to make lazy decisions that do not reflect their values. Today many parents who may not agree with the criteria used to assign movie ratings still forbid their children to see movies rated PG-13 or R; it is too hard for them to weigh the merits of each movie by themselves.

Labeling organizations must choose vocabularies carefully to match the criteria that most people care about, but even so, no single vocabulary can serve everyone's needs. Labels concerned only with rating the level of sexual content at a site will be of no use to someone concerned about hate speech. And no labeling system is a full substitute for a thorough and thoughtful evaluation: movie reviews in a newspaper can be far more enlightening than any set of predefined codes.

Perhaps most troubling is the suggestion that any labeling system, no matter how well conceived and executed, will tend to stifle noncommercial communication. Labeling requires human time and energy; many sites of limited interest will probably go unlabeled. Because of safety concerns, some people will block access to materials that are unlabeled or whose labels are untrusted. For such people, the Internet will function more like broadcasting, providing access only to sites with sufficient mass-market appeal to merit the cost of labeling.

While lamentable, this problem is an inherent one that is not caused by labeling. In any medium, people tend to avoid the unknown when there are risks involved, and it is far easier to get information about material that is of wide interest than about items that appeal to a small audience.

Although the Net nearly eliminates the technical barriers to communication with strangers, it does not remove the social costs. Labels can reduce those costs, by letting us control when we extend trust to potentially boring or dangerous software or Web sites. The challenge will be to let labels guide our exploration of the global city of the Internet and not limit our travels. SA

The Author

PAUL RESNICK joined AT&T Labs–Research in 1995 as the founding member of the Public Policy Research group. He is also chairman of the PICS working group of the World Wide Web Consortium. Resnick received his Ph.D. in computer science in 1992 from the Massachusetts Institute of Technology and was an assistant professor at the M.I.T. Sloan School of Management before moving to AT&T.

Further Reading

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RECOMMENDER SYSTEMS. Special section in *Communications of the ACM*, Vol. 40, No. 3; March 1997 (in press).

The Platform for Internet Content Selection home page is available on the World Wide Web at http://www.w3.org/PICS

JEFF BRICE

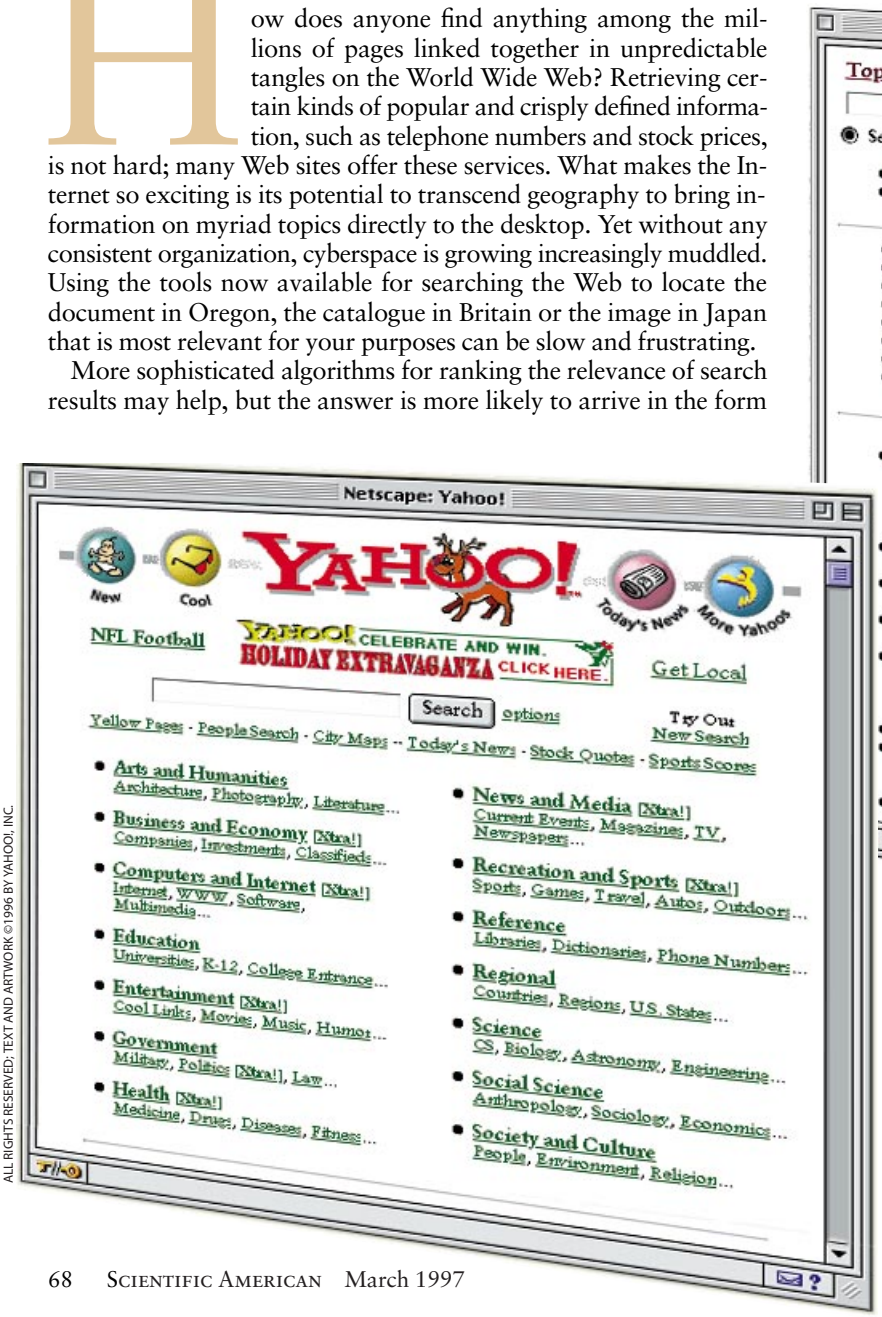
INTERFACES FOR SEARCHING THE WEB

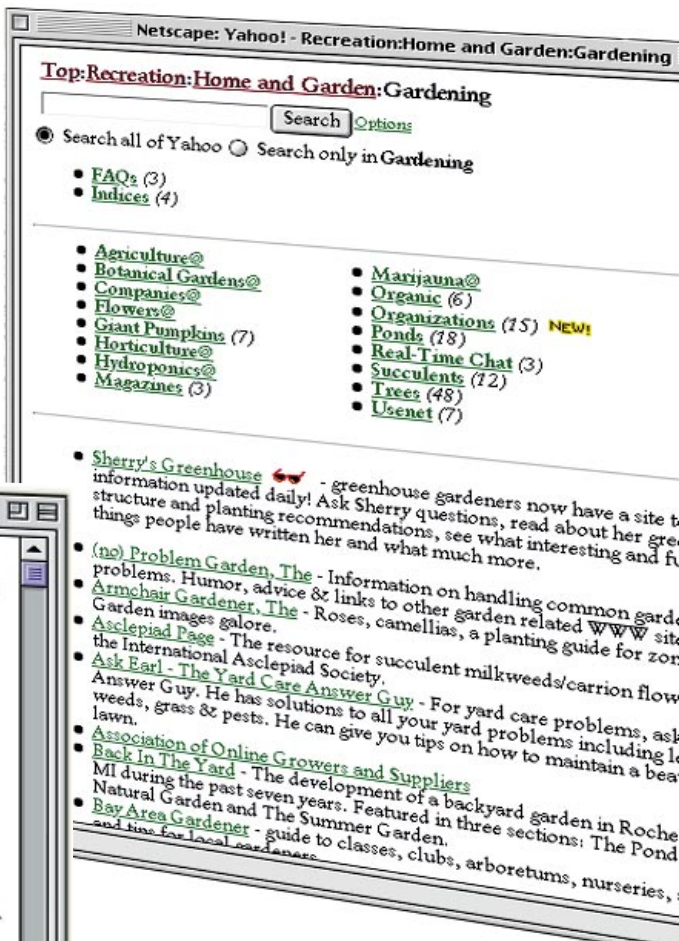
The rapid growth of the World Wide Web is outpacing current attempts to search and organize it. New user interfaces may offer a better approach

by Marti A. Hearst

How does anyone find anything among the millions of pages linked together in unpredictable tangles on the World Wide Web? Retrieving certain kinds of popular and crisply defined information, such as telephone numbers and stock prices, is not hard; many Web sites offer these services. What makes the Internet so exciting is its potential to transcend geography to bring information on myriad topics directly to the desktop. Yet without any consistent organization, cyberspace is growing increasingly muddled. Using the tools now available for searching the Web to locate the document in Oregon, the catalogue in Britain or the image in Japan that is most relevant for your purposes can be slow and frustrating.

More sophisticated algorithms for ranking the relevance of search results may help, but the answer is more likely to arrive in the form

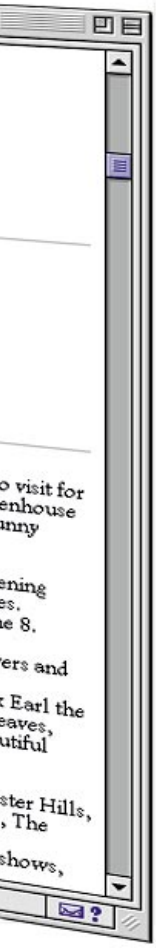


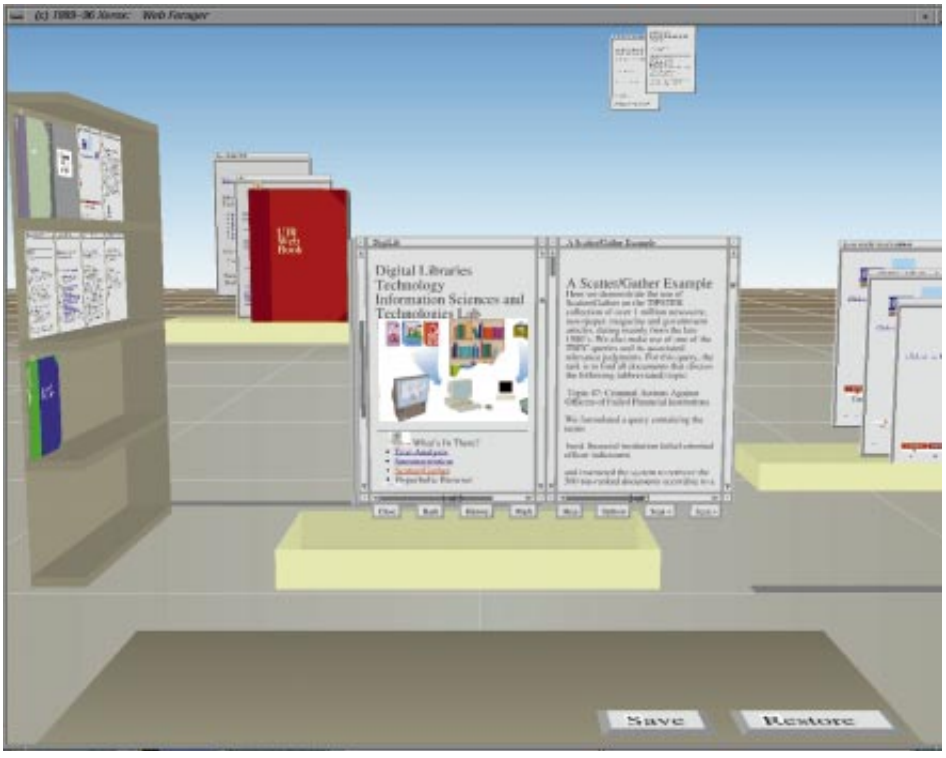


PAGE MODEL used by most World Wide Web sites imposes unnecessary constraints on services, such as Yahoo, that attempt to organize the contents of the Web into a hierarchy of categories. If, for example, a user wants to find out what kind of edible bulbs (such as garlic) can be planted in the autumn, he or she must choose one category at a time. The farther down the user goes in the hierarchy, the harder it can be to remember which potentially useful categories have not yet been explored.

of new user interfaces. Today software designed to analyze text and to manipulate large hierarchies of data can provide better ways to look at the contents of the Internet or other large text collections. True, the page metaphor used by most Web sites is familiar and simple. From the perspective of user interface design, however, the page is unnecessarily restrictive. In the future, it will be superseded by more powerful alternatives that allow users to see information on the Web from several perspectives simultaneously.

Consider Aunt Alice in Arizona, who connects to the Net to find out what kind of edible bulbs, such as garlic or onions, she can plant in her garden this autumn. Somewhere in the vast panorama of the Web lie answers to her question. But how to find them?





MARTI A. HEARST; XEROX PARC

VIRTUAL BOOKS hold Web pages or links to Web sites retrieved by a search program. The books store the results and can be placed in a bookshelf to be looked at later. Or they can guide the user in creating additional queries.

Alice currently has several options, none of them particularly helpful. She can ask friends for recommended Web sites. Or she can turn to Web indexes, of which there are at present two kinds: manually constructed tables of contents that list Web sites by category and search engines that can rapidly scan an index of Web pages for certain key words.

Using dozens of employees who assign category labels to hundreds of Web sites a day, Yahoo compiles the best-known table of contents. To use Yahoo, one chooses from a menu [*see illustration at far left*] the category that seems most promising, then views either a more specialized submenu or a list of sites that Yahoo technicians thought belonged in that section. The interface can be awkward, however. The categories are not always mutually exclusive: Should Alice choose "Recreation," "Regional" or "Environment"? Whatever she selects, the previous menu will vanish from view, forcing her either to make a mental note of all the alternative paths she could have taken or to retrace her steps methodically and reread each menu. If Alice guesses wrong about which subcategory is most relevant (it is not "Environment"), she has to back up and try again. If the desired information is deep in the hierarchy, or is not available at all, this process can be time-consuming and aggravating.

The (Slow) Speed of Thought

Research in the field of information visualization during the past decade has produced several useful techniques for transforming abstract data sets, such as Yahoo's categorized list, into displays that can be explored more intuitively. One strategy is to shift the user's mental load from slower, thought-intensive processes such as reading to faster, perceptual processes such as pattern recognition. It is easier, for example, to compare bars in a graph than numbers in a list. Color is very useful for helping people quickly select one particular word or object from a sea of others.

Another strategy is to exploit the illusion of depth that is possible on a computer screen if one departs from the page model. When three-dimensional displays are animated, the perceptual clues offered by perspective, occlusion and shadows can help clarify relations among large groups of objects that would simply clutter a flat page. Items of greater interest can be moved to the foreground, pushing less interesting objects toward the rear or the periphery. In this way, the display can help the user preserve a sense of context.

Such awareness of one's virtual surroundings can make information access a more exploratory process. Users may find partial results that they would like to reuse later, hit on better ways to express their queries, go down paths they didn't think relevant at first—perhaps even think about their topic from a whole new perspective. Aunt Alice could accomplish a lot of this by jotting down notes as she pokes around Yahoo, but a prototype interface developed by my colleagues at the Xerox Palo Alto Research Center aims to make such sensemaking activities more efficient.

Called the Information Visualizer, the software draws an animated 3-D tree [*see illustration on next page*] that links each category with all its subcategories. If Alice searches the Yahoo tree for "garden," all six areas of Yahoo in which "garden" or "gardening" is a subcatego-

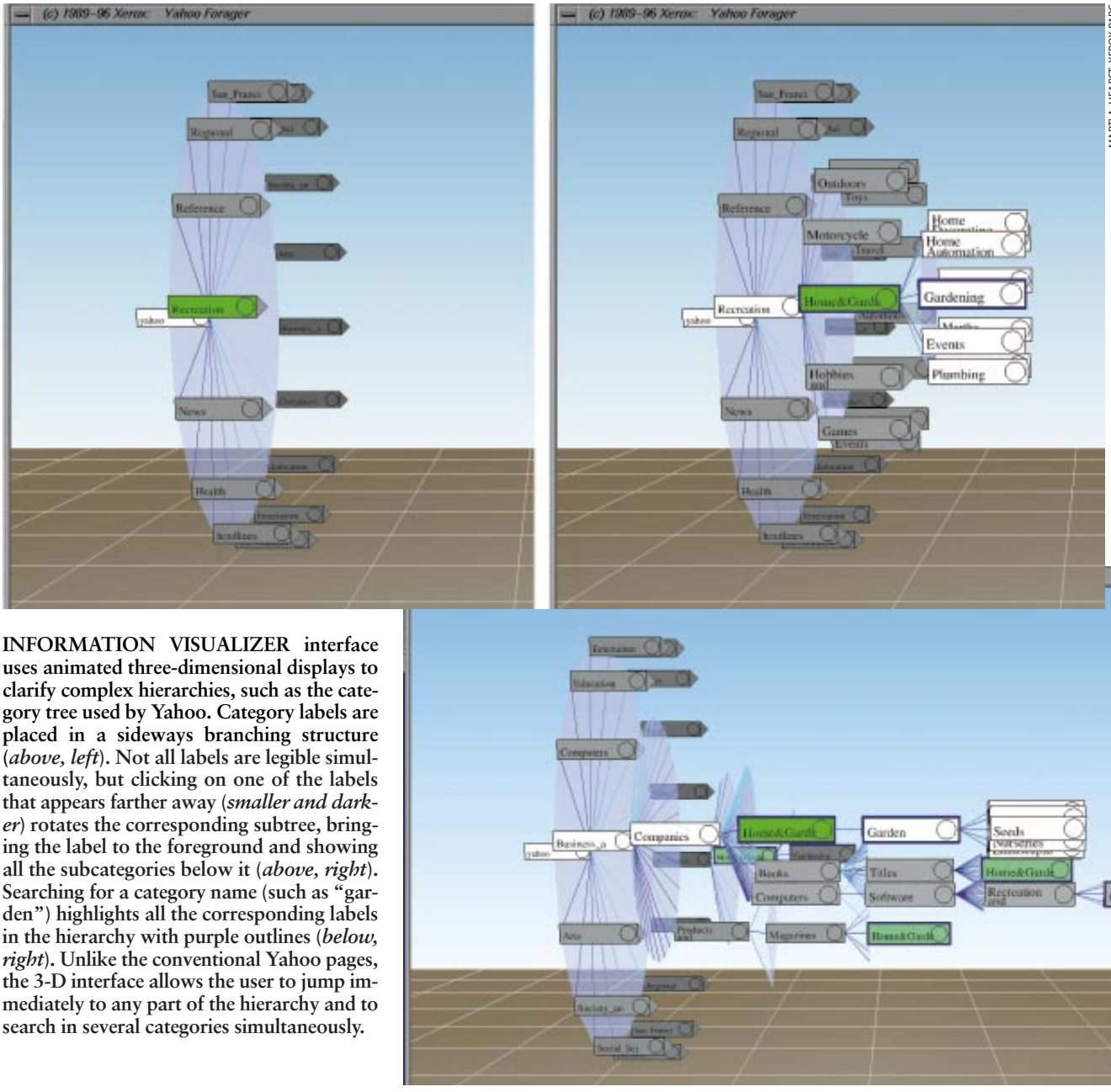
ry will light up. She can then "spin" each of these categories to the front to explore where it leads. When one path hits a dead end, the roads not taken are just a click away.

When Alice finds useful documents, this interface allows her to store them, along with the search terms that took her to them, in a virtual book. She can place the book on a virtual bookshelf where it is readily visible and clearly labeled. Next weekend, Alice can pick up where she left off by reopening her book, tearing out a page and using it to resubmit her query.

Our interface does not offer much help to the Sisyphean attempt to organize the contents of the entire Web. Because new sites appear on the Web far faster than they can be indexed by hand, the fraction listed by Yahoo (or any other service) is shrinking rapidly. And sites, such as *Time* magazine's, that contain articles on many topics often appear under only a few of the many relevant categories.

Search engines such as Excite and AltaVista are considerably more comprehensive—but this is their downfall. Poor Aunt Alice, entering the string of key words "garlic onion autumn fall garden grow" into Excite will, as of this writing, retrieve 583,430 Web pages, which (at two minutes per page) would take more than two years to browse through nonstop. Long lists littered with unwanted, irrelevant material are an unavoidable result of any search that strives to retrieve all relevant documents; conversely, a more discriminating search will almost certainly exclude many useful pages.

The short, necessarily vague queries that most Internet search services encourage with their cramped entry forms exacerbate this problem. One way to help users describe what they want more



MARTI A. HEARST; XEROX PARC

INFORMATION VISUALIZER interface uses animated three-dimensional displays to clarify complex hierarchies, such as the category tree used by Yahoo. Category labels are placed in a sideways branching structure (*above, left*). Not all labels are legible simultaneously, but clicking on one of the labels that appears farther away (*smaller and darker*) rotates the corresponding subtree, bringing the label to the foreground and showing all the subcategories below it (*above, right*). Searching for a category name (such as "garden") highlights all the corresponding labels in the hierarchy with purple outlines (*below, right*). Unlike the conventional Yahoo pages, the 3-D interface allows the user to jump immediately to any part of the hierarchy and to search in several categories simultaneously.

precisely is to let them use logical operators such as AND, OR and NOT to specify which words must (or must not) be present in retrieved pages. But many users find such Boolean notation intimidating, confusing or simply unhelpful. And even experts' queries are only as good as the terms they choose.

When thousands of documents match a query, giving more weight to those containing more search terms or uncommon key words (which tend to be more important) still does not guarantee that the most relevant pages will appear near the top of the list. Consequently, the user of a search engine often has no choice but to sift through the retrieved entries one by one.

Organizing Search Results

A better solution is to design user interfaces that impose some order on the vast pools of information generated by Web searches. Algorithms exist that can automatically group pages into certain categories, as Yahoo technicians do. But that approach does not address the fact that most texts cannot be shoehorned into just one category. Real objects can often be assigned a single place in a taxonomy (an onion is a kind of vegetable), but it is a rare Web page indeed that is only about onions. Instead a typical text might discuss produce distributors, or soup recipes, or a debate over planting imported versus indigenous vegetables. The tendency in building hierarchies is to create ever more specific categories to handle such cases ("onion distributors," for example, or "soup recipes with onion," or "agricultural debates about onions," and so on). A more manageable solution is to describe documents by whole sets of categories that apply to them, along with another set of attributes (such as source, date, genre and author). Researchers in Stanford University's digital library project are developing an interface called SenseMaker along these lines.

At Xerox PARC, we have developed an alternative scheme for grouping the list of pages retrieved by a search engine. Called Scatter/Gather, the technique creates a table of contents that changes along with a user's growing understanding of what kind of documents are available and which are most relevant.

Imagine that Aunt Alice runs her search using Excite and retrieves the first 500 Web pages it suggests. The Scatter/Gather system can then analyze those pages and divide them into groups based on their similarity to one another [*see upper illustration on next page*]. Alice can rapidly scan each cluster and select those groups that appear interesting.

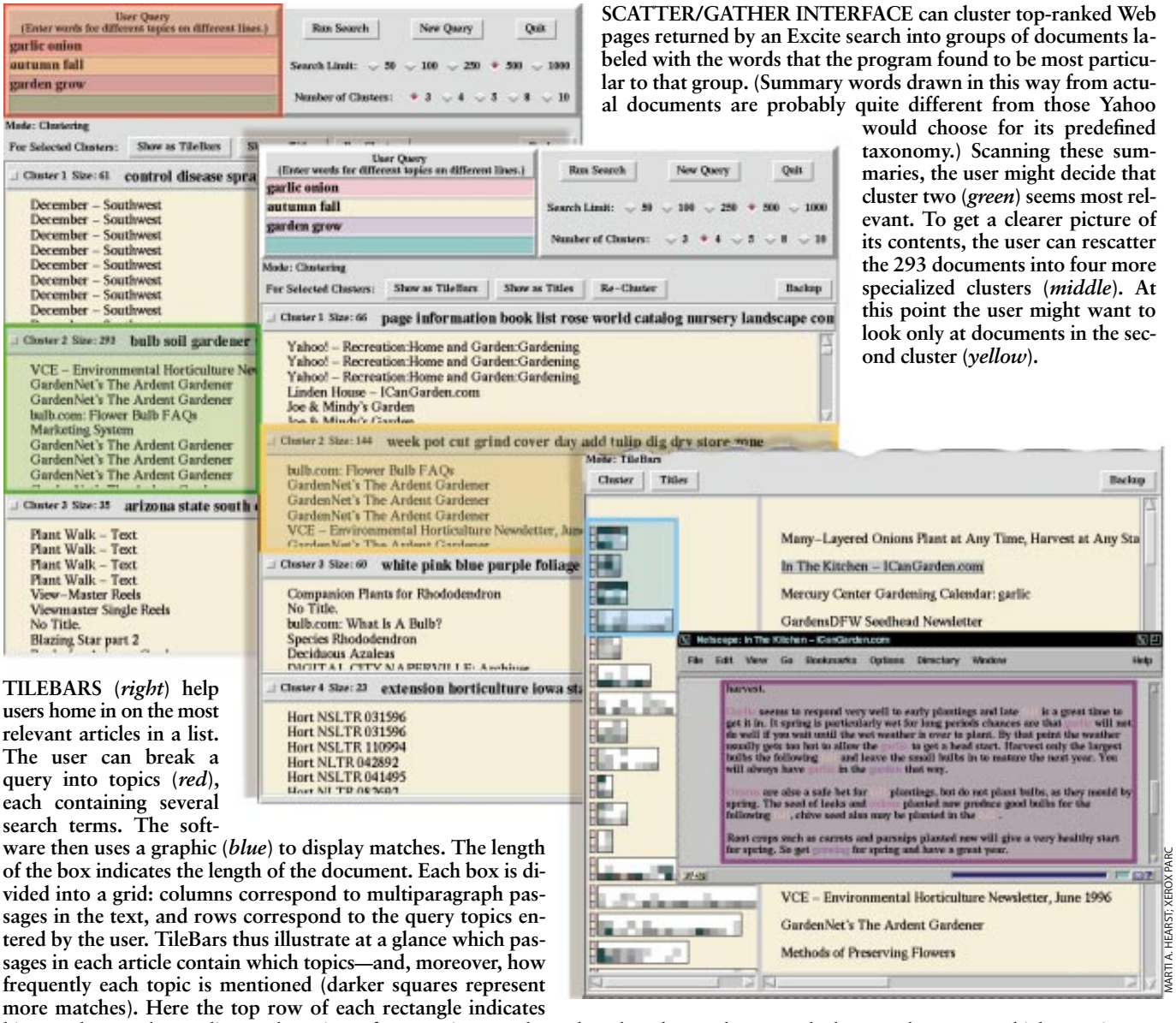
Although evaluation of user behavior is an inexact process that is difficult to evaluate, preliminary experiments suggest that clustering often helps users zero in on documents of interest. Once Alice has decided, for example, that she is particularly keen on the cluster of 293 texts summarized by "bulb," "soil" and "gardener," she can run them through Scatter/Gather once again, rescattering them into a new set of more specific clusters. Within several iterations, she can whittle 500 mostly irrelevant pages down to a few dozen useful ones.

By itself, document grouping does not solve another common problem with Web-based search engines such as Excite: the mystery of why they list the documents they do. But if the entry form encourages users to break up their query into several groups of related key words, then a graphical interface can indicate which search topics occurred where in the retrieved documents. If hits on all topics overlap within a single passage, the document is more likely to be relevant, so the program ranks it higher. Alice might have a hard time spelling out in advance which topics must occur in the document or how close together they must lie. But she is likely to recognize what she wants when she sees it and to be able to fine-tune her query in response. More important, the technique, which I call TileBars, can help users decide which documents to view and can speed them directly to the most relevant passages.

The potential for innovative user interfaces and text analysis techniques has only begun to be tapped. Other techniques that combine statistical methods

COURTESY OF EXCITE, INC.

WEB SEARCH ENGINES, such as Excite, retrieve many related documents—the query "garlic onion autumn fall garden grow" returns more than half a million links—but many are irrelevant. Even the best algorithms for ranking texts in order of relevance are unreliable when queries contain just a handful of search terms. Existing search engines often give no indication of why articles were retrieved and ranked as they were.



MARTI A. HEARST; XEROX PARC

SCATTER/GATHER INTERFACE can cluster top-ranked Web pages returned by an Excite search into groups of documents labeled with the words that the program found to be most particular to that group. (Summary words drawn in this way from actual documents are probably quite different from those Yahoo would choose for its predefined taxonomy.) Scanning these summaries, the user might decide that cluster two (*green*) seems most relevant. To get a clearer picture of its contents, the user can rescatter the 293 documents into four more specialized clusters (*middle*). At this point the user might want to look only at documents in the second cluster (*yellow*).

TILEBARS (*right*) help users home in on the most relevant articles in a list. The user can break a query into topics (*red*), each containing several search terms. The software then uses a graphic (*blue*) to display matches. The length of the box indicates the length of the document. Each box is divided into a grid: columns correspond to multiparagraph passages in the text, and rows correspond to the query topics entered by the user. TileBars thus illustrate at a glance which passages in each article contain which topics—and, moreover, how frequently each topic is mentioned (darker squares represent more matches). Here the top row of each rectangle indicates hits on the words "garlic" and "onion" from topic one; the middle row corresponds to the terms "autumn" and "fall," and so on. This interface allows the user to make informed decisions about which documents to read. The top two articles, in which all three topics overlap in several passages, are more likely to be relevant than, say, the bottom document, which contains no mention of garlic or onions. Clicking on any square within a box summons a Web browser window (*purple*) displaying the corresponding passage within the text, with query words highlighted in appropriate colors.

with rules of thumb can automatically summarize documents and place them within an existing category system. They can suggest synonyms for query words and answer simple questions. None of these advanced capabilities has yet been integrated into Web search engines, but they will be. In the future, user interfaces may well evolve even beyond two- and three-dimensional displays, drawing on such other senses as hearing to help Aunt Alices everywhere find their bearings and explore new vistas on the information frontier. SA

The Author

MARTI A. HEARST has been a member of the research staff at the Xerox Palo Alto Research Center since 1994. She received her B.A., M.S. and Ph.D. degrees in computer science from the University of California, Berkeley. Hearst's Ph.D. dissertation, which she completed in 1994, examined context and structure in text documents and graphical interfaces for information access.

Further Reading

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WEBSURFING WITHOUT A MONITOR

by T. V. Raman

When I hook up to the Internet to check out the news on CNN, to peruse a colleague's latest paper or to see how Adobe's stock price is doing, I leave the display on my laptop turned off. The batteries last much longer that way. Besides, because I cannot see, a monitor is of no use to me.

That a blind person can navigate the Internet just as efficiently and effectively as any sighted person attests to the profound potential of digital documents to improve human communication. Printed documents are fixed snapshots of changing ideas; they limit the means of communication to the paper on which they are stored. But in electronic form, documents can become raw material for computers that can extract, catalogue and rearrange the ideas in them. Used properly, technology can separate the message from the medium so that we can access information wherever, whenever and in whatever form we want.

In my case—and in the case of someone who, while using a telephone or a tiny handheld computer, becomes functionally blind—it is much easier to hear material spoken out loud than to try to view it on a screen. But it is no good to have the computer simply recite the page from top to bottom, as conventional screen-reading programs do. Imagine trying to read a book using only a one-line, 40-character display through which text marches continuously.

Ideally, an aural interface would preserve the best features of its visual counterpart. Consider this special section of *Scientific American*. By reading the table of contents, skimming the introductory article and flipping through the section, you can quickly obtain a high-level overview and decide which parts you want to read in detail. This works because the information has structure: the contents are arranged in a list, titles are set in large type and so on. But the passive, linear nature of listening typically prohibits such multiple views—it is impossible to survey the whole first and then "zoom in" on portions of interest.

Computers can remove this roadblock, but they need help. The author scribbling on his virtual page must tag each block of text with a code indicating its function (title, footnote, summary, and so on) rather than its mere appearance (24-point boldface, six-point roman, indented italics, and so on). Programs can then interpret the structural tags to present documents as the reader, rather than the creator, wishes. Your software may render titles in large type, whereas mine could read them à la James Earl Jones (*below*). Moreover, listeners can browse through a structured text selectively in the same way you skim this printed magazine.

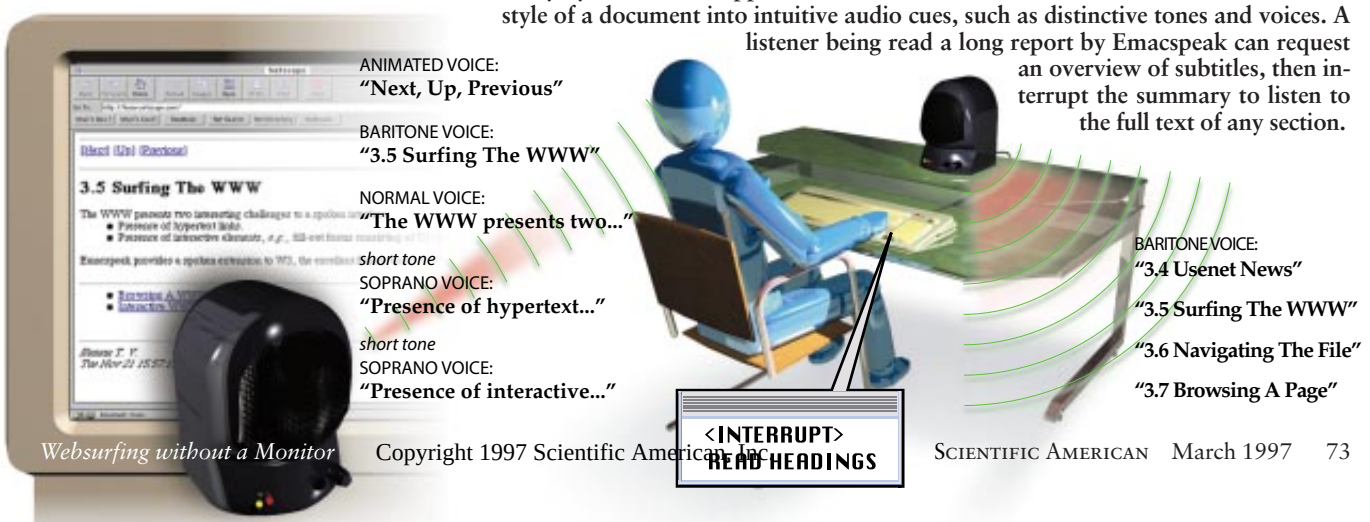
Fortunately, Hypertext Markup Language (HTML)—the encoding system used to prepare text for the World Wide Web—was designed to capture the structure of documents. If it were used as originally intended, the same electronic source could be rendered in fine detail on a printer, at lower resolution on a screen, in spoken language for functionally blind users, and in myriad other ways to suit individual preferences.

Unfortunately, HTML is steadily evolving under commercial pressure to enable the design of purely visual Web pages that are completely unusable unless one can see the color graphics and can rapidly download large images. This current rush to design Web pages that can be viewed properly with only the most popular programs and standard displays, and that moreover lack important structural information, threatens to undermine the usefulness of the documents archived on the Internet.

For users with special needs, the only efficient way to obtain certain information is to get it on-line. In the end, unprocessable digital documents are not only useless to the blind but also represent a missed opportunity for everyone. Archiving texts in a structurally rich form ensures that this vast repository of knowledge can be reused, searched and displayed in ways that best suit individuals' needs and abilities, using software not yet invented or even imagined. SA

T. V. RAMAN is a researcher in the Advanced Technology Group at Adobe Systems in San Jose, Calif.

EMACSPEAK, a speech interface for desktop computers developed and distributed freely by the author, supports a Web browser that translates the visual structure and style of a document into intuitive audio cues, such as distinctive tones and voices. A listener being read a long report by Emacspeak can request an overview of subtitles, then interrupt the summary to listen to the full text of any section.



BRYAN CHRISTIE

MULTILINGUALISM ON THE INTERNET

by Bruno Oudet

In recent years, American culture has increased its worldwide influence through international trade and Hollywood productions. As the Internet reaches into ever more remote corners of the globe, an obvious question arises: Will it amplify this trend, so that English is used everywhere? Or will a diversity of languages enrich the on-line universe? Some observers predict that local languages will not survive on-line: English will rule.

Such a sweeping dominance will have drawbacks. Most people use English as a second language, and their grasp of it may be quite rudimentary—sufficient only for understanding basic information such as the weather report, and sometimes not even that. For more in-depth discussions, almost everyone tends to fall back on his or her native language. If the Internet does not allow multilingual conversations, its role as a facilitator of international communication will be severely limited. Mistakes and misunderstandings will become rampant, and many users will be cut out of the tremendous opportunities that international communication has to offer.

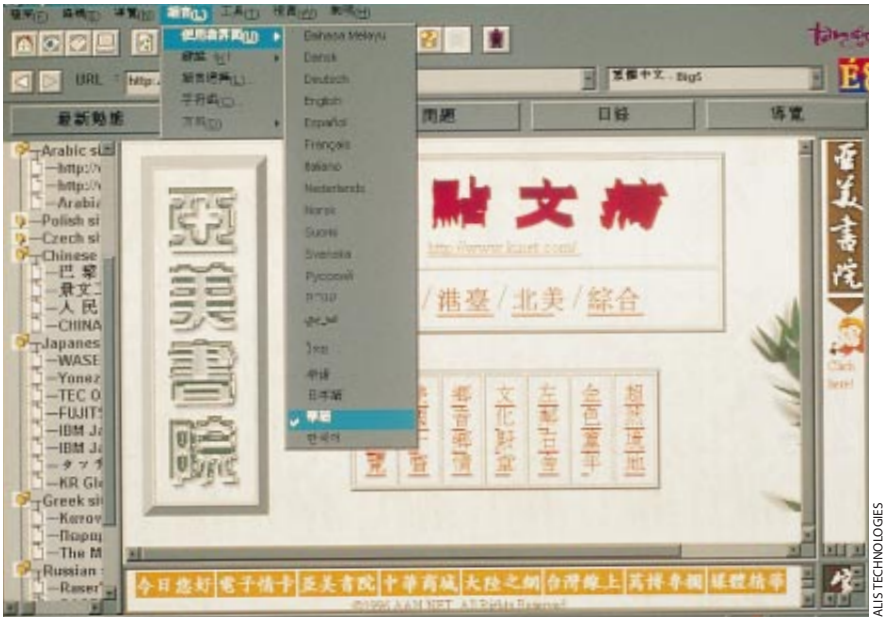
Several forces will affect the diversity of languages most likely to be found on the network in the future. At present, about 60 percent of the Internet's host computers are located in the U.S. Outside North America and some European countries, most of the world's connections to the Internet are very recent and limited. But computers everywhere are becoming increasingly linked. As the cost of installing communications networks continues to fall, the distribution of Internet users will come to resemble that of computers.

With its low cost and theoretically easy-to-use technology, the Internet allows some writers—particularly those using Latin alphabets—to publish or exchange messages in their own tongue. Some promoters of native languages have already used the medium to their advantage. For instance, roughly 30 percent of all World Wide Web pages published in French come from Quebec, even though French Canadians represent only 5 percent of all French speakers. But the worldwide reach of the Internet also favors a language that can be, at least superficially, understood by the largest number of people. As a result, I believe the Internet will support many languages for local communications and English for limited international discourse.

Of course, the technical difficulties of communicating in the majority of the world's languages are not trifling. Hardware and software were first designed to process English text. But difficulties linger even with standard Latin characters. In the early days of the Arpanet—the predecessor of the Internet—only electronic-mail messages coded with seven-bit ASCII text could be sent. (In this code, each of 128 characters is specified by a string of seven binary digits.) Nowadays the Extended Simple Mail Transport Protocol permits the processing of the eight bits required for communicating in ISO-Latin, prescribed by the International Organization for Standardization. ISO-Latin allows for 256 characters, so that the diacritical signs (such as acute and grave accent marks) of all western European languages can be displayed. But because many interlinked computers on the network have outdated software, the eighth bit sometimes gets dropped, rendering the message almost incomprehensible. Out of 12,000 users who received the daily French news that I sent out in 1995 via the Internet, 8,500 asked to receive a version coded in seven-bit ASCII rather than the crippled ISO-Latin version.

Although some recent programs can express their output in many different scripts, most are essentially bilingual: the software can deal with only one local language, such as Japanese, and English. One could argue that the technical obstacles to displaying other alphabets are temporary. Unicode (ISO 10646), a coding scheme for characters of most of the world's scripts, is being progressively implemented. The code allows a user to receive almost any language (although it may not always be properly displayed).

We nonetheless have a long way to go before we get to a truly multilingual Internet, in which an author can include a



ALIS TECHNOLOGIES

LANGUAGE OF CHOICE may be viewed on-screen at this World Wide Web site using Unicode, a coding scheme for the world's scripts.

Greek quotation in a Russian text that will be properly displayed on the reader's computer in South America. Software standards with this kind of capability are emerging. But the primary software producers, in their race to dominate the market, keep producing new versions, giving little chance to the usually small enterprises that develop multilingual products to keep up.

In real life, interpreters help to overcome language barriers. Human translators can also be employed on the Internet, but given the volume and variety of exchanges, they will play a limited role. Only machine-aided translation can bring us closer to a world, perhaps a utopia, where all the attendees at a virtual conference of the United Nations can each use his or her native language, which will be simultaneously translated into all other languages.

Research on machine-aided translation has been pursued over the past 50 years with somewhat mixed results. The systems actually in use are small in number and located mostly in Japan, Canada and Europe—the last of which faces the largest multilingual translation load. Electronic interpreters are usually just bilingual and need to be heavily specialized if they are to produce raw translations good enough to be revisable by human editors.

The first system available for general public use was Systran, which could translate 14 pairs of languages and was accessible as early as 1983 on the French Minitel network. Used by the European Commission, Systran now converts hundreds of thousands of pages a year. Another success story is the Meteo system, which translates Canadian meteorological bulletins between English and French. It handles 80,000 words (about 400 bulletins) every day, with only three to five human editing operations for every 100 words.

Multilingual translation will benefit from a two-step process now being developed by several groups. The text is first thoroughly analyzed into component parts (title, paragraph, sentence), clarified when possible by a dialogue with the author, then translated into an intermediate, abstract representation—which is used to generate translations in different languages. The effort is worth the expense when the text needs to be translated into more than 10 languages. The United Nations University in Tokyo has recently announced a 10-year collaborative project for implementing this two-stage scheme.

But a truly multilingual Internet will come to pass only with concerted international effort. Will we give it enough priority? The answer is not clear. It is so easy to let ourselves drift toward English as a unique common language. SA

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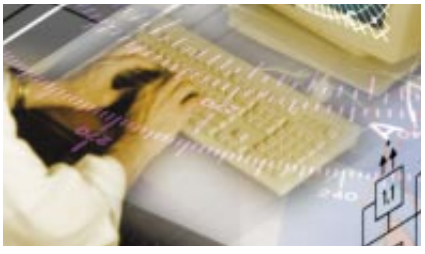
TRUSTED SYSTEMS

Devices that enforce machine-readable rights to use the work of a musician or author may create secure ways to publish over the Internet

by Mark Stefik

Everyday experience with computers has led many people to believe that anything digital is ripe for copying—computer programs, digital books, newspapers, music and video. Some digital-age pundits have gone so far as to proclaim that the ease of duplicating data heralds an end to copyright: information "wants to be free," they assert. It is impossible to thwart the spread of information, so the argument goes. Anything that can be reduced to bits can be copied.

This provocative notion undermines the dream behind the creation of the Internet: the possibility of universal access in a digital age—where any author's work could be available to anyone, anywhere, anytime. The experience of most people, however, is not that the Net contains great works and crucial research information. Instead most of what is there is perceived to be of low value.



JEFF BRICE

The root of the problem is that authors and publishers cannot make a living giving away their work. It now takes only a few keystrokes to copy a paragraph, an entire magazine, a book or even a life's work. Uncontrolled copying has shifted the balance in the social contract between creators and consumers of digital works to the extent that most publishers and authors do not release their best work in digital form.

Behind the scenes, however, technology is altering the balance again. Over the past few years, several companies, including Folio, IBM, Intertrust, NetRights, Xerox and Wave Systems, have developed software and hardware that enable a publisher to specify terms and conditions for digital works and to control how they can be used. Some legal scholars believe the change is so dramatic that publishers will be left with too much power, undercutting the rights and needs of consumers and librarians.

Yet consumers' needs can be served

even as this transformation progresses. As technology brings more security, better-quality works will reach the Net. Noted authors might be willing to publish directly on the World Wide Web. Although information might not be free, it will most likely cost less because of lower expenses to publishers for billing, distribution and printing. These savings could be passed on to consumers.

The key to this technological shift is the development of what computer scientists know as trusted systems: hardware and software that can be relied on to follow certain rules. Those rules, called usage rights, specify the cost and a series of terms and conditions under which a digital work can be used. A trusted computer, for instance, would refuse to make unauthorized copies or to play audio or video selections for a user who has not paid for them.

Trusted systems can take different forms, such as trusted readers for viewing digital books, trusted players for playing audio and video recordings, trusted printers for making copies that contain labels ("watermarks") that denote copyright status, and trusted servers that sell digital works on the Internet. Although the techniques that render a system trustworthy are complex, the result is simple. Publishers can distribute their work—in encrypted form—in such a way that it can be displayed or printed only by trusted machines. At first, trusted security features would be bundled into a printer or handheld digital reader at some additional cost to the consumer, because they would provide the ability to access material of much higher value. Eventually the costs would fall as the technology became widely implemented. Of course, a publisher could still opt to make some works available for free—and a trusted server would still allow anyone to download them.

How does a trusted system know what the rules are? At Xerox and elsewhere, researchers have attempted to express the fees and conditions associated with any particular work in a formal language that can be precisely interpreted by trusted systems. Such a usage-rights language is essential to electronic commerce: the range of things that people can or cannot do must be made explicit so that buyers and sellers can negotiate and come to agreements. Digital rights fall into several natural categories. Transport rights include permission to copy, transfer or loan. Render rights allow for playing and printing. Derivative-work rights include extracting and editing information and embedding it in other publications. Other rights govern the making and restoring of backup copies.

How Trusted Systems Work

Different intellectual works have different security requirements. But trusted systems allow publishers to specify the required security level to safeguard a document or video. The most valuable digital properties might be protected by systems that detect any tampering, set off alarms and erase the information inside. At an intermediate level, a trusted system would block a nonexpert attack with a simple password scheme. And at a lower security level, it would offer few obstacles to infringers but would mark digital works so that their source could be traced (such digital watermarking is now embedded in some image-manipulation software).

Most trusted computers have the capability to recognize another trusted system, to execute usage rights and to render works so that they either cannot be copied exactly or else carry with them a signature of their origin. For executing a highly secure transaction, two trusted systems exchange data over a communications channel, such as the Internet, providing assurances about their true identities. Managing communications over a secure channel can be accomplished with encryption and what are known as challenge-response protocols.

One example of the use of this protocol would be if computer A wishes to communicate with computer B. Computer A has to prove to B that it is a trusted system and that it is who it says it is. The interaction begins when A sends B a digital certificate confirming that it has entered its name with a registry of trusted systems. B decrypts the certificate. This action confirms that the certificate is genuine. But because a certificate can be copied, how does B know it is really in communication with A? To verify A's identity, B composes a random string of numbers called a nonce. It encrypts the nonce with a public software key that A has sent within the digital certificate. The public key allows B to send messages that only A will understand when it decrypts them with its own private key.

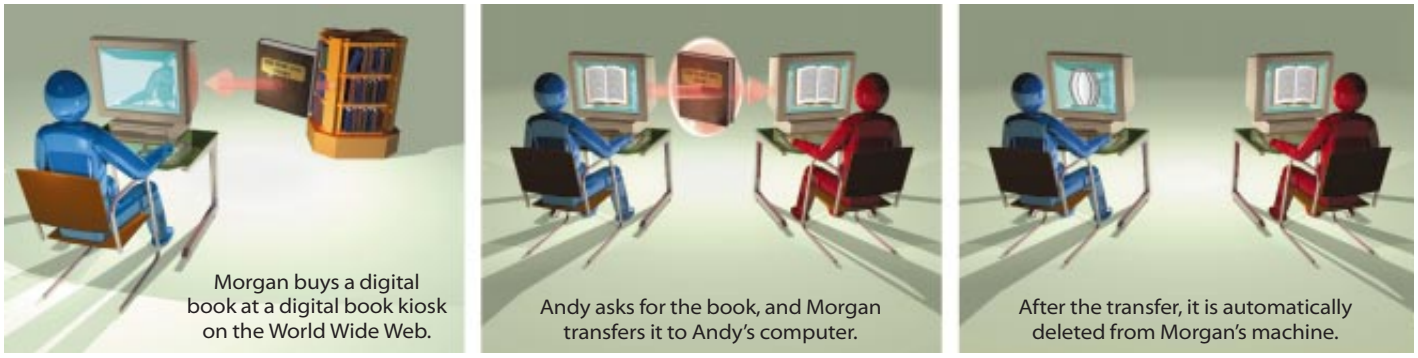
B sends the nonce to A, which decrypts it and returns an unencrypted message to B containing the numbers in the nonce. If the return message matches the one it first sent, B knows it is, in fact, communicating with A, because only A could have decrypted the message with its private key. In a few more steps, the two computers may be ready to transfer a book or carry out some other transaction.

Although not all trusted systems use

COURTESY OF VIRGIN RECORDS; JASON GOLTZ

TRY BEFORE YOU BUY—a sales method for music stores—may endure with trusted systems that allow for sampling and buying over the Internet.

TRANSFER



BRYAN CHRISTIE

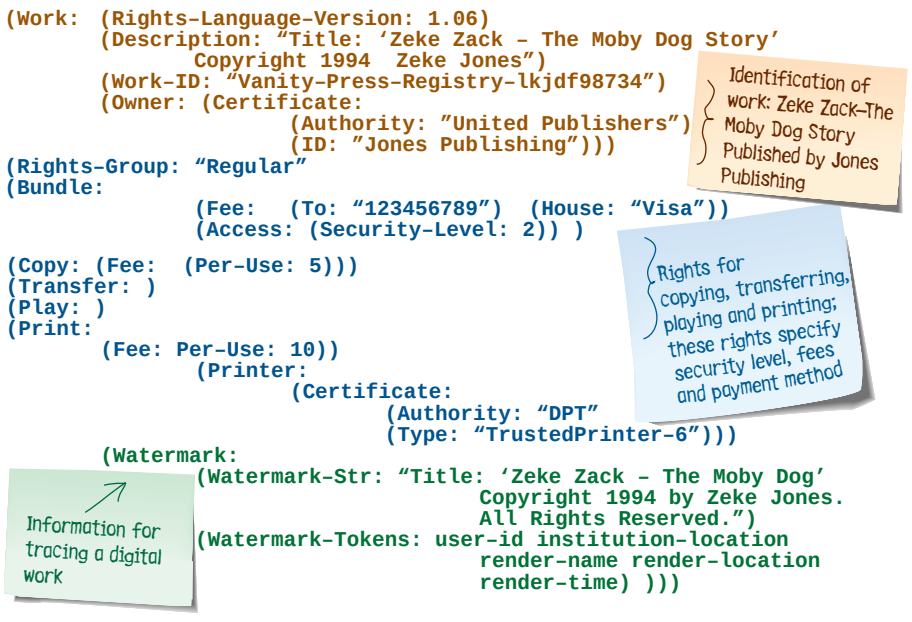
TRANSFERRING A DIGITAL WORK from one trusted system to another resembles transferring money from a savings to a checking account. The money is in one account or the other. Digital-property rights distinguish the right to copy a digital work (which increases the number of copies) from the right to transfer a digital work (which preserves the number of copies).

a challenge-response protocol, most use encryption for exchanging digital works. They may also incorporate other security features. Some systems contain tamperproof clocks to prevent a user from exercising expired rights. Others have secure memories for recording billing transactions. Still others must be connected to an on-line financial clearinghouse during transactions.

Trusted systems can place identifying watermarks that make it possible to track down unauthorized duplications or alterations. Watermarks maintain a record of each work, the name of the purchaser and a code for the devices on which they are being played. This information can be hidden—in the white space and gray shades of a text image, for instance. As such, the identifying information would be essentially invisible to lawful consumers—and unremovable by would-be infringers.

Publishers would still need to be watchful for unlicensed distribution of their property. A computer user can always print a digital page and then photocopy it. A digital-movie pirate can sit in front of the screen with a camcorder. What trusted systems prevent, however, is the wholesale copying and distribution of perfect digital originals. With appropriate watermarks, for instance, even pirated copies should still be traceable.

In digital publishing, trusted systems would allow commerce to proceed in a manner not unlike the way it is carried out in the distribution of paper copies. Suppose that Morgan wishes to buy a digital book on the Web [*see top illustration on these two pages*]. Copying the book initiates a transaction between the seller's system and Morgan's computer. At the end of the transaction, Morgan has used a credit card or digital cash to buy a copy of a book that can be read with a personal computer or some other digital reader. The entire transaction, moreover, is preceded by an exchange of information in which the seller ensures that Morgan's machine is a trusted system.



JENNIFER C. CHRISTIANSEN

USAGE RIGHTS, the terms and conditions for a trusted digital book, called *Zeke Zack—The Moby Dog Story,* are written in a machine-interpretable language.

Exercising Usage Rights

As with a paper book, Morgan can give away his digital opus. If Morgan's friend Andy asks for it, Morgan can exercise a free-transfer right. At the end of the transaction, the book resides on Andy's reader and not on Morgan's. Andy can then read the book, but Morgan cannot. The transfer preserves the number of copies. Their computers, reading and interpreting the rights attached to the file containing the book, perform the transfer in this way, and neither Morgan nor Andy can command otherwise.

Morgan can also lend a book to a friend. If Ryan wants to borrow a book for a week, Morgan can transfer it to his computer, but while the digital book is on loan, Morgan cannot use it. When the week runs out, Ryan's system deactivates its copy, and Morgan's system marks its copy as usable again. Without any action by either of them, the digital book has been "returned" to its lender. The right to lend is crucial in enabling

LOAN

Copying a work usually requires paying a fee, whereas transferring a work does not. Loaning a digital work is another transaction distinct from copying and transferring. The process is analogous to loaning a book in the sense that it temporarily grants use of the work to a second party, and the owner of the work cannot use it while it is loaned out.

the establishment of digital libraries.

Usage rights can be tailored for reading a work, printing it or creating derivative works. Depending on the publisher, particular rights can carry a fee or not. For some works, copying is free, but viewing them costs a fee. Fees can be billed for each use or by the hour; they may be billed when the user obtains the work or whenever a right is exercised. There can be discounts, sales and free trials. Distribution can be limited to people who can certify that they are members of a book club, a certain age group or citizens of a particular country.

Trusted systems can also respect the type of fair-use provisions that currently apply to libraries and some other institutions, allowing a reasonable number of free copies or quotations to be used. Members of the public with special needs—librarians, researchers and teachers—could receive licenses from an organization representing publishers that let them make a certain number of free or discounted copies of a work, if the rights of an author are understood. To balance against the risks of illegal copying, an insurance fund could be set up to protect against losses.

What's in all this for consumers? Why should they welcome an arrangement in which they have less than absolute control over the equipment and data in their possession? Why should they pay when they could get things for free? Because unless the intellectual-property rights of publishers are respected and enforced, many desirable items may never be made digitally available, free or at any price. Trusted systems address the lack of control in the digital free-for-all of the Internet. They make it possible not only for entire libraries to go on-line but also for bookstores, newsstands, movie theaters, record stores and other businesses that deal in wholly digital information to make their products available. They give incentives for 24-hour access to quality fiction, video and musical works, with immediate delivery anywhere in the world. In some cases, this technological approach to protecting authors and publishers may even avoid the need for heavy-handed regulations that could stifle digital publishing.

Fully realizing this vision will necessitate developments in both technology and the marketplace. Users will need routine access to more communications capacity. Publishers must institute measures to ensure the privacy of consumers who use trusted systems, although the same technology that guards the property rights of publishers could also protect personal details about consumers. Trusted systems also presume that direct sales, not advertising, will pay the costs of distributing digital works. Advertising will most likely prevail only for works with substantial mass-market appeal. By protecting authors' rights, trusted systems will enable specialized publishing to flourish: compare, for instance, the diverse collection of books in a library to the relative paucity of programs for television.

The dynamics of a competitive marketplace form the most imposing roadblock to fashioning protections for digital rights. Several companies have trusted systems and software in the early stages of testing. With some exceptions, though, the software is proprietary and incompatible. Whereas the technology could provide the infrastructure for digital commerce, the greatest benefits will accrue only if the various stakeholders, from buyers and sellers to librarians and lawmakers, work together. SA

The Author

MARK STEFIK is a principal scientist in the information sciences and technology laboratory at the Xerox Palo Alto Research Center. Stefik received a bachelor's degree in mathematics and a doctorate in computer science, both from Stanford University. In 1980 he joined Xerox PARC. There he has done research on expert systems, collaborative systems and technology for digital commerce. For several years, Stefik taught a graduate course on expert systems at Stanford. He wrote the textbook *Introduction to Knowledge Systems* (Morgan Kaufmann, 1995).

Further Reading

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JEFF BRICE

PRESERVING THE INTERNET

An archive of the Internet may prove to be a vital record for historians, businesses and governments

by Brewster Kahle

Manuscripts from the library of Alexandria in ancient Egypt disappeared in a fire. The early printed books decayed into unrecognizable shreds. Many of the oldest cinematic films were recycled for their silver content. Unfortunately, history may repeat itself in the evolution of the Internet—and its World Wide Web.

No one has tried to capture a comprehensive record of the text and images contained in the documents that appear on the Web. The history of print and film is a story of loss and partial reconstruction. But this scenario need not be repeated for the Web, which has increasingly evolved into a storehouse of valuable scientific, cultural and historical information.

The dropping costs of digital storage mean that a permanent record of the Web and the rest of the Internet can be preserved by a small group of technical professionals equipped with a modest complement of computer workstations and data storage devices. A year ago I and a few others set out to realize this vision as part of a venture known as the Internet Archive.

By the time this article is published, we will have taken a snapshot of all parts of the Web freely and technically accessible to us. This collection of data will measure perhaps as much as two trillion bytes (two terabytes) of data, ranging from text to video to audio recording. In comparison, the Library of Congress contains about 20 terabytes of text information. In the coming months, our computers and storage media will make records of other areas of the Internet, including the Gopher information system and the Usenet bulletin boards. The material gathered so far has already proved a useful resource to historians. In the future, it may provide the raw material for a carefully indexed, searchable library.

The logistics of taking a snapshot of the Web are relatively simple. Our Internet Archive operates with a staff of 10 people from offices located in a converted military base—the Presidio—in downtown San Francisco; it also runs an information-gathering computer in the San Diego Supercomputer Center at the University of California at San Diego.

The software on our computers "crawls" the Net—downloading documents, called pages, from one site after another. Once a page is captured, the software looks for cross references, or links, to other pages. It uses the Web's hyperlinks—addresses embedded within a document page—to move to other pages. The software then makes copies again and seeks additional links contained in the new pages. The crawler avoids downloading duplicate copies of pages by checking the identification names, called uniform resource locators (URLs), against a database. Programs such as Digital Equipment Corporation's AltaVista also employ crawler software for indexing Web sites.

What makes this experiment possible is the dropping cost of data storage. The price of a gigabyte (a billion bytes) of hard-disk space is $200, whereas tape storage using an automated mounting

NATIONAL MUSEUM OF AMERICAN HISTORY *We the People: Winning the Vote* exhibition

INTERNET ARCHIVE has provided the Smithsonian Institution's National Museum of American History with a collection of World Wide Web sites of the 1996 presidential elec-

device costs $20 a gigabyte. We chose hard-disk storage for a small amount of data that users of the archive are likely to access frequently and a robotic device that mounts and reads tapes automatically for less used information. A disk drive accesses data in an average of 15 milliseconds, whereas tapes require four minutes. Frequently accessed information might be historical documents or a set of URLs no longer in use.

We plan to update the information gathered at least every few months. The first full record required nearly a year to compile. In future passes through the Web, we will be able to update only the information that has changed since our last perusal.

The text, graphics, audio clips and other data collected from the Web will never be comprehensive, because the crawler software cannot gain access to many of the hundreds of thousands of sites. Publishers restrict access to data or store documents in a format inaccessible to simple crawler programs. Still, the archive gives a feel of what the Web looks like during a given period of time even though it does not constitute a full record.

After gathering and storing the public contents of the Internet, what services will the archive provide? We possess the capability of supplying documents that are no longer available from the original publisher, an important function if the Web's hypertext system is to become a medium for scholarly publishing. Such a service could also prove worthwhile for business research. And the archival data might serve as a "copy of record" for the government or other institutions with publicly available documents. So, over time, the archive would come to resemble a digital library.

tion. The computer that accesses the sites is part of an exhibit on presidential campaigns.

Keeping Missing Links

Historians have already found the material useful. David Allison of the Smithsonian Institution has tapped into the archive for a presidential election Web site exhibit at the museum, a project he compares to saving videotapes of early television campaign advertisements. Many of the links for these Web sites, such as those for Texas Senator Phil Gramm's campaign, have already disappeared from the Internet.

Creating an archive touches on an array of issues, from privacy to copyright. What if a college student created a Web page that had pictures of her then current boyfriend? What if she later wanted to "tear them up," so to speak, yet they lived on in the archive? Should she have the right to remove them? In contrast, should a public figure—a U.S. senator, for instance—be able to erase data posted from his or her college years? Does collecting information made available to the public violate the "fair use" provisions of the copyright law? The issues are not easily resolved.

To address these worries, we let authors exclude their works from the archive. We are also considering allowing researchers to obtain broad censuses of the archive data instead of individual documents—one could count the total number of references to pachyderms on the Web, for instance, but not look at a specific elephant home page. These measures, we hope, will suffice to allay immediate concerns about privacy and intellectual-property rights. Over time, the issues addressed in setting up the Internet Archive might help resolve the larger policy debates on intellectual property and privacy by testing concepts such as fair use on the Internet.

The Internet Archive complements other projects intended to ensure the longevity of information on the Internet. The Commission on Preservation and Access in Washington, D.C., researches how to ensure that data are not lost as the standard formats for digital storage media change over the years. In another effort, the Internet Engineering Task Force and other groups have labored on technical standards that give a unique identification name to digital documents. These uniform resource names (URNs), as they are called, could supplement the URLs that currently access Web documents. Giving a document a URN attempts to ensure that it can be traced after a link disappears, because estimates put the average lifetime for a URL at 44 days. The URN would be able to locate other URLs that still provided access to the desired documents.

Other, more limited attempts to archive parts of the Internet have also begun. DejaNews keeps a record of messages on the Usenet bulletin boards, and InReference archives Internet mailing lists. Both support themselves with revenue from advertisers, a possible funding source for the Internet Archive as well. Until now, I have funded the project with money I received from the sale of an Internet software and services company. Major computer companies have also donated equipment.

It will take many years before an infrastructure that assures Internet preservation becomes well established—and for questions involving intellectual-property issues to resolve themselves. For our part, we feel that it is important to proceed with the collection of the archival material because it can never be recovered in the future. And the opportunity to capture a record of the birth of a new medium will then be lost. SA

The Author

BREWSTER KAHLE founded the Internet Archive in April 1996. He invented the Wide Area Information Servers (WAIS) system in 1989 and started a company, WAIS, Inc., in 1992 to commercialize this Internet publishing software. The company helped to bring commercial and government agencies onto the Internet by selling publishing tools and production services. Kahle also served as a principal designer of the Connection Machine, a supercomputer produced by Thinking Machines. He received a bachelor's degree from the Massachusetts Institute of Technology in 1982.

Psychiatry's Global Challenge

An evolving crisis in the developing world signals the need for a better understanding of the links between culture and mental disorders

by Arthur Kleinman and Alex Cohen

Over the past 50 years, the health and living conditions of people in developing nations have improved dramatically. Average life expectancy in Egypt and India, among other countries, has risen from around 40 to 66 years. Smallpox, which once killed millions annually, has been completely eradicated, and infant mortality has fallen from about 28 to 10 percent of live births. Real average incomes more than doubled, and the percentage of rural families with access to safe water increased from less than 10 to almost 60 percent.

Unfortunately, this remarkable progress in physical well-being has been accompanied by a deterioration in mental health. In many areas outside North America and western Europe, schizophrenia, dementia and other forms of mental illness are on the rise. For example, schizophrenia—one of the most debilitating of mental illnesses, in which thoughts and emotions are sometimes disconnected or distorted by delusions—is expected to afflict 24.4 million people in low-income societies by the year 2000, a 45 percent increase over the number afflicted in 1985.

Behind this rise in the prevalence of mental illness is an array of demographic and social factors. Better physical health means, inevitably, that more people are living into the age of increased risk for some mental disorders, especially dementia. Moreover, increases in population, because of longer life spans, mean that the absolute number of people afflicted by mental disorders of all kinds is greater. In addition, the very economic and industrial development that has benefited some has also engendered massive societal changes. Rapid urbanization, chaotic modernization and economic restructuring have left many developing countries reeling. Increased rates of violence, drug and alcohol abuse, and suicide have accompanied disruptions in cultural practices, social routines, and traditional work and family roles.

Numerous studies have found that mental illness is a sharply increasing part of the health care burden for low-income societies. Depressive and anxiety disorders are the leading causes of disability around the globe, according to the World Health Organization (WHO). This United Nations agency estimates that such illnesses are responsible for approximately one quarter of all visits to health care centers worldwide. Suicide attempts and Alzheimer's disease and other dementias also cause large burdens, followed by epilepsy, psychoses, drug dependence and post-traumatic stress disorder.

The WHO study also found that, on average, general health care physicians everywhere fail to diagnose mental health disorders properly more than half the time. More dishearteningly, even when a case of mental illness is correctly diagnosed, the physician often prescribes drug treatments that are not pertinent to the condition.

Four Persistent Myths

What is the psychiatric profession as a whole doing in response to these disturbing developments? It appears to be clinging to outmoded theories and practices, which poorly suit lower-income countries and the nonindustrial world. At present, the trend is to discount the uniqueness of symptoms that are found in a particular culture and instead to search for manifestations of mental illness that are culturally independent and are thus thought to be more closely linked to the biological basis of an illness. In turning its back on the great diversity of symptoms, however, psychiatric science is denying itself an enormous pool of data. And this failure seems to be blocking progress precisely when it is needed most.

Progress in improving mental health care in developing countries is obstructed by the persistence of several myths. Three of them have become central to psychiatry, and a fourth is current among some international health specialists. The first is that the forms of mental illness everywhere display similar degrees of prevalence. Myth number two can be described as an excessive adherence to a principle known as the pathogenetic/pathoplastic dichotomy, which holds that biology is responsible for the underlying structure of a malaise, whereas cultural beliefs shape the specific ways in which a person experiences it. The third myth maintains that various unusual, culture-specific disorders whose biological bases are uncertain occur only in exotic places outside the West. The fourth, held by many international health experts who discount mental health problems to begin with, holds that not much can be done to treat mental illness.

Myth number one has its roots in a previous, rather contradictory misconception. This earlier myth centered on the idea of the "noble savage" unencumbered by the exigencies of the "modern" world—a cornerstone of anthropology in the 19th century. As far back as the 1950s, however, the work of psychiatric anthropologists and cultural psychiatrists disproved the notion that the mental health problems of the undeveloped countries were trivial. Alexander Leighton, now professor emeritus of social psychiatry at the Harvard School of Public Health, T. A. Lambo, formerly deputy director general of WHO, and their colleagues found higher rates of depression among Nigeria's Yoruba tribe than among the people in a county in

RAPHAEL WOLLMAN *Gamma Liaison*

BLEAK CONDITIONS are endured by patients in this psychiatric institution in Argentina. At a time when serious mental illnesses are drastically on the rise throughout the developing world, psychiatric care leaves much to be desired.

Nova Scotia. In a later study, John Orley, now at WHO, and John Wing of London's Royal College of Psychiatrists found that women living in a rural area of Uganda had higher rates of depression and suffered from more severe forms than women did in a suburb of London. Large surveys over the past 20 years of both rural and urban populations in China and Taiwan have also revealed the widespread presence of neuropsychiatric disorders. Finally, a host of studies have found that people throughout the world suffer from schizophrenia.

Eventually the mainstream of the mental health profession accepted that psychiatric illness occurs everywhere. Unfortunately, it replaced one myth with another. In the 1980s biological explanations of psychiatric phenomena were ascendant; the predominant theory maintained that the various types of mental illness were each distributed more or less uniformly on the earth. This view persists, despite the findings of many anthropological and epidemiological studies showing that the incidence and the symptoms of disorders vary markedly from one culture to another and also with respect to class, gender and other variables. Study after study, for example, has demonstrated a correlation between socioeconomic status and health, both mental and physical.

Sex differences have been extensively documented as well. A WHO study in 14 countries (some industrial, some less so) found, overall, that women suffer from depression at almost twice the rate of men. In Santiago, Chile, however, women's risk for depression was almost five times that of men. A rather dramatic gender difference was revealed by a 1982 survey of more than 38,000 people in 12 areas in China. This research found not only that women suffered from neurotic disorders (primarily neurasthenia, dissociative neurosis and depressive neurosis) at nine times the rate of men but that the prevalence of schizophrenia was 75 percent higher among women.

This latter finding is puzzling if one regards schizophrenia as only biologically based. It may suggest that the disorder has a stronger cultural or environmental component than is generally recognized, or it may simply call into question the way in which the study was executed (although the work was regarded as rigorous, and no such criticisms have been raised). Deepening the mystery, the increased risk for schizophrenia among women has not been found in Taiwan.

Suicide rates, which have been linked to depression and substance abuse, are reported, with varying degrees of accuracy, in many countries and are sometimes used as an indicator of social health. The link between suicide rates and social upheaval was established around the turn of the century through the work of the French sociologist Emile Durkheim. Recently two Taiwanese psychiatrists, Mian-Yoon Chong of the Kaohsiung Medical College and Tai-Ann Cheng of the Academia Sinica, have revealed that Taiwan's suicide rates have varied greatly since the end of World War II. The two researchers found that the mass migration from the mainland and the rapid industrialization of what had been a rural economy were accompanied by the highest suicide rates. Those rates are now stable, although, interestingly, they are higher in rural areas than in the cities. They are also highest among the island's aboriginal peoples, who have been the most dislocated by social change.

ARTHUR KLEINMAN

MOTHER AND DAUGHTER were treated for neurasthenia in rural Hunan. This neurotic disorder, as experienced by Chinese, has symptoms in common with both depressive and anxiety disorders.

China's suicide rate appears to be twice that of the U.S. and is most common among rural women. Elsewhere, it is men who are most at risk. Drawing on data from the World Bank, Michael Phillips, a Harvard University psychiatrist working at Hui Long Guan Psychiatric Hospital in Beijing, showed that more than 40 percent of all suicides in the world occur in China. Surprisingly, however, depression is three to five times less common in China than in the West; the country also has much less substance abuse. For troubled women in rural China, suicide appears to be almost a normative strategy for coping with distress.

Great variation has also been found, from country to country, in the most common forms of a particular mental illness. These results, too, are almost impossible to reconcile with today's emphasis on the underlying biological commonality of all mental illness. Schizophrenia, for example, has several different forms, including paranoid, which is characterized by thoughts of persecution, and catatonic, marked by immobility, such as catalepsy or stupor. Another form is known as hebephrenic; its prominent features include emotional bluntness and disorganized speech and behavior. The relative proportions of these types of the disorder vary considerably from one region to another, for reasons that are not entirely clear.

Norman Sartorius, Assen Jablensky and their colleagues at WHO recently found that paranoid schizophrenia was about 50 percent more common in the developed countries. On the other hand, the catatonic subtype was diagnosed more than six times more frequently among patients in the developing nations. (Indeed, this subtype, which was once quite common in the West, has all but disappeared there.) Hebephrenic schizophrenia was found four times as often among patients in the developed countries. Other researchers have noted that even within the industrial nations variation exists; the hebephrenic subtype, for example, is common among hospitalized Japanese patients but is unusual today in the U.S.

How do researchers account for this striking variation in the symptoms of disorders? This question brings us to our second myth. In their search for uniformity, psychiatrists and psychiatric epidemiologists have constructed a model of pathogenicity/pathoplasticity in which biology is responsible for the cause and structure of the forms of mental disease, whereas cultural factors at most shape the "content" of a disorder. For example, in paranoid schizophrenia, biology alone accounts for the fact that sufferers have delusional thoughts. Cultural beliefs, however, determine various specifics—whether the persecutor, in the afflicted's view, is the Central Intelligence Agency, evil spirits or beings from outer space.

Too Much of a Good Model

The model is not without utility; it has allowed psychiatrists to categorize an extensive array of psychiatric symptoms into a more manageable and coherent system of diagnostic classes. Unfortunately, modern psychiatry has pushed the model to such extremes that it is counterproductive for understanding anxiety disorders and, especially, depression outside industrial regions in the West. In the developed Western world the symptoms of depression tend to be both psychological states—feelings of despair, sadness, belief that life is meaningless—and physical complaints. In general health care, patients highlight physical symptoms, whereas in psychiatric settings they emphasize psychological complaints. In non-Western societies and among traditionally oriented ethnic groups, there tends to be an emphasis primarily on bodily complaints (headaches, fatigue, dizziness, for example), and psychological symptoms are less frequent.

Modern psychiatry regards the bodily complaints as symptoms that merely mask the "real," biologically based emotional disease. But lacking a clear biological marker that could enable us to identify a specific disease conclusively, how can we be sure that the condition afflicting a Yoruba tribesman in Nigeria is the same as the disorder afflicting a lawyer in New York City or a fisherman in Nova Scotia? Furthermore, who is to say what actually constitutes the bedrock of depression: emotions or a mixture of emotional and bodily complaints with no clear organic cause?

Such questions aside, several maladies, including organic mental disorders, substance abuse, depression, manic-depression (bipolar disorder), various anxiety disorders and schizophrenia, are almost certainly global. But (turning to the third myth) as many as hundreds of other conditions appear to be culture-specific, local forms of pathology. A standard reference, the *Diagnostic and Statistical Manual of Mental Disorders* of the American Psychiatric Association, appears to acknowledge this fact in an appendix to its fourth edition. This appendix, however, with its thumbnail sketches of esoteric syndromes, is little more than a sop thrown to cultural psychiatrists and psychiatric anthropologists.

The appendix lists such exotica as amok, a condition distinguished by frenzied violent behavior directed at both people and objects, and latah, in which words and movements are repeated during sudden fright. All these conditions are presented as unique to the non-Western world. What psychiatric researchers are less willing to concede is that anorexia nervosa, multiple personality disorder, chronic fatigue syndrome and, perhaps, agoraphobia are probably culture-bound syndromes of the West, including Westernized elites in Asia. Perhaps three fourths of the manual's hundreds of diseases are, in fact, unique or most salient in North America.

The fourth and final myth comes from outside psychiatry. It contends that not much can be done to treat mental illnesses, even if they are widespread and

costly. In fact, beneficial medications and therapies are becoming available at an accelerating rate, especially for the globally distributed conditions. We have effective medications for depression and anxiety. Schizophrenia can, for many patients, be managed successfully with a combination of antipsychotic medication and psychosocial interventions (family therapy or training in occupational or social skills).

Also, in the past two decades, Chinese mental health practitioners have developed a few impressive programs of psychiatric rehabilitation, notable for their ability to care effectively and humanely for people who suffer from severe mental disorders. These programs are particularly important because they appear to be applicable to other underserved populations. The incidence of several other conditions, such as mental retardation and epilepsy, could be reduced by preventing birth-related traumas, infections and nutritional deficiencies.

JOAO SILVA *Sygma*

TRAUMATIZED by a civil war, the more violent patients who were committed to a psychiatric hospital in Luanda, Angola, were restrained by being chained to engine parts. Most developing world institutions are underequipped; this one lacked straitjackets.

An Opportunity Neglected

In an effort to base psychiatry in "hard" science and thus raise its status to that of other medical disciplines, psychiatrists have narrowly focused on the biological underpinnings of mental disorders while discounting the importance of such "soft" variables as culture and socioeconomic status. But the study of variation is a cornerstone of science, and the diversity of symptoms, outcome and prevalence of mental illness offers a tremendous opportunity to test the way human cultures and environments shape the formation, distribution and manifestation of disorders. So far this opportunity has been neglected. And in view of the hardships that mental illness imposes globally, this disinterest amounts to a tragedy of ever expanding proportions.

Of course, an enlightened view of the relation between culture and mental illness will not, by itself, suffice to improve conditions. Mental health care in the developing world is plagued by a variety of troubles, including an inability to expand small, local programs to cover more people. Additionally, low-income countries, faced with extreme poverty and limited funds, are forced to try to control such maladies as malaria and diarrhea, rather than invest in the "luxury" of mental health treatment. And although this is understandable, it is not acceptable. For depression alone, the cost of the failure to recognize and treat patients in primary care settings is enormous—depression causes more disability than arthritis, diabetes, hypertension and back pain.

Psychiatry must now confront what may be the most damaging myth of all: that a knowledge base compiled almost exclusively from North American and European cases can be effectively applied to the 80 percent of the world's population that lives in Asia, Africa and South America as well as to the immigrant communities of North America and Europe. The need to establish cultural variation as a pillar of mental health studies comes from the empirical reality that distress, disease and treatment—however biological their roots—are experienced in contexts of cultural and social processes that make symptoms and outcomes different. Psychiatry's next challenge, then, is to formulate a perspective that better explains the interplay between the socioeconomic, cultural and biological aspects of mental illness. SA

The Authors

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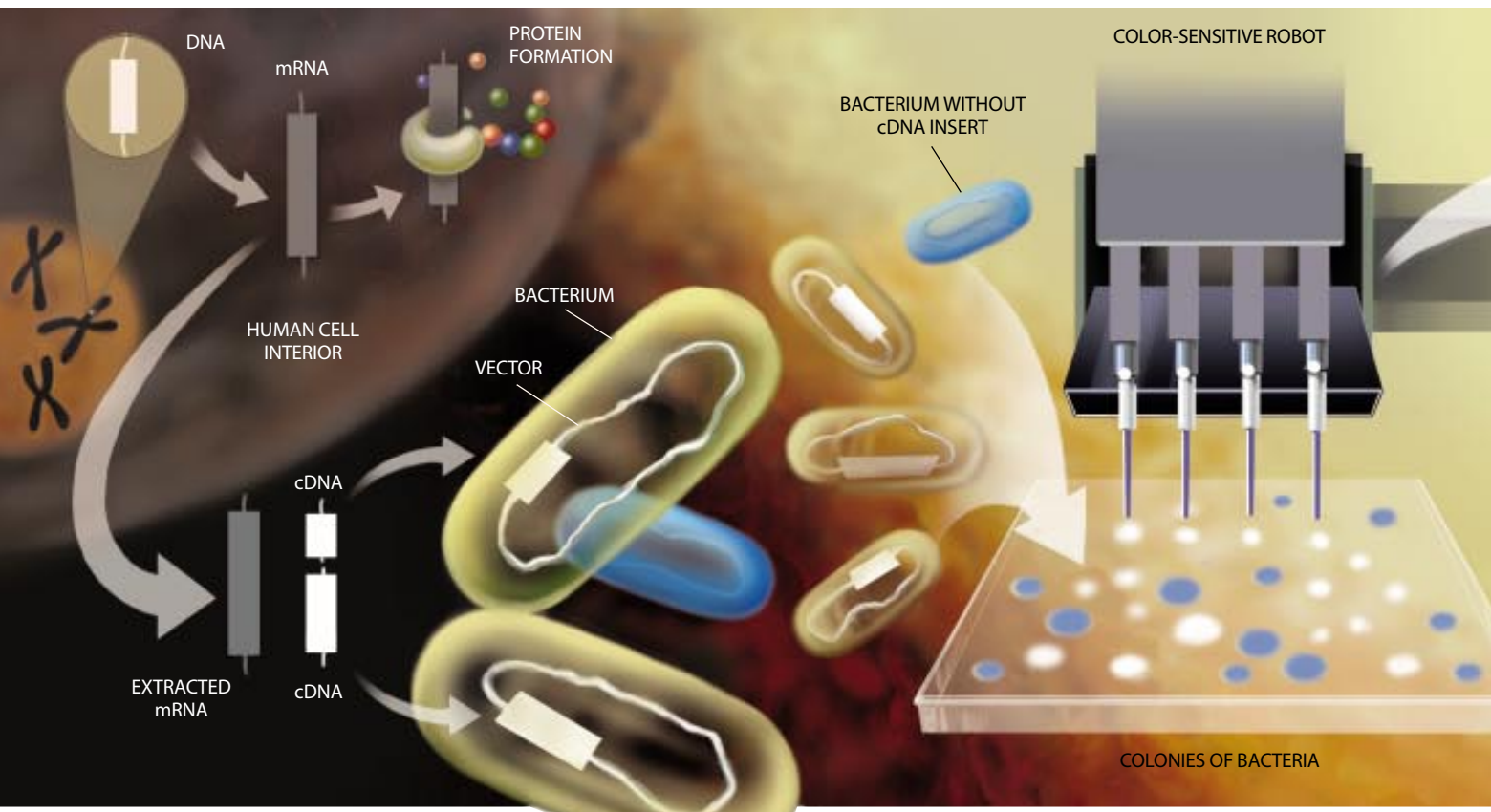
Discovering Genes for New Medicines

By identifying human genes involved in disease, researchers can create potentially therapeutic proteins and speed the development of powerful drugs

by William A. Haseltine

Most readers of this magazine are probably familiar with the idea of a gene as something that transmits inherited traits from one generation to the next. Less well appreciated is that malfunctioning genes are deeply involved in most diseases, not only inherited ones. Cancer, atherosclerosis, osteoporosis, arthritis and Alzheimer's disease, for example, are all characterized by specific changes in the activities of genes. Even infectious disease usually provokes the activation of identifiable genes in a patient's immune system. Moreover, accumulated damage to genes from a lifetime of exposure to ionizing radiation and injurious chemicals probably underlies some of the changes associated with aging.

A few years ago I and some like-minded colleagues decided that knowing where and when different genes are switched on in the human body would lead to far-reaching advances in our ability to predict, prevent, treat and cure disease. When a gene is active, or as a geneticist would say, "expressed," the sequence of the chemical units, or bases, in its DNA is used as a blueprint to produce a specific protein. Proteins direct, in various ways, all of a cell's functions. They serve as structural components, as catalysts that carry out the multiple chemical processes of life and as control elements that regulate cell reproduction, cell specialization and physiological activity at all levels. The development of a human from fertilized egg to mature adult is, in fact, the consequence of an



orderly change in the pattern of gene expression in different tissues.

Knowing which genes are expressed in healthy and diseased tissues, we realized, would allow us to identify both the proteins required for normal functioning of tissues and the aberrations involved in disease. With that information in hand, it would be possible to develop new diagnostic tests for various illnesses and new drugs to alter the activity of affected proteins or genes. Investigators might also be able to use some of the proteins and genes we identified as therapeutic agents in their own right. We envisaged, in a sense, a high-resolution description of human anatomy descending to the molecular level of detail.

It was clear that identifying all the expressed genes in each of the dozens of tissues in the body would be a huge task. There are some 100,000 genes in a typical human cell. Only a small proportion of those genes (typically about 15,000) is expressed in any one type of cell, but the expressed genes vary from one cell type to another. So looking at just one or two cell types would not reveal the genes expressed in the rest of the body. We would also have to study tissues from all the stages of human development. Moreover, to identify the changes in gene expression that contribute to sickness, we would have to analyze diseased as well as healthy tissues.

Technological advances have provided a way to get the job done. Scientists can now rapidly discover which genes are expressed in any given tissue. Our strategy has proved the quickest way to identify genes of medical importance.

Take the example of atherosclerosis. In this common condition, a fatty substance called plaque accumulates inside arteries, notably those supplying the heart. Our strategy enables us to generate a list of genes expressed in normal arteries, along with a measure of the level of expression of each one. We can then compare the list with one derived from patients with atherosclerosis. The difference between the lists corresponds to the genes (and thus the proteins) involved in the disease. It also indicates how much the genes' expression has been increased or decreased by the illness. Researchers can then make the human proteins specified by those genes.

Once a protein can be manufactured in a pure form, scientists can fairly easily fashion a test to detect it in a patient. A test to reveal overproduction of a protein found in plaque might expose early signs of atherosclerosis, when better options exist for treating it. In addition, pharmacologists can use pure proteins to help them find new drugs. A chemical that inhibited production of a protein found in plaque might be considered as a drug to treat atherosclerosis.

Our approach, which I call medical genomics, is somewhat outside the mainstream of research in human genetics. A great many scientists are involved in the Human Genome Project, an international collaboration devoted to the discovery of the complete sequence of the chemical bases in human DNA. (All the codes in DNA are constructed from an alphabet consisting of just four bases.) That information will be important for studies of gene action and evolution and will particularly benefit research on inherited diseases. Yet the genome project is not the fastest way to discover genes, because most of the bases that make up DNA actually lie outside genes. Nor will the project pinpoint which genes are involved in illness.

In 1992 we created a company, Human Genome Sciences (HGS), to pursue our vision. Initially we conducted the work as a collaboration between HGS and the Institute for Genomic Research, a not-for-profit organization that HGS supports; the institute's director, J. Craig Venter, pioneered some of the key ideas in genomic research. Six months into the collaboration, SmithKline Beecham,

JENNIFER C. CHRISTIANSEN

How to Make and Separate cDNA Molecules

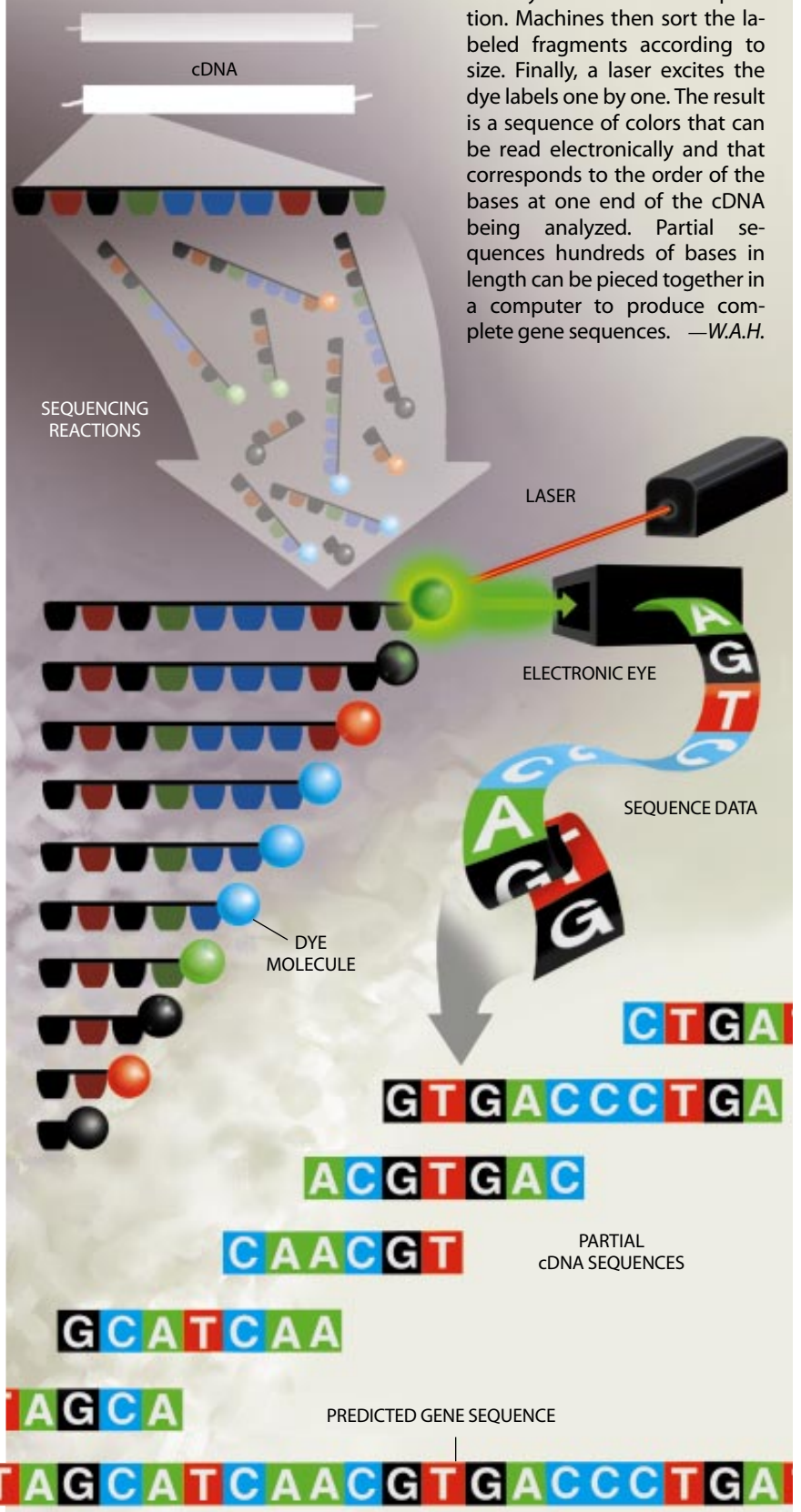
Cells use messenger RNA to make protein. We discover genes by making complementary DNA (cDNA) copies of messenger RNA. First we have to clone and produce large numbers of copies of each cDNA, so there will be enough to determine its constituent bases. Molecular biologists have developed ways to insert cDNA into specialized DNA loops, called vectors, that can reproduce inside bacterial cells. A mixture of cDNAs from a given tissue is called a library.

Researchers at HGS have now prepared human cDNA libraries from almost all normal organs and tissues, as well as from many that are diseased. To make multiple copies of a library, we add it to bacteria that take up the vectors.

All the bacteria are then spread out on a plate of nutrient gel and allowed to grow into colonies, so that each colony derives from a single bacterium. Next we use a robot that can automatically spot and pick off the gel those colonies that did successfully acquire a cDNA. The robot accomplishes this by color. The vectors we use are designed so that if they fail to combine with a cDNA insert, they produce a blue pigment. The robot, which picks as many as 10,000 colonies of bacteria every day, identifies those containing human cDNA by avoiding blue ones. The cDNA from each picked colony, now in analyzable quantities, is then robotically purified. —*W.A.H.*

How to Find a Partial cDNA Sequence

Researchers find partial cDNA sequences by chemically breaking down copies of a cDNA molecule to create an array of fragments that differ in length by one base. In this process, the base at one end of each fragment is attached to one of four fluorescent dyes, the color of the dye depending on the identity of the base in that position. Machines then sort the labeled fragments according to size. Finally, a laser excites the dye labels one by one. The result is a sequence of colors that can be read electronically and that corresponds to the order of the bases at one end of the cDNA being analyzed. Partial sequences hundreds of bases in length can be pieced together in a computer to produce complete gene sequences. —*W.A.H.*



JENNIFER C. CHRISTIANSEN

one of the world's largest pharmaceutical companies, joined HGS in the effort. After the first year, HGS and SmithKline Beecham continued on their own. We were joined later by Schering-Plough, Takeda Chemical Industries in Japan, Merck KGaA in Germany and Synthelabo in France.

Genes by the Direct Route

Because the key to developing new medicines lies principally in the proteins produced by human genes, rather than the genes themselves, one might wonder why we bother with the genes at all. We could in principle analyze a cell's proteins directly. Knowing a protein's composition does not, however, allow us to make it, and to develop medicines, we must manufacture substantial amounts of proteins that seem important. The only practical way to do so is to isolate the corresponding genes and transplant them into cells that can express those genes in large amounts.

Our method for finding genes focuses on a critical intermediate product created in cells whenever a gene is expressed. This intermediate product is called messenger RNA (mRNA); like DNA, it consists of sequences of four bases. When a cell makes mRNA from a gene, it essentially copies the sequence of DNA bases in the gene. The mRNA then serves as a template for constructing the specific protein encoded by the gene. The value of mRNA for research is that cells make it only when the corresponding gene is active. Yet the mRNA's base sequence, being simply related to the sequence of the gene itself, provides us with enough information to isolate the gene from the total mass of DNA in cells and to make its protein if we want to.

For our purposes, the problem with mRNA was that it can be difficult to handle. So we in fact work with a surrogate: stable DNA copies, called complementary DNAs (cDNAs) of the mRNA molecules. We make the cDNAs by simply reversing the process the cell uses to make mRNA from DNA.

The cDNA copies we produce this way are usually replicas of segments of mRNA rather than of the whole molecule, which can be many thousands of bases long. Indeed, different parts of a gene can give rise to cDNAs whose common origin may not be immediately apparent. Nevertheless, a cDNA containing just a few thousand bases still preserves its parent gene's unique signature.

That is because it is vanishingly unlikely that two different genes would share an identical sequence thousands of bases long. Just as a random chapter taken from a book uniquely identifies the book, so a cDNA molecule uniquely identifies the gene that gave rise to it.

Once we have made a cDNA, we can copy it to produce as much as we want. That means we will have enough material for determining the order of its bases. Because we know the rules that cells use to turn DNA sequences into the sequences of amino acids that constitute proteins, the ordering of bases tells us the amino acid sequence of the corresponding protein fragment. That sequence, in turn, can be compared with the sequences in proteins whose structures are known. This maneuver often tells us something about the function of the complete protein, because proteins containing similar sequences of amino acids often perform similar tasks.

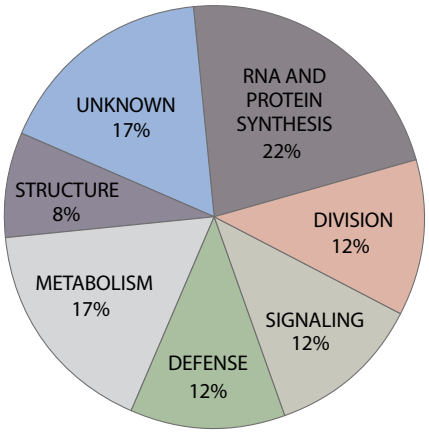
Analyzing cDNA sequences used to be extremely time-consuming, but in recent years biomedical instruments have been developed that can perform the task reliably and automatically. Another development was also necessary to make our strategy feasible. Sequencing equipment, when operated on the scale we were contemplating, produces gargantuan amounts of data. Happily, computer systems capable of handling the resulting megabytes are now available, and we and others have written software that helps us make sense of this wealth of genetic detail.

Assembling the Puzzle

Our technique for identifying the genes used by a cell is to analyze a sequence of 300 to 500 bases at one end of each cDNA molecule. These partial cDNA sequences act as markers for genes and are sometimes referred to as expressed sequence tags. We have chosen this length for our partial cDNA sequences because it is short enough to analyze fairly quickly but still long enough to identify a gene unambiguously. If a cDNA molecule is like a chapter from a book, a partial sequence is like the first page of the chapter—it can identify the book and even give us an idea what the book is about. Partial cDNA sequences, likewise, can tell us something about the gene they derive from. At HGS, we produce about a million bases of raw sequence data every day.

Our method is proving successful: in less than five years we have identified thousands of genes, many of which may play a part in illness. Other companies and academic researchers have also initiated programs to generate partial cDNA sequences.

HGS's computers recognize many of the partial sequences we produce as deriving either from one of the 6,000 genes researchers have already identified by other means or from a gene we have previously found ourselves. When we cannot definitely assign a newly generated partial sequence to a known gene, things get more interesting. Our computers then scan through our databases as well as public databases to see whether the new partial sequence overlaps something someone has logged before. When we find a clear overlap, we piece together the overlapping partial sequences into ever lengthening segments called contigs. Contigs correspond, then, to incomplete sequences we infer to be present somewhere in a parent gene. This process is somewhat analogous to fishing out the phrases "a midnight dreary, while I pondered" and "while I pondered, weak and weary/Over many a . . . volume" and combining them into a fragment recognizable as part of Edgar Allan Poe's "The Raven."



PERCENTAGE OF GENES devoted to each of the major activities in the typical human cell has been deduced from a study of 150,000 partial sequences. Similarities with human or other genes of known function were used to assign provisional categories of activity.

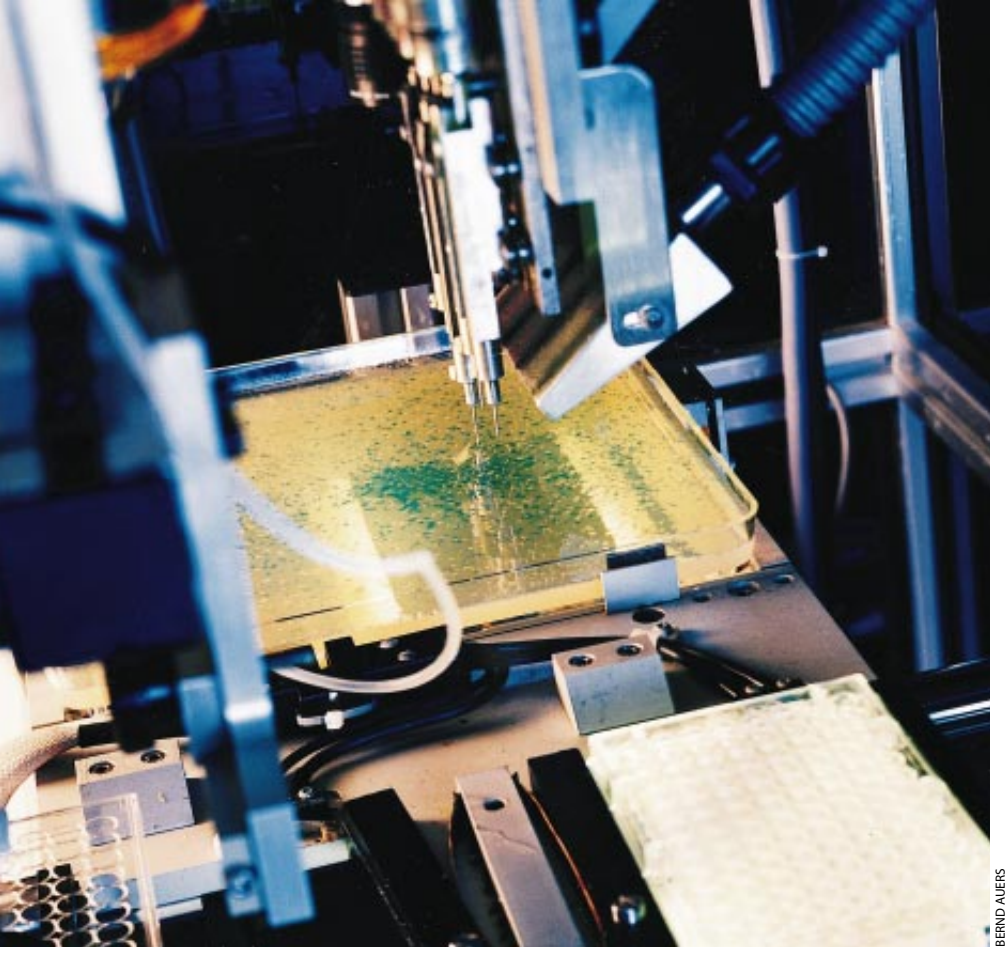
At the same time, we attempt to deduce the likely function of the protein corresponding to the partial sequence. Once we have predicted the protein's structure, we classify it according to its similarity to the structures of known proteins. Sometimes we find a match with another human protein, but often we notice a match with one from a bacterium, fungus, plant or insect: other organisms produce many proteins similar in function to those of humans. Our computers continually update these provisional classifications.

Three years ago, for example, we predicted that genes containing four specific contigs would each produce proteins similar to those known to correct mutations in the DNA of bacteria and yeast. Because researchers had learned that failure to repair mutations can cause colon cancer, we started to work out the full sequences of the four genes. When a prominent colon cancer researcher later approached us for help in identifying genes that might cause that illness—he already knew about one such gene—we were able to tell him that we were already working with three additional genes that might be involved.

Subsequent research has confirmed that mutations in any one of the four genes can cause life-threatening colon, ovarian or endometrial cancer. As many as one in every 200 people in North America and Europe carry a mutation in one of these mismatch repair genes, as they are called. Knowing this, scientists can develop tests to assess the mismatch repair genes in people who have relatives with these cancers. If the people who are tested display a genetic predisposition to illness, they can be monitored closely. Prompt detection of tumors can lead to lifesaving surgery, and such tests have already been used in clinical research to identify people at risk.

Our database now contains more than a million cDNA-derived partial gene sequences, sorted into 170,000 contigs. We think we have partial sequences from almost all expressed human genes. One indication is that when other scientists log gene sequences into public databases, we find that we already have a partial sequence for more than 95 percent of them. Piecing together partial sequences frequently uncovers entire new genes. Overall more than half of the new genes we identify have a resemblance to known genes that have been assigned a probable function. As time goes by, this proportion is likely to increase.

If a tissue gives rise to an unusually large number of cDNA sequences that derive from the same gene, it provides an indication that the gene in question is producing copious amounts of mRNA. That generally happens when the cells are producing large amounts of the cor-



BERND AUERS

ROBOT used to distinguish bacterial colonies that have picked up human DNA sequences is at the top. The instrument's arms ignore colonies that are blue, the sign that they contain no human DNA. By analyzing the sequences in the bacteria, researchers can identify human genes.

responding protein, suggesting that the protein may be doing a particularly vital job. HGS also pays particular attention to genes that are expressed only in a narrow range of tissues, because such genes are most likely to be useful for intervening in diseases affecting those tissues. Of the thousands of genes we have discovered, we have identified about 300 that seem especially likely to be medically important.

New Genes, New Medicines

Using the partial cDNA sequence technique for gene discovery, researchers have for the first time been able to assess how many genes are devoted to each of the main cellular functions, such as defense, metabolism and so on. The vast store of unique information from partial cDNA sequences offers new possibilities for medical science. These opportunities are now being systematically explored.

Databases such as ours have already proved their value for finding proteins that are useful as signposts of disease. Prostate cancer is one example. A widely used test for detecting prostate cancer measures levels in the blood of a protein called prostate specific antigen. Patients who have prostate cancer often exhibit unusually high levels. Unfortunately, slow-growing, relatively benign tumors as well as malignant tumors requiring aggressive therapy can cause elevated levels of the antigen, and so the test is ambiguous.

HGS and its partners have analyzed mRNAs from multiple samples of healthy prostate tissue as well as from benign and malignant prostate tumors. We found about 300 genes that are expressed in the prostate but in no other tissue; of these, about 100 are active only in prostate tumors, and about 20 are expressed only in tumors rated by pathologists as malignant. We and our commercial partners are using these 20 genes and their protein products to devise tests to identify malignant prostate disease. We have similar work under way for breast, lung, liver and brain cancers.

Databases of partial cDNA sequences can also help find genes responsible for rare diseases. Researchers have long known, for example, that a certain form of blindness in children is the result of an inherited defect in the chemical breakdown of the sugar galactose. A search of our database revealed two previously unknown human genes whose corresponding proteins were predicted to be structurally similar to known galactose-metabolizing enzymes in yeast and bacteria. Investigators quickly confirmed that inherited defects in either of these two genes cause this type of blindness. In the future, the enzymes or the genes themselves might be used to prevent the affliction.

Partial cDNA sequences are also establishing an impressive record for helping researchers to find smaller molecules that are candidates to be new treatments. Methods for creating and testing small-molecule drugs—the most common type—have improved dramatically in the past few years. Automated equipment can rapidly screen natural and synthetic compounds for their ability to affect a human protein involved in disease, but the limited number of known protein targets has delayed progress. As more human proteins are investigated, progress should accelerate. Our work is now providing more than half of SmithKline Beecham's leads for potential products.

Databases such as ours not only make it easier to screen molecules randomly for useful activity. Knowing a protein's structure enables scientists to custom-design drugs to interact in a specific way with the protein. This technique, known as rational drug design, was used to create some of the new protease inhibitors that are proving effective against HIV (although our database was not involved in this particular effort). We are confident that partial cDNA sequences will allow pharmacologists to make more use of rational drug design.

One example of how our database has already proved useful concerns cells known as osteoclasts, which are normally present in bone; these cells produce an enzyme capable of degrading bone tissue. The enzyme appears to be produced in excess in some disease states, such as osteoarthritis and osteoporosis. We found in our computers a sequence for a gene expressed in osteoclasts that appeared to code for the destructive enzyme; its sequence was similar to that of a gene known to give rise to an enzyme that degrades cartilage. We confirmed

that the osteoclast gene was responsible for the degradative enzyme and also showed that it is not expressed in other tissues. Those discoveries meant we could invent ways to thwart the gene's protein without worrying that the methods would harm other tissues. We then made the protein, and SmithKline Beecham has used it to identify possible therapies by a combination of high-throughput screening and rational drug design. The company has also used our database to screen for molecules that might be used to treat atherosclerosis.

One extremely rich lode of genes and proteins, from a medical point of view, is a class known as G-protein coupled receptors. These proteins span the cell's outer membrane and convey biological signals from other cells into the cell's interior. It is likely that drugs able to inhibit such vital receptors could be used to treat diseases as diverse as hypertension, ulcers, migraine, asthma, the common cold and psychiatric disorders. HGS has found more than 70 new G-protein coupled receptors. We are now testing their effects by introducing receptor genes we have discovered into cells and evaluating how the cells that make the encoded proteins respond to various stimuli. Two genes that are of special interest produce proteins that seem to be critically involved in hypertension and in adult-onset diabetes. Our partners in the pharmaceutical industry are searching for small molecules that should inhibit the biological signals transmitted by these receptors.

Last but not least, our research supports our belief that some of the human genes and proteins we are now discovering will, perhaps in modified form, themselves constitute new therapies. Many human proteins are already used as drugs; insulin and clotting factor for hemophiliacs are well-known examples. Proteins that stimulate the production of blood cells are also used to speed patients' recovery from chemotherapy.

Protein	Activity	Possible Uses
Keratinocyte growth factor	Stimulates regrowth of skin	Healing wounds , stimulating hair growth, protecting against chemotherapy's side effects
Myeloid progenitor Inhibitory protein 1	Prevents chemotherapy drugs from killing bone marrow cells	Protecting against chemotherapy's side effects
Motor neuron growth factor	Prevents trauma-induced motor neuron death	Treating Lou Gehrig's disease, traumatic nerve injury, stroke and muscle atrophy in aging
Monocyte colony inhibitory factor	Inhibits macrophages	Treating rheumatoid arthritis and other autoimmune and macrophage-related diseases

JENNIFER C. CHRISTIANSEN

HUMAN PROTEINS made after their genes were discovered at Human Genome Sciences include several that demonstrate powerful effects in isolated cells and in experimental animals. These examples are among a number of human proteins now being tested to discover their possible medical value.

The proteins of some 200 of the full-length gene sequences HGS has uncovered have possible applications as medicines. We have made most of these proteins and have instituted tests of their activity on cells. Some of them are also proving promising in tests using experimental animals. The proteins include several chemokines, molecules that stimulate immune system cells.

Developing pharmaceuticals will never be a quick process, because medicines, whether proteins, genes or small molecules, have to be extensively tested. Nevertheless, partial cDNA sequences can speed the discovery of candidate therapies. HGS allows academic researchers access to much of its database, although we ask for an agreement to share royalties from any ensuing products.

The systematic use of automated and computerized methods of gene discovery has yielded, for the first time, a comprehensive picture of where different genes are expressed—the anatomy of human gene expression. In addition, we are starting to learn about the changes in gene expression in disease. It is too early to know exactly when physicians will first successfully use this knowledge to treat disease. Our analyses predict, however, that a number of the resulting therapies will form mainstays of 21st-century medicine. SA

To obtain high-quality reprints of this article, please see page 123.

The Author

WILLIAM A. HASELTINE is chairman of the board of directors and chief executive officer of Human Genome Sciences in Rockville, Md. He has a doctorate in biophysics from Harvard University and from 1976 to 1993 was a professor with appointments at the Dana-Farber Cancer Institute, Harvard Medical School and Harvard School of Public Health. Haseltine has won numerous scientific awards for his research on cancer and AIDS; he has also been awarded more than 50 patents. Since 1981 he has founded seven biotechnology companies. In 1988, together with Flossie Wong-Staal, Haseltine wrote in *Scientific American* about the molecular biology of the AIDS virus.

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Heike Kamerlingh Onnes's Discovery of Superconductivity

The turn-of-the-century race to reach temperatures approaching absolute zero led to the unexpected discovery of electric currents that flowed with no resistance

by Rudolf de Bruyn Ouboter

Superconductivity—the disappearance of resistance in an electric current—is one of nature's stranger phenomena. Ten years ago this month, in what some called the "Woodstock of physics," hundreds of scientists crowded into a ballroom at the New York City Hilton to receive hurried reports of superconductivity at much higher temperatures than ever previously reported. Thirty years before that, John Bardeen, Leon N. Cooper and J. Robert Schrieffer established the theoretical foundations that best explained superconductivity. Almost forgotten in the search for theory, and for materials that superconduct at ever higher temperatures, is the work of the brilliant experimental physicist Heike Kamerlingh Onnes, superconductivity's discoverer.

Onnes was a man attracted to cold, which no doubt added to his enjoyment of the December day in Stockholm in 1913 when he received the Nobel Prize for Physics. His primary research goal was to quantify the behavior of gases at extremely low temperatures; the experimental program that allowed him to reach ever lower temperatures also led to the discovery of superconductivity.

Onnes was born in 1853 in Groningen, in the northeastern Netherlands. His father owned a roofing-tile factory, but his mother's more artistic temperament seems to have influenced the family. His brother and nephew became highly regarded painters, his sister married the well-known Leiden artist Floris Verster, and Onnes dabbled in poetry as a youth. A remnant of Onnes's poetic leanings can be found in his laboratory motto, *Door meten tot weten:* "Through measurement to knowledge." Onnes's passions, however, would be fully ignited only by his later pursuits in low-temperature physics.

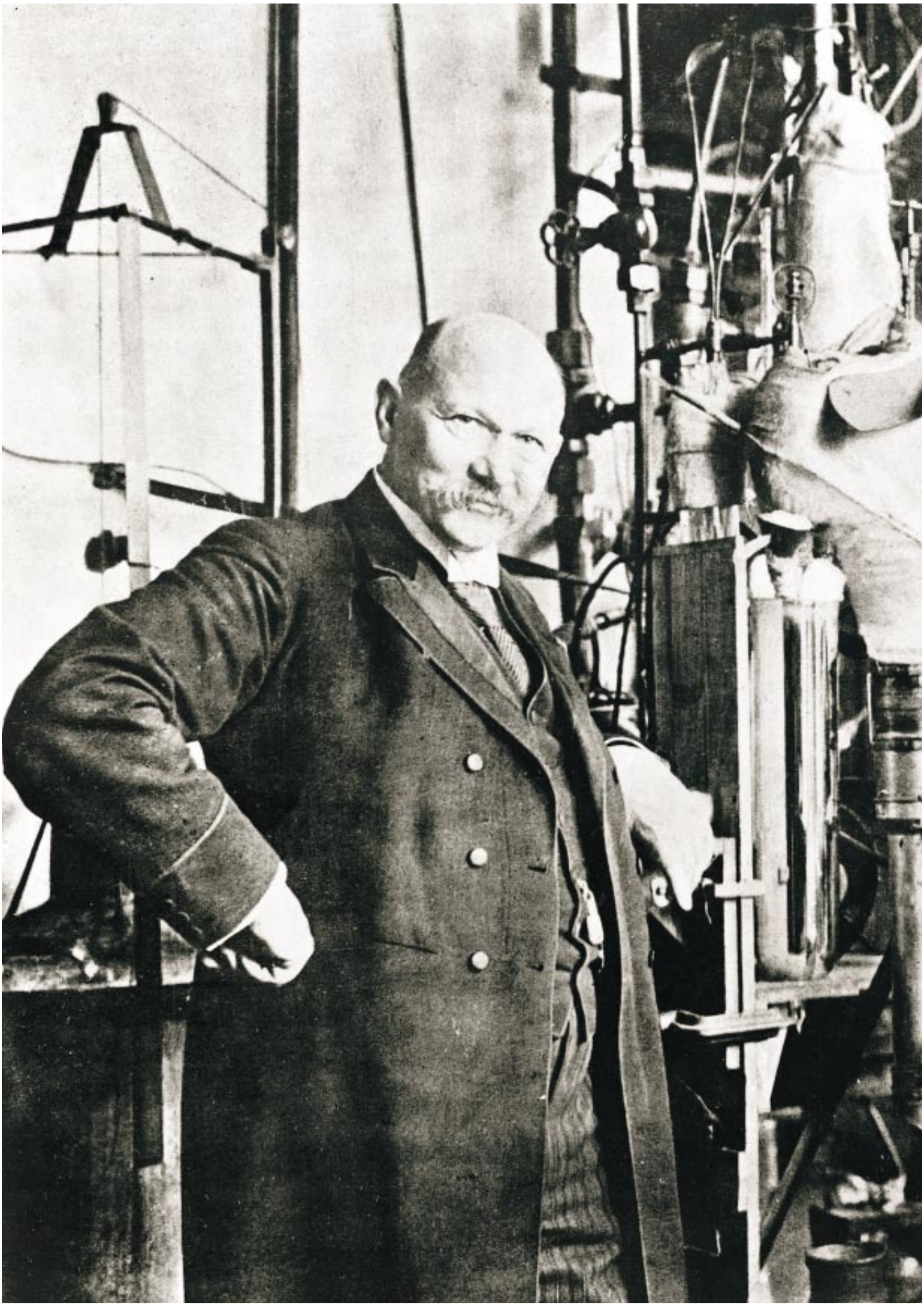
RON MAY

In 1870 Onnes enrolled at the University of Groningen to study physics. He apparently had a bit of wanderlust, as he transferred the following year to the University of Heidelberg in Germany, where he studied with the chemist Robert Bunsen (whose last name is familiar to everyone who has lit a burner in a high school chemistry laboratory course) and with the physicist Gustav Kirchhoff. In 1873 he returned to Groningen, where five years later he defended his doctorate on the influence of the earth's rotation on a short pendulum. Accounts allege that at the conclusion of that defense his examiners burst into applause.

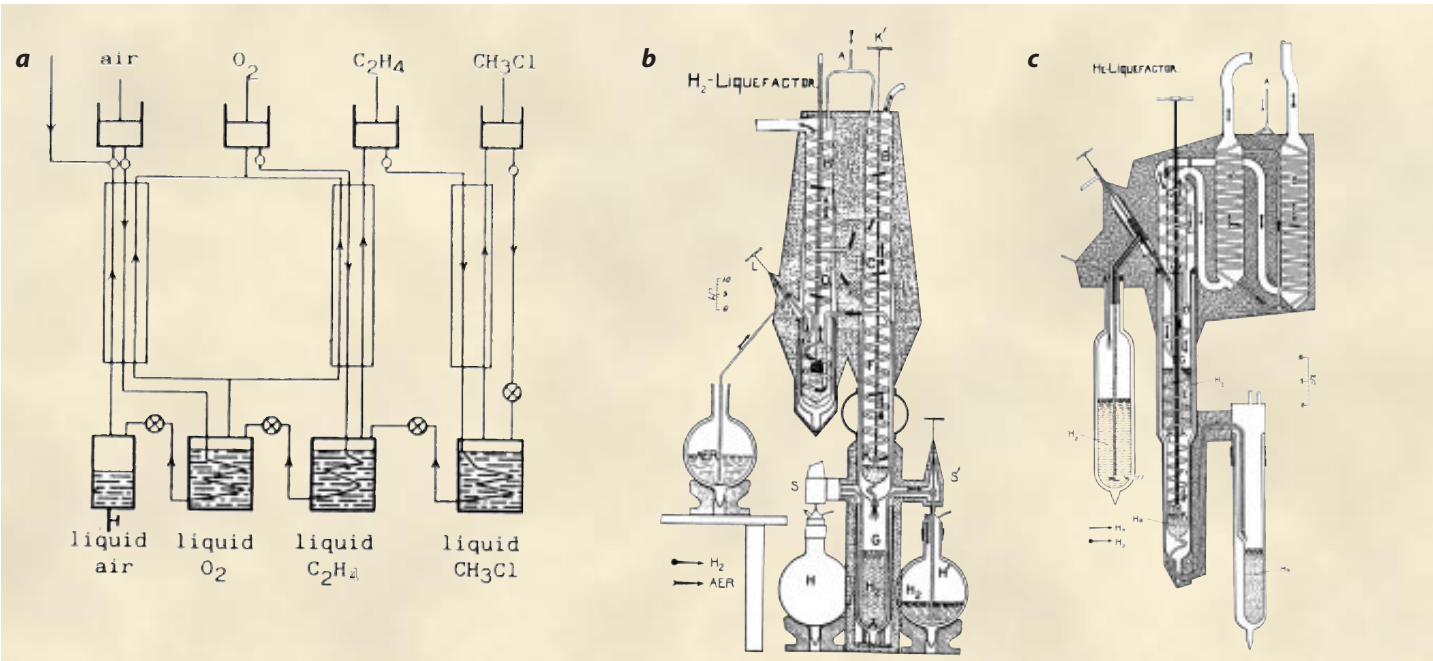
Toward the end of his doctoral work, Onnes became acquainted with Johannes Diderik van der Waals, then professor of physics at the University of Amsterdam. The behavior of gases had been approximately known since the late 17th century, when Anglo-Irish scientist Robert Boyle showed that pressure was inversely proportional to volume at any given temperature. The resulting equations describing the behavior of gas pertained to a mythical perfect gas, whose molecules occupied no volume and exerted no forces on one another. As measuring techniques improved, however, chemists and physicists began to notice deviations from the perfect comportment of gases.

Van der Waals set about to develop a coherent description of real gases, taking into account the actual space occupied by real gas molecules, along with the forces they exert on one another. In 1873 he succeeded in formulating the van der Waals law, describing real gas behavior for individual gases; seven years later he published his law of corresponding states: a single equation accounting for the behavior of all real gases. Although Onnes's work in mechanics was exemplary, he found himself far

HEIKE KAMERLINGH ONNES stands in front of the apparatus he used to bring helium close to absolute zero and thereby liquefy it. As a by-product of this quest to reach extremely low temperatures, he serendipitously discovered the phenomenon he named "superconductivity." In recent years, superconductivity at ever increasing temperatures has raised expectations of expanding the market for devices that exploit the phenomenon. Above, a technician engaged in such research checks a coil submerged in inexpensive liquid nitrogen at a temperature of about 77 kelvins.



COURTESY OF THE KAMERLINGH ONNES LABORATORY, LEIDEN UNIVERSITY, THE NETHERLANDS



CASCADE APPARATUS (*a*) constructed by Onnes in 1892 could produce 14 liters of liquid air per hour. Liquid air was essential for operating the hydrogen liquefier (*b*) he perfected in 1906. The hydrogen gas travels through the system to a liquid air bath and ultimately to an expansion valve, which permits hydrogen gas to expand and liquefy. The liquid hydrogen is collected, while gas returns to the compressor. Onnes developed the first helium liquefier (*c*) in 1908. He posed with his mentor, Johannes Diderik van der Waals, in front of the device in 1911 (*d*) and, a decade later, with his chief assistant, Gerrit Flim (*e*).

more interested in following van der Waals's lead and exploring the behavior of gases.

Cascading toward Liquid Hydrogen

In 1882 Onnes was appointed professor in physics at Leiden University. Although quantitative techniques were the rule in mechanics and electromagnetic research, studies of matter, rather than forces, could still often be quite qualitative. Onnes set about to make quantitative analyses universal; mathematical rigor was essential for the scientific problems concerning him.

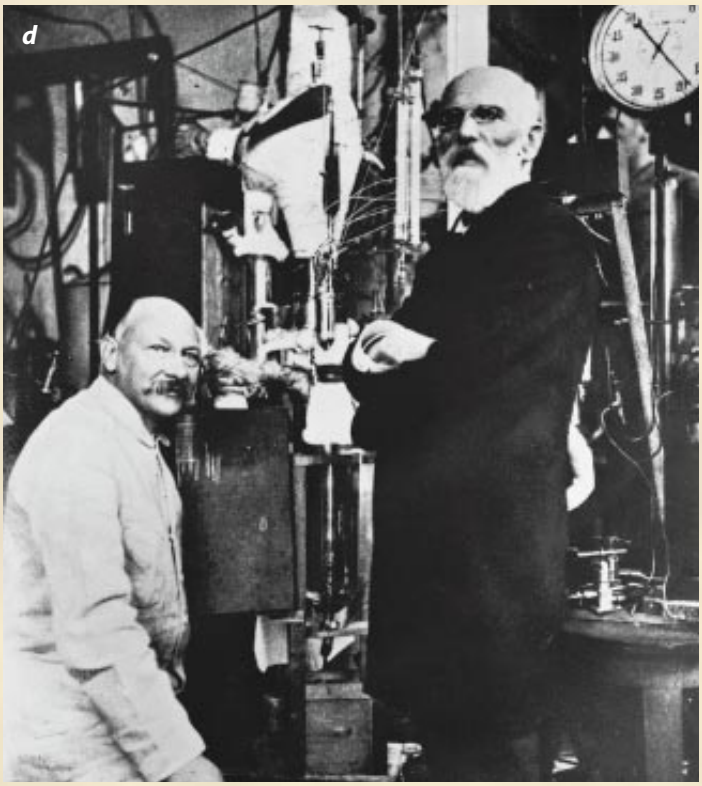
The only way to test van der Waals's ideas was to measure gaseous behavior at extreme conditions. At exceedingly low temperatures, for example, a particular gas deviates ever more greatly from the ideal gas laws, following instead van der Waals's predictions for real gases. The need for extremely cold conditions led Onnes to establish a cryogenic laboratory at Leiden. (The facility was renamed the Kamerlingh Onnes Laboratory in 1932.) The correspondent need for trained craftsmen to create the complex and delicate instruments necessary for cryogenic work led him to establish the Society for the Promotion of the Training of Instrument Makers. This school within the university churned out highly skilled technicians, including glassblowers, who would create devices for him and many other researchers around the world.

In 1877 French physicist Louis P. Cailletet and Swiss scientist Raoul P. Pictet independently succeeded in liquefying both oxygen and nitrogen. Before that achievement, many in the scientific community assumed that those gases, along with hydrogen, were perhaps beyond liquefaction. (Although helium had been seen in solar spectra, that gas would not be discovered on the earth until 1895.) The problem lay in achieving the exceedingly low temperatures required to condense these gases. The quantities of liquid that Cailletet and Pictet could produce were extremely small. Onnes, however, needed large amounts to conduct his research.

By 1892 Onnes had succeeded in developing an apparatus for producing those large amounts. The system took advantage of what became known as the cascade process—a series of gases with ever lower condensation temperatures are compressed, cooled to their liquefaction point and then expanded. The vapor coming from the evaporating liquid cools the next compressed vapor in the series. Starting with methyl chloride, which condenses at +21 degrees Celsius under five atmospheres (atm) of pressure, Onnes sequentially condensed ethylene (–87 degrees C at 3 atm), then oxygen (–145 degrees C at 17 atm), and finally air (–193 degrees C at 1 atm).

For the liquefaction of hydrogen, however, the temperature necessary would be significantly closer to absolute zero, making the construction of the apparatus more delicate. According to the laws governing the behavior of an ideal gas, at constant volume, the pressure falls with falling temperature. In theory, the pressure becomes zero at –273.15 degrees C (although real gases would already have liquefied). This temperature defines zero on the Kelvin scale and is called absolute zero because it is the lowest temperature attainable.

In 1898 James Dewar, the Scottish low-temperature physicist, beat Onnes to liquid hydrogen by taking advantage of a thermodynamic effect known as Joule-Thomson expansion: the temperature of a gas changes, usually going down, as it expands through a valve. Joule-Thomson expansion was used as part of the cascade process; Dewar made it central to his effort for liquefying hydrogen, because if hydrogen is first cooled to below –80 degrees C and then expanded, its temperature drops further.



COURTESY OF THE KAMERLINGH ONNES LABORATORY, LEIDEN UNIVERSITY (*a–e*)

(Curiously, above –80 degrees C, hydrogen warms if it expands, which is why this point is known as its inversion temperature.) In this way, Dewar drove hydrogen down to its liquefaction temperature of about –253 degrees C, or 20 kelvins.

Dewar's apparatus produced only small amounts of liquid hydrogen. That result was probably not a disappointment to him, however. Whereas Onnes seems to have been motivated by observations of gas behavior at low temperatures, Dewar's objective was simply to achieve temperatures approaching absolute zero. Nevertheless, it was Onnes who became known as "the gentleman of absolute zero."

Onnes was interested in producing much larger amounts of liquid hydrogen than Dewar had, which is one reason why he did not liquefy hydrogen until eight years after Dewar did. Another factor was a frightened Leiden community. In 1807, during the Napoleonic occupation of the Netherlands, an ammunition ship exploded in a canal in the center of Leiden. The Onnes laboratory was built on the ruins of the destroyed section of town. In 1896, when the town council learned that the laboratory housed considerable quantities of compressed hydrogen, a wildly combustible gas, the historical memory of the ship's explosion drove them into a panic. The authorities appointed a commission to study the matter, but even with the presence of van der Waals on that commission and a letter from Dewar imploring the council to permit the research to continue, Onnes's hydrogen work was shut down for two years.

Helium Becomes the Prize

By 1906 Onnes and his team had developed an apparatus capable of producing relatively large amounts of liquid hydrogen via Joule-Thomson expansion. The liquefier compressed hydrogen gas, passed it through a region chilled by liquid air and then allowed it to expand, thereby cooling the hydrogen enough to liquefy at least some of it. Any remaining gaseous hydrogen was captured and returned to the system for another attempt. The apparatus could produce four liters of liquid hydrogen an hour at first and up to 13 liters with later improvements.

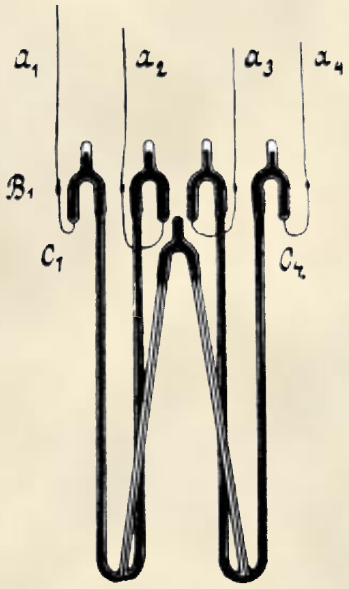
In 1895, while Onnes and Dewar had been attempting to liquefy hydrogen, William Ramsay in England discovered helium on the earth. Helium is the lightest of the inert gases; its atoms exert extremely weak forces among themselves. Those weak interactions contribute to an exceptionally low condensation temperature. Where the grail had been liquid hydrogen, it now became liquid helium. "I resolved to make reaching the end of the road my purpose immediately," Onnes wrote.

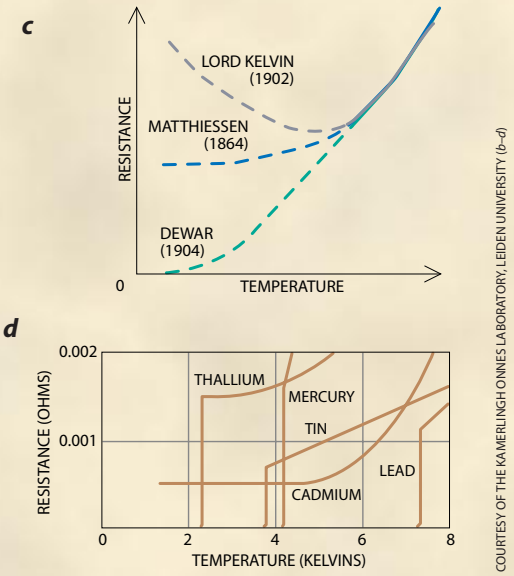
The first step was acquiring a sufficient amount of the recently discovered helium gas. Fortunately, Onnes's brother was director of the Office of Commercial Intelligence in Amsterdam, and he was able to arrange for large amounts of monazite sand, which contains helium, to be purchased from North Carolina. Onnes was able to extract about 300 liters of helium gas (at 1 atm) from the sand shipment.

The availability of a steady supply of liquid hydrogen was the key to the attempt to liquefy helium. Onnes designed a new apparatus, using liquid air and finally liquid hydrogen as the coolants. Again, a Joule-Thomson expansion would be tried to condense helium and obtain a few precious drops of liquid. The system was up and running on July 10, 1908, and word spread throughout the university. A small audience of scientists gathered to watch.

By midafternoon, helium gas flowed through the circuit, but no helium liquid was apparent by early evening, and the

COURTESY OF MUSEUM BOERHAAVE, LEIDEN





COURTESY OF THE KAMERLINGH ONNES LABORATORY, LEIDEN UNIVERSITY (*b–d*)

CAILLETET COMPRESSOR (*a*), invented by Louis P. Cailletet, who liquefied oxygen and nitrogen, was extremely useful to Onnes throughout his research. Because no gas is lost during compression or expansion, the device was suitable for working with pure and costly gases. A W-shaped capillary tube (*b*) carried the mercury wire used in the tests for mercury's resistance at low temperatures. Before Onnes began his investigations, the predicted behavior of metals (*c*) was quite different from what he actually found. He discovered that sharp drops in resistance (*d*) accompany decreasing temperatures for mercury and a number of other metals.

thermometer refused to go any lower than 4.2 kelvins. A chemistry professor who happened by, Fransiscus Schreinemakers, suggested that perhaps the thermometer reading had stopped declining because liquid helium was in fact already there but was simply hard to see. Onnes proceeded to illuminate the collection vessel from below. He later recounted that this was a wonderful moment, with the surface of liquid helium suddenly becoming clear against the glass wall of its vessel like the edge of a knife, and that he was overjoyed to be able to show liquid helium to van der Waals. By reducing the pressure, Onnes brought the temperature down to 1.7 kelvins, tantalizingly close to absolute zero for those days. They used helium gas thermometers to measure these extremely low temperatures. (At constant volume and low pressure, helium in the thermometer behaves closely enough to the mythical ideal gas to allow for temperature measurement: because pressure times volume is proportional to temperature, measuring the pressure at constant volume reveals the temperature.)

Over the next three years, Onnes devoted himself to developing better apparatus for using liquid helium in research. Merely moving the liquid from the vessel in which the helium condenses into a storage vessel presented great technical challenges. Finally, in 1911, a helium cryostat, which could maintain the liquid at a constant low temperature, was ready for investigating the behavior of other substances at the liquid-helium temperatures.

Cold and Currents

It was well known by this time that the electrical resistance in a metal decreased with temperature. Exactly what would happen to resistance at temperatures approaching absolute zero, however, was hotly debated. Lord Kelvin believed that the flow of electrons, which seemingly improved with decreasing temperatures as the lower resistance indicated, might actually stop altogether, the electrons becoming frozen in place. The resistance at absolute zero would thus be infinitely high. Others, including Onnes and Dewar, assumed that the decrease in resistance with falling temperature would continue in an orderly fashion, ultimately reaching zero at the zero temperature point. (In 1905 Walther H. Nernst of Germany showed that the laws of thermodynamics prohibit reaching absolute zero experimentally. Temperatures of 0.3 kelvin have since been reached using the rare isotope helium 3, and the demagnetization of atomic nuclei has produced temperatures as low as 0.00001 kelvin.) What actually happened was stunning and, given the understanding of matter at the atomic level in 1911, completely unpredictable.

Because impurities in a metal might disturb an electric current and confuse experimental results, Onnes decided to work with mercury. He could repeatedly distill liquid mercury at room temperature, thus producing a very pure sample for his low-temperature experiments. The mercury was incorporated into a U-shaped glass capillary tube with electrodes on both ends so that current could be measured passing through it while still liquid. Finally, the mercury was cooled to a solid wire. At all measured temperatures, the Onnes team found the expected regular decrease in resistance. At liquid-helium temperatures still measurably higher than absolute zero, however, the resistance already appeared to have completely vanished.

Onnes, Gerrit Flim, chief of the technical staff, and their co-workers Gilles Holst and Cornelius Dorsman performed the experiments. Onnes and Flim looked after the cryogenic apparatus in which the mercury was cooled, while Holst and Dorsman sat in a dark room 50 meters away, recording the resistance readings from the galvanometer.

Jacobus de Nobel, a researcher in the cryogenic laboratory of Leiden, recently recounted the story that he heard from Flim on arriving there as a young man in 1931. (Of course, one must be care-

ful in taking these accounts too literally, for much time has passed, and the story is thirdhand.) Repeated trials all indicated zero resistance at the liquid-helium temperatures. The workers assumed that some kind of short circuit was responsible and replaced the U-tube with a W-shaped tube with electrodes at both ends and at the kinks, presenting four different segments for measurement. Again, the resistance was zero, and no short circuits could be found in any of the segments.

They continued to repeat the experiment. A student from the instrument-makers school was charged with watching the readings of a pressure meter connected to the apparatus. The helium vapor pressure in the cryostat needed to be slightly lower than the atmospheric pressure so that air would rush into any tiny leaks, freeze, and seal them. During one experimental run, the youngster nodded off. The pressure slowly rose, as did the temperature. As it passed near to 4.2 kelvins, Holst saw the galvanometer readings suddenly jump as resistance appeared.

According to de Nobel's story, Holst had unwittingly witnessed, in reverse, the transition at which mercury went from its normal conductive behavior into the state that Onnes would call "superconductivity." Repeated trials convinced Onnes that the sudden loss of mercury's resistance at about 4.2 kelvins was real. He published the finding in November 1911 as "On the Sudden Change in the Rate at Which the Resistance of Mercury Disappears." Subsequent tests of tin and lead showed that superconductivity was a property of numerous metals if they were cooled sufficiently.

By 1914 Onnes established a permanent current, or what he called a "persistent supercurrent," in a superconducting coil of lead. The coil was placed in a cryostat at low temperature, with the current being induced by an external magnetic field. With no resistance, the electrons in the coil were free to continue to flow indefinitely. After seeing the current, Austrian-Dutch physicist Paul Ehrenfest wrote to Nobel physicist Hendrik Lorentz in the Netherlands, "It is uncanny to see the influence of these 'permanent' currents on a magnetic needle. You can feel almost tangibly how the ring of electrons in the wire turns around, around, around—slowly, and without friction."

Onnes was disappointed, however, to discover that even a minor magnetic field could quench superconductivity. This sensitivity meant that only small amounts of current could pass through superconducting materials despite the lack of resistance—the magnetic fields associated with currents of sufficient strength extinguished the superconductivity. This issue remained the biggest impediment toward practical applications of Onnes's discovery during his lifetime. Half a century would pass before materials were discovered and processed in ways allowing for large currents and associated magnetic fields. The magnetic resonance imaging (MRI) devices that have become mainstays of modern diagnostic medicine have been the best-known important practical application of the advances in superconductivity made in the second half of this century.

Heike Kamerlingh Onnes died in 1926. His accomplishments are all the more remarkable given that he suffered from a bronchial condition that forced him away from the laboratory for long periods of recovery in Switzerland. His physical absence apparently did not prevent Onnes from piloting his laboratory workers—even death did not stop him. According to Leiden legend, his funeral service lasted longer than expected, forcing the procession to rush through town to be on time for the scheduled burial in the nearby village of Voorschoten. As the procession hurried along, Gerrit Flim is said to have remarked, "That is the old man all right—even now he keeps us running."

Although superconductivity remained an esoteric scientific research area during his lifetime, Onnes firmly believed that the resistance-free current would eventually allow for the creation of many practical devices. Levitating trains and superconducting electrical transmission lines are two of the most frequently mentioned potential applications. The ongoing drive to discover materials that superconduct at more convenient temperatures may yet make Onnes's discovery a part of everyday life. SA

COURTESY OF THE KAMERLINGH ONNES LABORATORY, LEIDEN UNIVERSITY

DRAWING OF ONNES was done by his nephew, Harm Kamerlingh Onnes, in 1922.

The Author

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Plants That Warm Themselves

Some plants produce extraordinary heat when they bloom. A few even regulate their temperature within narrow limits, much as if they were warm-blooded animals

by Roger S. Seymour

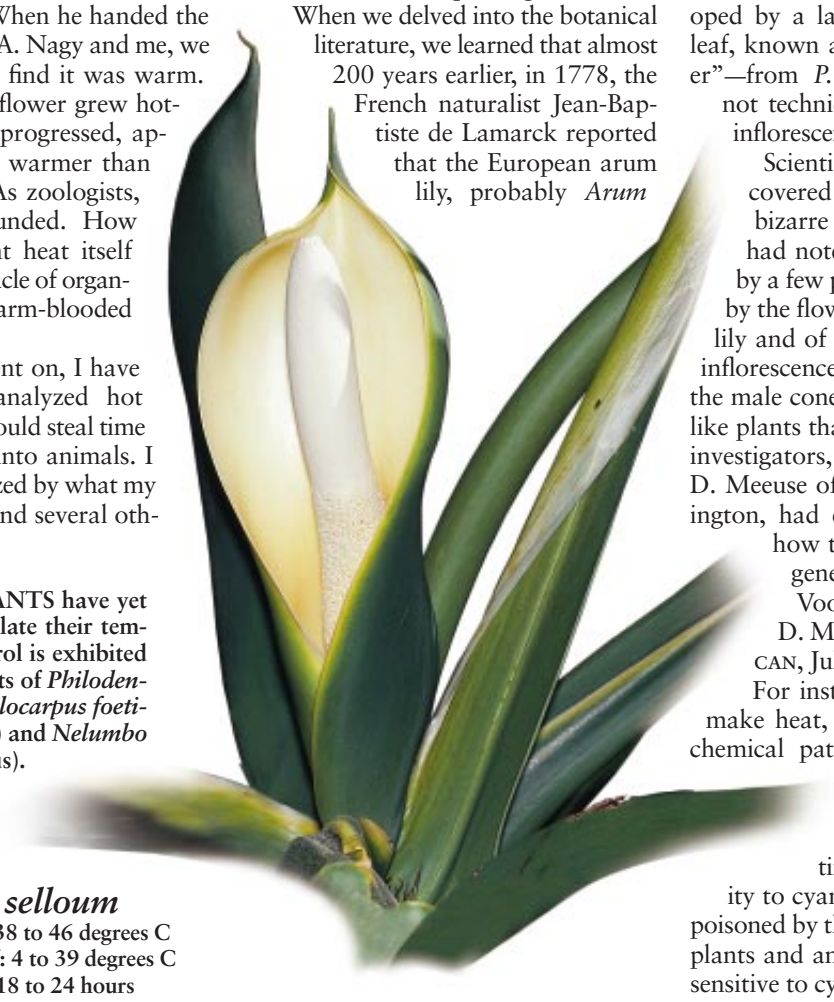
In the spring of 1972 George A. Bartholomew, a leader in the study of animal physiology, invited a group of his students and co-workers from the University of California at Los Angeles to a dinner party. Among his guests was Daniel K. Odell, now of Sea World in Florida. En route to the affair, Dan noticed some striking flowers. They consisted of a rather phallic projection that was about nine inches long and partly enveloped by a leaflike structure. Intrigued, he picked one to show the other partygoers. When he handed the cutting to Kenneth A. Nagy and me, we were astonished to find it was warm. What is more, the flower grew hotter as the evening progressed, appearing to become warmer than the human body. As zoologists, we were dumbfounded. How could a mere plant heat itself more than the pinnacle of organic evolution—the warm-blooded animal?

From that moment on, I have hunted for and analyzed hot plants whenever I could steal time from my research into animals. I continue to be amazed by what my colleagues and I—and several other researchers—have found. Among our discoveries is that some plants produce as much heat for their weight as birds and insects in flight, the greatest heat producers of all. And a few plants actually thermoregulate, almost as if they were birds or mammals: they not only generate warmth, they alter their heat production to keep their temperature surprisingly constant in fluctuating air temperatures.

We were not, it turns out, the first to realize that some plants give off heat. When we delved into the botanical literature, we learned that almost 200 years earlier, in 1778, the French naturalist Jean-Baptiste de Lamarck reported that the European arum lily, probably *Arum italicum,* became warm when it flowered. This plant is a member of the huge family Araceae, which includes *Philodendron,* the kind of plant Dan had plucked. It also includes jack-in-the-pulpit, skunk cabbage and many other familiar plants. In these so-called aroids, or arum lilies, the flowering part is termed a spadix and is not a true flower; it is an "inflorescence," or clustering of small flowers (florets). The aroid spadix, which consists of hundreds of florets assembled on a common stalk, is partly enveloped by a large bract, or specialized leaf, known as a spathe. Dan's "flower"—from *P. selloum*—was therefore not technically a flower; it was an inflorescence.

Scientists had subsequently discovered that other species of this bizarre family heat up, and they had noted weak heat production by a few plants outside the aroids—by the flowers of the Amazon water lily and of the custard apple, by the inflorescences of a few palms, and by the male cones of certain cycads (fernlike plants that resemble palms). Some investigators, among them Bastiaan J. D. Meeuse of the University of Washington, had even uncovered clues to how the cells of various plants generate warmth [see "The Voodoo Lily," by Bastiaan J. D. Meeuse; SCIENTIFIC AMERICAN, July 1966].

For instance, they found that to make heat, aroids activate two biochemical pathways in mitochondria, which are often called the power plants of cells. These pathways are distinguished by their sensitivity to cyanide. The one that can be poisoned by the chemical is common to plants and animals; the one that is insensitive to cyanide occurs in heat-pro-



ONLY THREE PLANTS have yet been shown to regulate their temperature. Such control is exhibited by the flowering parts of *Philodendron selloum, Symplocarpus foetidus* (skunk cabbage) and *Nelumbo nucifera* (sacred lotus).

Philodendron selloum
Flower temperature: 38 to 46 degrees C
In air temperatures of: 4 to 39 degrees C
Period of regulation: 18 to 24 hours

GEORGE K. BRYCE

ducing plants, certain other plants, fungi and some unicellular organisms. Both pathways typically use nutrients and oxygen to manufacture an energy-rich molecule called ATP (adenosine triphosphate), which can subsequently be broken apart to provide energy for cellular activities or to produce heat. It is unclear, however, whether aroid cells that warm up generally do so by first making ATP and then breaking it down or by simply liberating heat directly from the pathways without producing ATP as an intermediate.

A "Warm-Blooded" *Philodendron*

We started off looking at *P. selloum* from an entirely different vantage. Instead of examining individual cells or molecules, as most botanists had done, we studied the inflorescences as if they were whole animals. Bartholomew's laboratory at U.C.L.A. conducted comparative studies on heat production and body temperature regulation in animals, and so all the needed equipment and methods were at hand. Furthermore, many *P. selloum* plants were in flower right outside our laboratory window, giving us easy access to our subjects.

Our earliest experiments, driven by sheer curiosity, aimed to do little more than determine whether the inflorescence truly had become as hot as we suspected at the party. We impaled spadices with temperature probes and connected the probes to a machine in the laboratory that recorded temperature continuously. During the measurement period, the air outside averaged about 20 degrees Celsius (68 degrees Fahrenheit), and the spadix temperature remained about 20 degrees C higher, near 40 degrees C (104 degrees F). The inflorescence was, indeed, hotter than its environment and hotter, too, than a person.

By then we were captivated and wanted to know more, such as the range of *P. selloum*'s heat-producing capabilities. Because we could not control the air temperature outdoors, we cut some specimens and put them into indoor cabinets where we could vary the temperature as we chose. Indoors, we could also examine the plant's rate of heat production by the simple expedient of measuring its rate of oxygen consumption. We felt confident in applying consumption of oxygen as a gauge because of the intimate connection between oxygen use and heat generation. In animals, every milliliter of oxygen consumed results in about 20 joules of heat. Thus, the rate of oxygen use can be converted readily to the rate of heat production in watts (joules per second).

We examined the inflorescences at air temperatures ranging from below freezing to uncomfortably hot for humans. At the coldest extremes, some of the inflorescences could not heat up at all. But their temperatures soared to as high as 38 degrees C (100 degrees F) when the environmental temperature was still a cool four degrees C (39 degrees F)—a 34 degree C difference between the inflorescence and the air. The cuttings became hotter still as the air temperature rose further, but the difference between them and their environment became less dramatic. The inflorescences peaked at 46 degrees C (115 degrees F) when the interior of the cabinet was a tropical 39 degrees C (102 degrees F). Further, the estimated rate of heat production decreased as the temperature of the environment increased.

The plant was obviously adjusting heat production to maintain warmth in cold weather and to prevent overheating in hot conditions. The conclusion was startling: these inflorescences did more than produce heat. Like warm-blooded birds and mammals, they were thermoregulating.

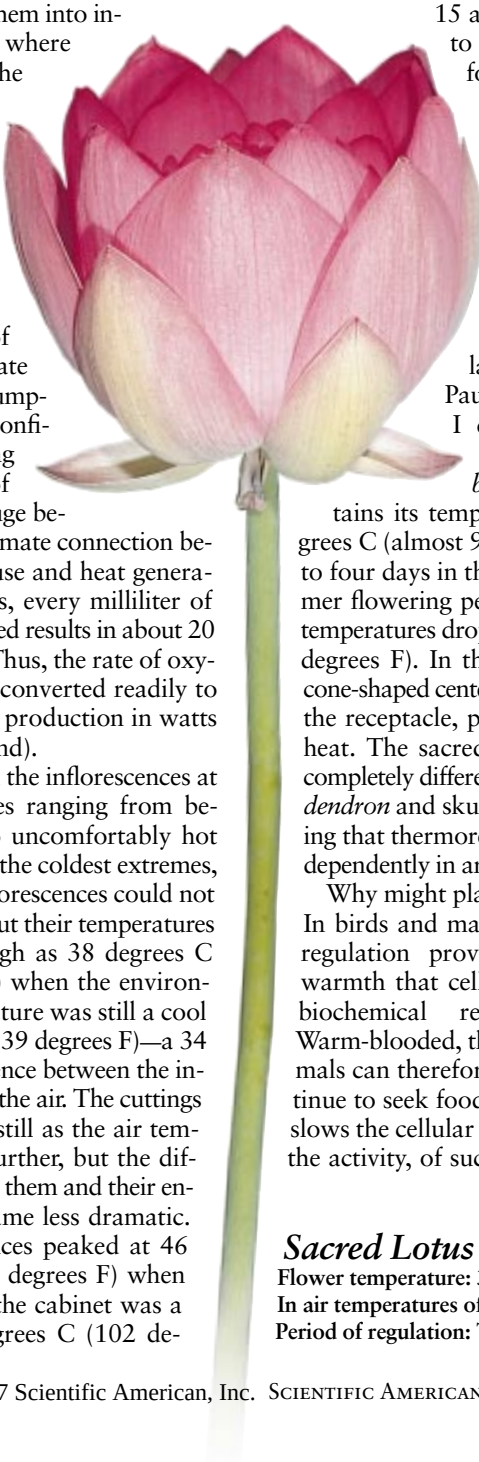
Two years after we discovered that *P. selloum* could thermoregulate, Roger M. Knutson, then at Luther College in Iowa, reported that the spadix of the eastern skunk cabbage, *Symplocarpus foetidus,* holds its temperature between 15 and 22 degrees C (59 to almost 72 degrees F) for at least two weeks during February and March, when air temperatures are below freezing. (The plant reportedly melts snow around it.) And just last year at the University of Adelaide in Australia, Paul Schultze-Motel and I discovered that the sacred lotus, *Nelumbo nucifera,* maintains its temperature near 32 degrees C (almost 90 degrees F) for two to four days in the middle of its summer flowering period, even when air temperatures drop to 10 degrees C (50 degrees F). In this case, the spongy, cone-shaped center of the flower, called the receptacle, produces most of the heat. The sacred lotus belongs to a completely different family from *Philodendron* and skunk cabbage, suggesting that thermoregulation evolved independently in aroids and in the lotus.

Why might plants thermoregulate? In birds and mammals, temperature regulation provides the consistent warmth that cells need to carry out biochemical reactions efficiently. Warm-blooded, thermoregulating animals can therefore be active and continue to seek food when cold weather slows the cellular reactions, and hence the activity, of such cold-blooded ani-

Skunk Cabbage

Flower temperature: 15 to 22 degrees C
In air temperatures of: –15 to 10 degrees C
Period of regulation: Two weeks or more

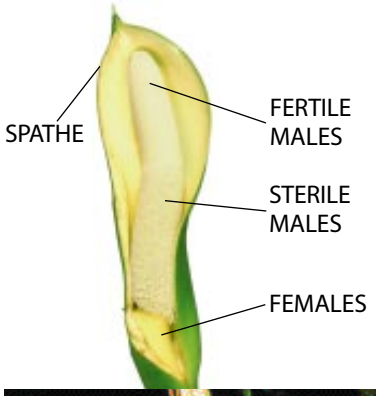
RAYMOND A. MENDEZ *Earth Scenes*



Sacred Lotus

Flower temperature: 30 to 37 degrees C
In air temperatures of: 10 to 35 degrees C
Period of regulation: Two to four days

PATTI MURRAY *Earth Scenes*



ROGER S. SEYMOUR

BEETLES are the natural pollinators of *P. selloum*, whose inflorescence, or flowering part, consists of three types of tiny flowers (florets)—fertile males, sterile males, and females—growing on a stalk (*top left*). During the plant's thermoregulatory period, the leaflike "spathe" around the inflorescence opens, giving the insects access to the florets (*bottom left*). The beetles brush pollen onto receptive female florets. Then, as the plant cools, the spathe folds around some of the insects. Later, the spathe reopens somewhat (*center*), and fertile males release their pollen. The small opening forces escaping beetles to crawl through the pollen (*right*), which sticks to them as they move on to other inflorescences. This convergence of the plant's warming and reproductive periods supports the idea that thermoregulation evolved in *P. selloum* as a reward to pollinating beetles.

GERHARD GOTTSBERGER *University of Ulm*

GEORGE K. BRYCE

GERHARD GOTTSBERGER *University of Ulm*

mals as reptiles. And birds and mammals whose thermostats are set high (close to 40 degrees C) ensure that their tissues can generate energy at the high rates needed for prolonged exercise, such as running or flying. But clearly, we must seek another explanation for temperature regulation in sedentary flowers.

The Value of Thermoregulating

Past work by others has made the reasonable case that aroids and certain other plants heat themselves to vaporize scents that attract insects. Vaporization of attractants could partly explain heating in thermoregulating plants but would not explain why heat production is raised and lowered to keep temperature within a set range. We can suggest two reasons for why thermoregulation evolved in some plant species.

First, it may create a warm, stable environment for pollinators and thereby facilitate reproduction. Large insects that carry pollen from one flower to another typically require high body temperatures for flight, locomotion and social interactions, and they often expend a great deal of energy keeping warm. Those that visit thermogenic flowers would be provided with a fairly steady level of heat directly from the plant. They could eat, digest, mate and function in other ways without having to squander energy of their own to stay warm. Alternatively, the flower itself may require a constant temperature for proper development of its own reproductive structures or to protect sensitive parts from damage that might occur if heat production were uncontrolled.

Either hypothesis could explain why a plant evolved the ability to thermoregulate. Yet the interaction between *P. selloum* and pollinating insects does lend some credence to the idea that thermoregulation in this plant may have been adopted because it abetted pollination. This interaction has been studied closely in Brazil, the plant's native territory, by Gerhard Gottsberger of the University of Ulm in Germany.

The inflorescence of *P. selloum* contains three types of florets. At the top are fertile males that produce pollen. At the base are females capable of producing fruit when they are fertilized. Separating the fertile males and females is a band of sterile males that provide nourishment to pollinating insects and also furnish most of the inflorescence's heat. Tantalizingly, the 18- to 24-hour period of temperature regulation in the inflorescence overlaps the period of female receptivity to pollination. During these hours, the spathe surrounding the spadix opens widely and gives pollen-bearing insects—mainly beetles—easy access to the warm, sterile florets and nourishment. Then the spadix cools, and the spathe closes around it, trapping some beetles inside. After about 12 hours, by which time the female florets are sure to have been pollinated, the flower warms up again, the spathe reopens partway, and the fertile male florets shed their pollen. The pollen sticks to escaping insects, which fly off to repeat the cycle. This sequence promotes cross-pollination and prevents self-pollination; it thereby increases genetic diversity, which favors reproductive success.

In common with *P. selloum*, the sacred lotus maintains high temperatures when the female stigmas are moist and receptive and before the pollen is shed. Heating begins before the petals open widely and ends when opening is complete. The shape of this flower is also appropriate for pollination by beetles. But whether thermoregulation evolved specifically to aid beetles in that endeavor is unclear. The uncertainty arises because we do not know the native habitat of this plant and whether beetles are

the main pollinators in that area. Further, the flower clearly is not dependent on beetles; it can be pollinated by other insects after the petals open widely and heat production subsides.

How *Philodendron* Operates

The question of how plants thermoregulate is as fascinating as that of why they do it and was in fact my main concern when I began studying *Philodendron* seriously. To address this problem, I teamed up in the early 1980s with Bartholomew and M. Christopher Barnhart, who is now at Southwest Missouri State University. The answer was not at all obvious, given that plants operate very differently from animals.

In animals, temperature regulation is a complex affair. It requires temperature receptors at many locations in the body, and it demands a nervous system equipped to integrate all the input and to direct various parts of the body to change their activities. For instance, the nervous system often signals animals to adjust to a drop in air temperature by fluffing up their fur or feathers, thereby increasing their insulation and stemming heat loss. This strategy works only to a point, however, and so the animals may also increase heat production as the environment gets colder. Typically they begin to shiver, working their muscles together and forcing them to use ATP. Warming of the body also requires increases in the rates of breathing and blood circulation, in order to increase delivery of nutrients and oxygen to heat-producing tissue.

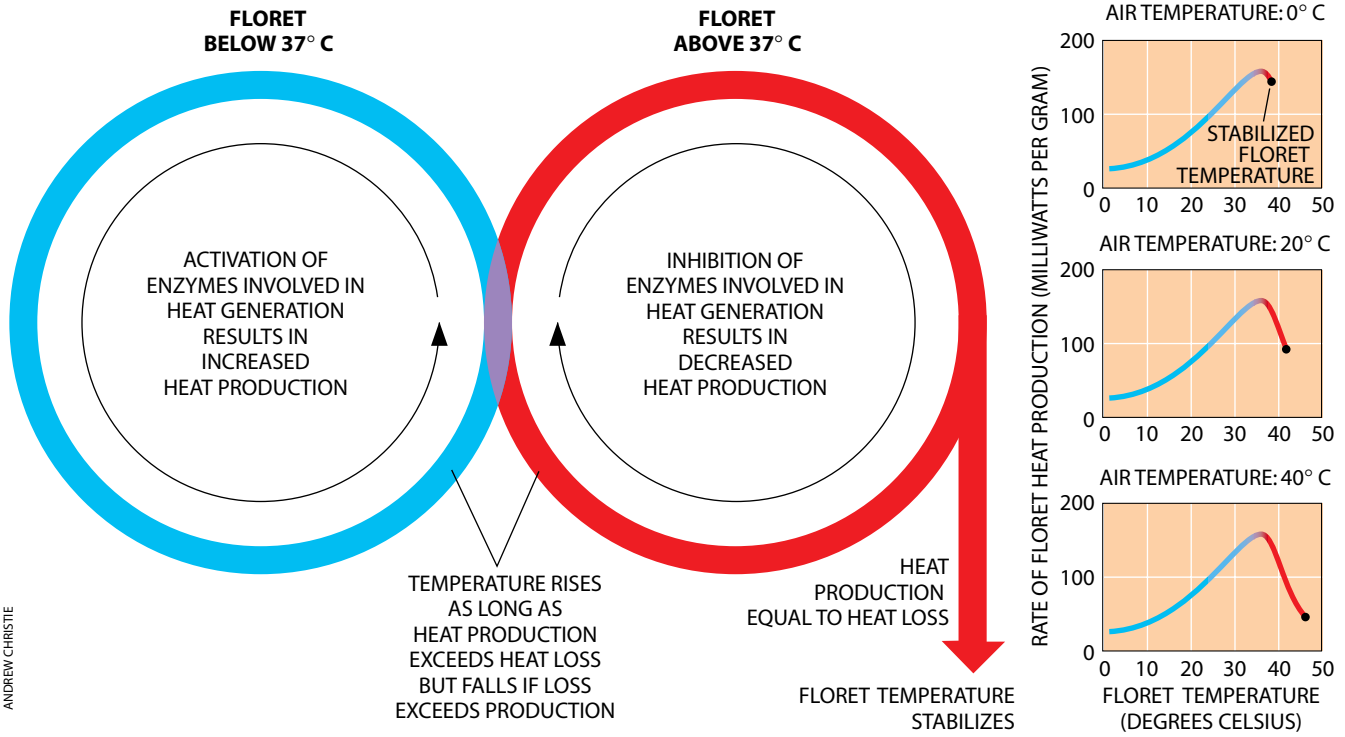
But plants have no fur, no feathers, no nervous system, no muscles, no lungs, no blood and no brain. How, then, we asked, does *P. selloum* raise and lower its temperature to keep the inflorescence in the 38 to 46 degree C range?

We first had to know which part of the inflorescence produced heat, a mystery at the time. We separated the three types of florets from their stalk and measured their oxygen consumption rates. On the basis of these measurements, we calculated the rate of heat production. The sterile males consumed the great bulk of the oxygen we supplied; the fertile males consumed a bit; and the females and the stalk took up almost none. Apparently the sterile florets were responsible for temperature control in the inflorescence. Subsequent studies confirmed this deduction and showed that the florets do not need the fancy temperature-regulating systems of animals. They contain their own thermostats, their own nutrient supplies and their own means of acquiring oxygen.

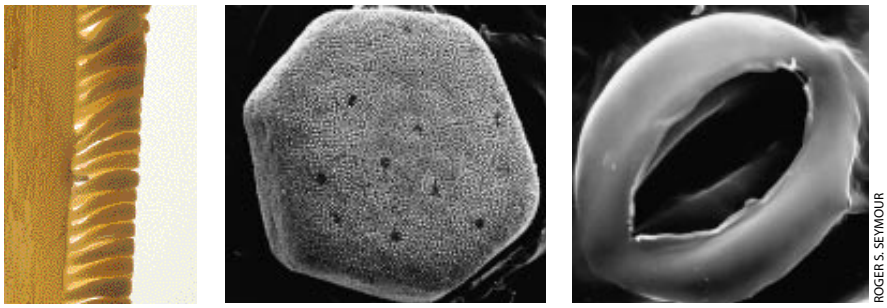
In the experiments revealing the existence of the thermostats we removed sterile male florets from the spadix and put individual florets in incubators kept at set temperatures. On their own, the

How *Philodendron* Achieves a Stable Temperature

The inflorescence of *Philodendron selloum* achieves temperature stability by essentially setting the thermostat of its sterile male florets—the main heat producers—to 37 degrees Celsius (*diagram*). If the temperature of the florets falls below that level, the florets increase their heat production (*left cycle*). As long as heat production surpasses heat loss, the floret temperature rises. As the floret temperature exceeds 37 degrees C (*right cycle*), enzymes needed for heat generation become progressively less active. Their inhibition leads to a decline in heat output. The decline continues until heat production equals heat loss, at which point the temperature stabilizes. The final floret temperature depends on the ambient temperature (*graphs*): If the air is cold, the florets lose heat quickly, so they produce it quickly, and their temperature stabilizes near 37 degrees C. If the air is hot, the florets retain heat, so they produce little of it, and their temperature stabilizes closer to 46 degrees C. —*R.S.S.*



ANDREW CHRISTIE



ROGER S. SEYMOUR

STERILE MALE FLORETS of *P. selloum* (*left*) take in oxygen through pores called stomates. Several stomates (*dark spheres*) are visible in the center micrograph, highlighting the tip of one floret. The micrograph at the right captures a single stomate.

florets could not warm one another and took on the temperature of the air around them. We could therefore assess how much heat they produced at particular temperatures.

The separated florets generated little heat when they were close to freezing, presumably because the enzymes (biological catalysts) needed for heat production—like most enzymes in living creatures—cannot function quickly when they are very cold. But at warmer temperatures, the florets displayed an interesting pattern of heat generation. (That pattern also occurs when the florets are attached to the spadix, except that in the intact spadix the florets gain added warmth from the heat emitted by one another.) As the temperature of the florets rises, so does their rate of heat production, which leads to further warming. This self-reinforcing increase continues until the florets reach 37 degrees C. At higher temperatures, the florets "turn down the furnace," dropping the rate of heat production steeply.

Exactly how far the rate declines depends on the environmental temperature. If the air is cold, say four degrees C, the florets lose heat quickly and their temperature stabilizes at about 38 degrees C (with a high rate of heat generation). On the other hand, when the environment is warm, perhaps 39 degrees C, they lose heat slowly and stabilize at about 46 degrees C (with a low rate of heat production). This pattern is reversible. A floret that has lowered heat production during the warmth of the day can resume generating heat when the temperature drops during the night.

Heat production declines in hot florets probably because the heat itself inhibits the pathways responsible for generating warmth. No one knows whether the high heat acts directly on certain enzymes in the pathways or whether it interferes with enzymatic activity by changing the structure of the membranes that bind the enzymes.

Extraordinary Wattage

Having gained insight into the setting maintained by the florets' thermostat, we began to investigate how the florets obtain the nutrients and oxygen they use during heating and exactly how much heat they produce. Although my earlier studies had estimated heat production on the basis of oxygen use, the results had not yet been confirmed.

It turned out that all the energy devoted to heating in *P. selloum* was present in the florets from the beginning. (This property may not reflect that of other thermoregulating plants, however. The skunk cabbage has to import fuel from the root.) And we were surprised to find that the flowers were "burning" fat, rather than carbohydrate, as had been shown in other aroids. In fact, electron microscopy of the sterile male florets revealed that their tissue contained fat droplets and many mitochon-

ROGER S. SEYMOUR

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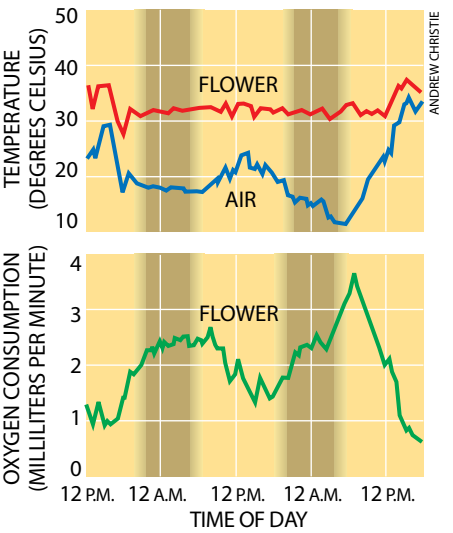


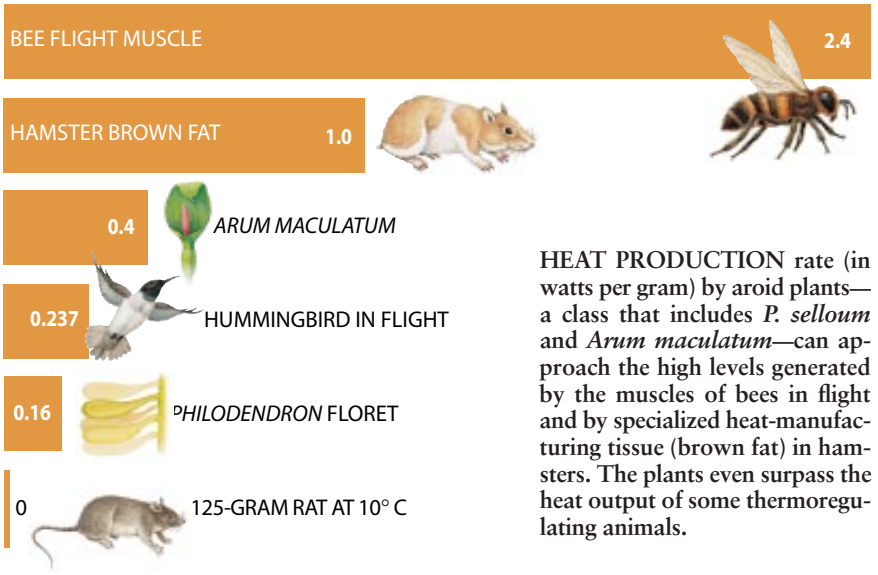
ANDREW CHRISTIE

ALL STAGES OF FLOWERING in the sacred lotus are visible in photograph at the right. Temperature regulation begins sometime between the formation of the unopened bud (*right of center*) and the loosening of the petals (*left*), when insects enter the flower. It ends when the petals open fully (*top*). After pollination, the petals fall off (*far right*), and the receptacle, containing the seeds, begins to grow (*green structure near bottom*). The receptacle, visible as the spongy yellow structure in the cross section (*photograph at left*), is also the source of most of the heat. The graph, plotting measurements on one flower, is typical of the data demonstrating that the sacred lotus can actively control its own temperature. The flower maintained a nearly constant temperature (*top*) even though the air temperature fluctuated. Also, the flower achieved this stability by stepping up oxygen consumption (and thus heat production) when the air was cold and stepping it down when the air was warm (*bottom*).

dria—in other words, the tissue was remarkably similar to brown fat, a specialized heat-producing tissue found in mammals. Plant and animal cells typically use mitochondria to incorporate into ATP most of the energy derived from nutrients. But in brown fat and apparently in *P. selloum*'s unusual tissue, nutrients and oxygen are used to make heat directly.

P. selloum's impressive ability to produce heat is perhaps best appreciated by comparing the plant's output with that of other plants and animals. A 125-gram spadix produces about nine watts of heat to maintain a temperature of 40 degrees C in a 10 degree C environment—about the same wattage produced by a three-kilogram cat in the same environment. (Because of this correspondence, I often envision *P. selloum* inflorescences as cats growing on stalks.) A rat weighing 125 grams would produce only two watts, but not for lack of ability; being well insulated by its fur, it would lose less heat to the air and so could conserve its energy for other functions.

On a weight-specific basis, the rate of heat production in *P. selloum* florets approaches the highest rates in flying birds and insects. The florets, which each weigh about eight milligrams, put out 0.16 watt per gram of tissue; the birds and insects emit 0.2 to 0.7 watt per gram. Indeed, when evaluated in this way, aroids in general turn out to be among the greatest heat producers, even if they are compared with animals. The peak performer of the aroids, *A. maculatum,* generates 0.4 watt per gram in its florets, not even an order of magnitude lower than the one watt per gram output of brown fat in Siberian hamsters and the approximately 2.4 watts per gram output of active flight muscles in bees. This bee muscle rate is the maximum I know for animal tissue.



TOMO NARASHIMA (*drawings*); ANDREW CHRISTIE

HEAT PRODUCTION rate (in watts per gram) by aroid plants—a class that includes *P. selloum* and *Arum maculatum*—can approach the high levels generated by the muscles of bees in flight and by specialized heat-manufacturing tissue (brown fat) in hamsters. The plants even surpass the heat output of some thermoregulating animals.

The high wattage of *P. selloum* raised the question of how it obtains the requisite oxygen, given that it lacks lungs, a circulatory system and the hormones that step up respiration and circulation in animals. We found that the florets gain the oxygen by simple diffusion from the air, which is normally about 21 percent oxygen. Because oxygen levels inside the florets are below the levels in the air, the oxygen moves down the gradient into the plants. Our experiments show that the diffusion of oxygen begins to decrease only after the oxygen concentration around the florets drops below about 17 percent. This level is almost never reached, however, even when the florets are producing heat at their maximum rate.

My recent anatomical studies have defined the pathway through which oxygen penetrates the florets. A floret is about seven millimeters long and 1.2 millimeters thick (roughly the size of an uncooked rice grain). Incredibly, oxygen enters through only about 170 pores, or stomates, and is distributed through a network of spaces that occupies less than 1 percent of the floret's volume. The diffusion path from the floret surface to each cell is somewhat less than 0.75 millimeter, a distance remarkably similar to the length of the air-filled tubes that supply oxygen to insect flight muscles.

Our work with hot plants demonstrates the power of applying ideas and methods developed in one field of science to another field. Driven by curiosity and logic, my co-workers and I were able to view unusual phenomena without the preconceptions that seem to channel research in well-traveled directions. As a result, we found striking similarities between animals and plants, two groups of organisms usually considered to have little in common. SA

The Author

ROGER S. SEYMOUR, who received his Ph.D. in zoology from the University of California, Los Angeles, is associate professor of zoology at the University of Adelaide in South Australia. In addition to studying heat-producing flowers, Seymour (here shown with *Philodendron selloum*) has recently been concentrating on the physiology of eggs. This is his third contribution to *Scientific American*.

KATHRYN J. SEYMOUR

Further Reading

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The Rising Seas

by David Schneider, *staff writer*

Many people were awakened by the air-raid sirens. Others heard church bells sounding. Some probably sensed only a distant, predawn ringing and returned to sleep. But before the end of that day—February 1, 1953—more than a million Dutch citizens would learn for whom these bells tolled and why. In the middle of the night, a deadly combination of winds and tides had raised the level of the North Sea to the brim of the Netherlands' protective dikes, and the ocean was beginning to pour in.

As nearby Dutch villagers slept, water rushing over the dikes began to eat away at these earthen bulwarks from the back side. Soon the sea had breached the perimeter, and water freely flooded the land, eventually extending the sea inward as far as 64 kilometers from the former coast. In all, more than 200,000 hectares of farmland were inundated, some 2,000 people died, and roughly 100,000 were left homeless. One sixth of the Netherlands was covered in seawater.

With memories of that catastrophe still etched in people's minds, it is no wonder that Dutch planners took a keen interest when, a quarter century later, scientists began suggesting that global warming could cause the world's oceans to rise by several meters. Increases in sea level could be expected to come about for various reasons, all tied to the heating of the earth's surface, which most experts deem an inevitable consequence of the mounting abundance of carbon dioxide and other heat-trapping "greenhouse gases" in the air.

First off, greenhouse warming of the earth's atmosphere would eventually increase the temperature of the ocean, and seawater, like most other substances, expands when heated. That thermal expansion of the ocean might be sufficient to raise sea level by about 30 centimeters or more in the next 100 years.

A second cause for concern has already shown itself plainly in many of Europe's Alpine valleys. For the past century or two, mountain glaciers there have been shrinking, and the water released into streams and rivers has been adding to the sea. Such meltwaters from mountain glaciers may have boosted the ocean by as much as five centimeters in the past 100 years, and this continuing influx will most likely elevate sea level even more quickly in the future.

But it is a third threat that was the real worry to the Dutch and to the people of other low-lying countries. Some scientists began warning more than 20 years ago that global warming might cause a precariously placed store of frozen water in Antarctica to melt, leading to a calamitous rise in sea level—perhaps five or six meters' worth.

Yet predicting exactly how—or whether—sea level will shift in response to global warming remains a significant challenge. Scientists trained in many separate disciplines are attempting to glean answers using a variety of experimental approaches, ranging from drilling into the Antarctic ice cap to bouncing radar off the ocean from space. With such efforts, investigators have learned a great deal about how sea level has varied in the past and how it is currently changing. For example, most of these scientists agree that the ocean has been creeping upward by two millimeters a year for at least the past several decades. But determining whether a warmer climate will lead to a sudden acceleration in the rate of sea level rise remains an outstanding question.

Antarctic Uncertainties

One of the first prominent geologists to raise concern that global warming might trigger a catastrophic collapse of the Antarctic ice cap was J. H. Mercer of Ohio State University. Because the thick slab of ice covering much of West Antarctica rests on bedrock well below sea level, Mercer explained in his 1978 article "West Antarctic Ice Sheet and CO_2 Greenhouse Effect: A Threat of Disaster," this "marine ice sheet" is inherently unstable. If the greenhouse effect were to warm the south polar region by just five degrees Celsius, the floating ice shelves surrounding the West Antarctic ice sheet would begin to disappear. Robbed of these buttresses, this grounded ice sheet—a vestige of the last ice age—would quickly disintegrate, flooding coastlines around the world in the process.

Mercer's disaster scenario was largely theoretical, but he pointed to some evidence that the West Antarctic ice sheet may, in fact, have melted at least once before. Between about 110,000 and 130,000 years ago, when the last shared ancestors of all humans probably fanned out of Africa into Asia and Europe, the earth experienced a climatic history strikingly similar to what has transpired in the past 20,000 years, warming abruptly from the chill of a great ice age.

That ancient warming may have achieved conditions that were a bit more balmy than at present. The geologic record of that time (known to the cognoscenti as interglacial stage 5e) remains somewhat murky, yet many geologists believe sea level stood about five meters higher than it does now—just the additional dollop that would be provided by the melting of the West Antarctic ice sheet. If such a collapse had occurred in Antarctica during a slightly hotter phase in the past, some reasoned, the current warming trend might portend a repeat performance.

That possibility spurred a group of American investigators to organize a coordinated research program in 1990, to which they attached the title "SeaRISE"

NETHERLANDS MINISTRY OF TRANSPORT AND PUBLIC WORKS

SEA DIKES protect low-lying areas of the Netherlands from the ocean, which rises well above the land in many places. The Dutch government must maintain hundreds of kilometers of dikes and other flood-control structures on the coast and along riverbanks.

Although some voice concern that global warming will lead to a meltdown of polar ice, flooding coastlines everywhere, the true threat remains difficult to gauge

(for Sea-level Response to Ice Sheet Evolution). The report of their first workshop noted some ominous signs on the southernmost continent, including the presence of five active "ice streams" drawing ice from the interior of West Antarctica into the nearby Ross Sea. They stated that these channels in the West Antarctic ice sheet, where glacial ice flows rapidly toward the ocean, "may be manifestations of collapse already under way."

But more recent research suggests that the dire warnings expressed up to that time may have been exaggerated. In the early 1990s, researchers using so-called global circulation models, complex computer programs with which scientists attempt to predict future climate by calculating the behavior of the atmosphere and ocean, began investigating how a warmed climate would affect the Antarctic ice cap. These researchers found that greenhouse heating would cause warmer, wetter air to reach Antarctica, where it would deposit its moisture as snow. Even the sea ice surrounding the continent might expand.

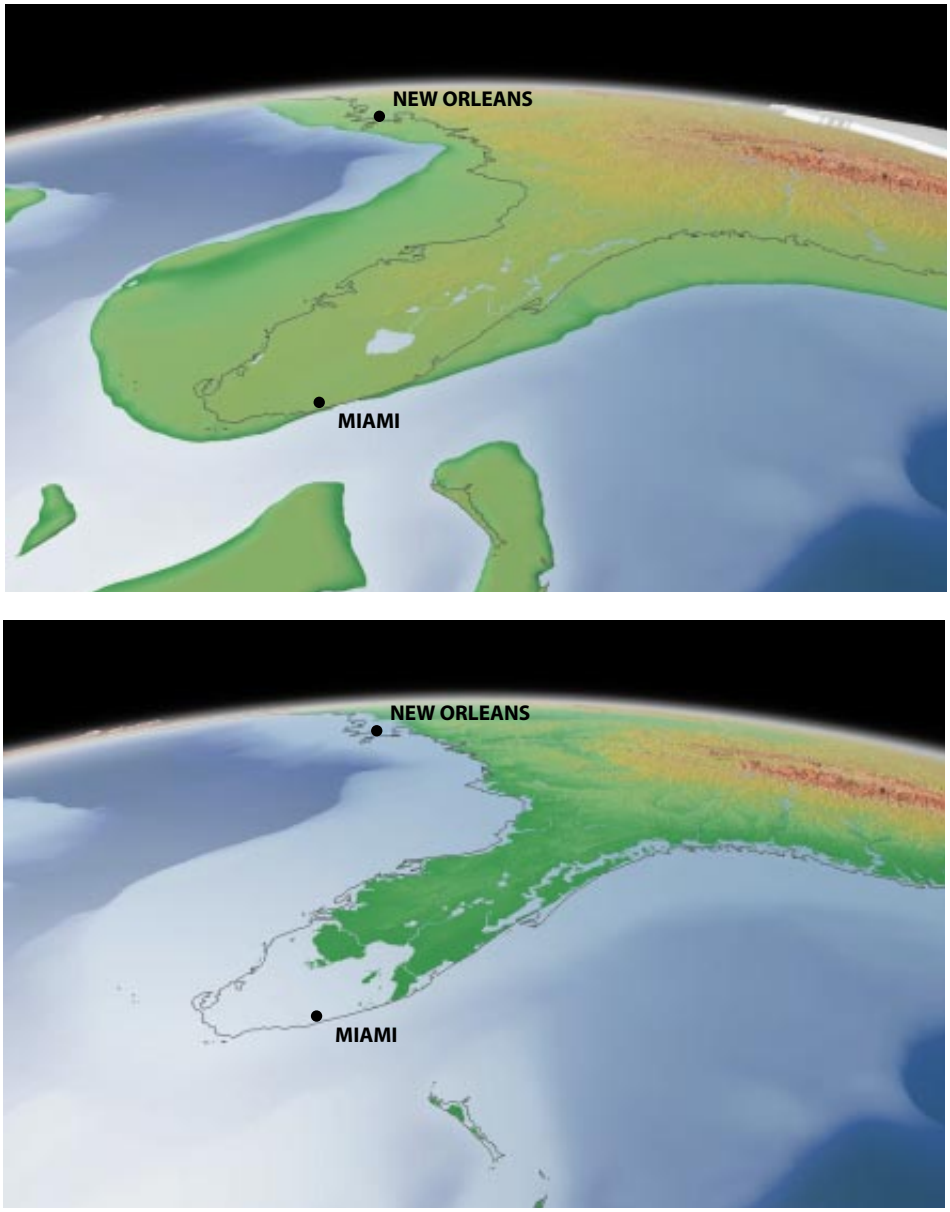
In other words, just as SeaRISE scientists were beginning to mount their campaign to follow the presumed collapse of the West Antarctic ice sheet, computer models were showing that the great mass of ice in the Antarctic could grow, causing sea level to drop as water removed from the sea became locked up in continental ice. "That really knocked the wind out of their sails," quips Richard G. Fairbanks, a geologist at the Columbia University Lamont-Doherty Earth Observatory.

Other observations have also steered the opinion of many scientists working in Antarctica away from the notion that sudden melting there might push sea level upward several meters sometime in the foreseeable future. For example, glaciologists now realize that the five major ice streams feeding the Ross Sea (named, rather uninventively, ice streams A, B, C, D and E) are not all relentlessly disgorging their contents into the ocean. One of the largest, ice stream C, evidently stopped moving about 130 years ago, perhaps because it lost lubrication at its base.

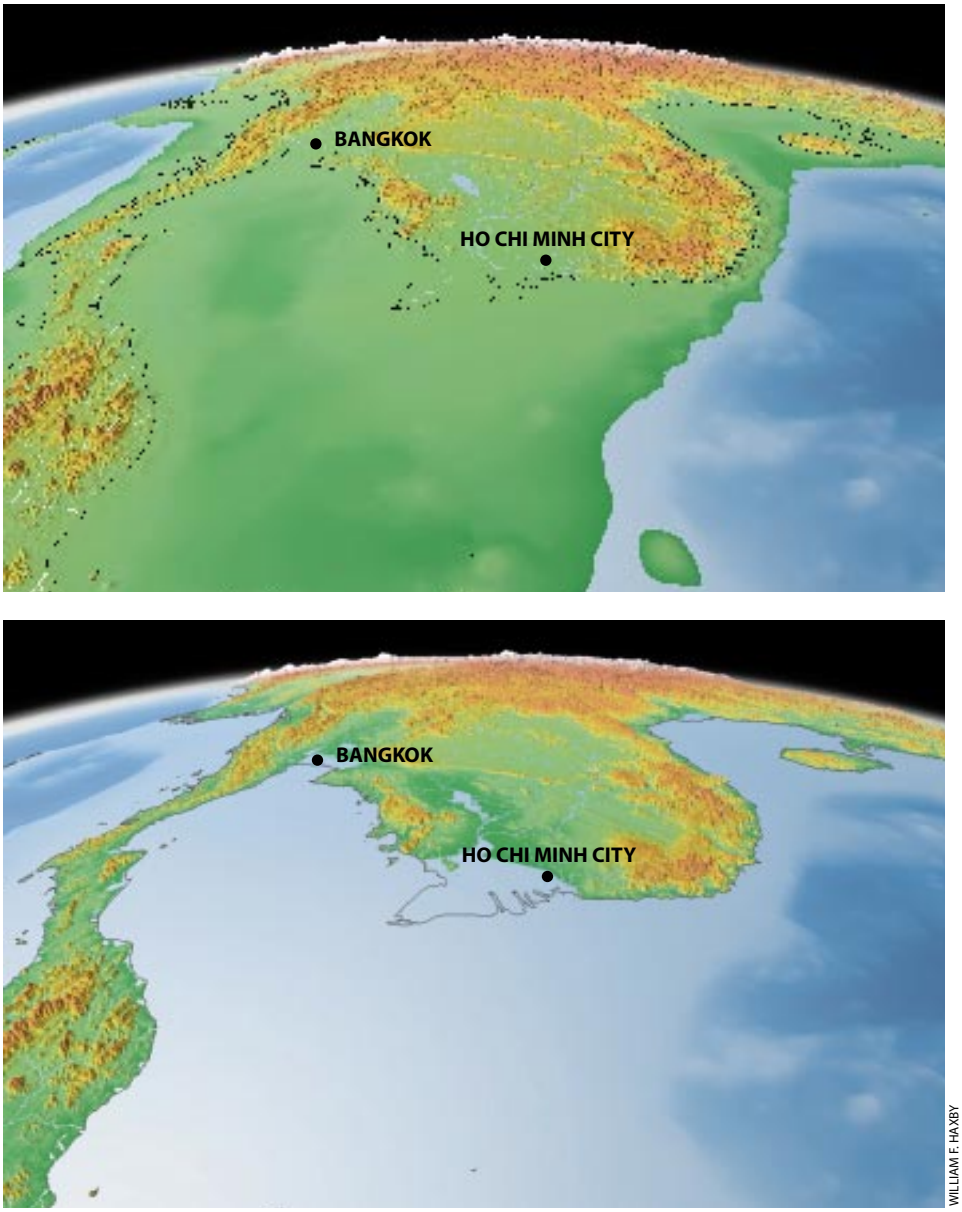
In fact, the connection between climatic warming and the movement of West Antarctic ice streams has become increasingly tenuous. Ellen Mosley-Thompson of the Ohio State University Byrd Polar Research Center notes that ice streams "seem to start and stop, and nobody really knows why." And her own measurements of the rate of snow accumulation near the South Pole show that snowfalls have mounted substantially in recent decades, a period in which global temperature has inched up; observations at other sites in Antarctica have yielded similar results.

But the places in Antarctica being monitored in this way are few and far between, Mosley-Thompson emphasizes. Although many scientists are now willing to accept that human activities have contributed to global warming, no one can say with any assurance whether the Antarctic ice cap is growing or shrinking in response. "Anybody who tells you that they know is being dishonest," she warns.

That uncertainty could disappear in just a few years if the National Aeronautics and Space Administration is successful in its plans to launch a satellite designed to map changes in the elevation of the polar ice caps with extraordinary accuracy—perhaps to within a centimeter a year. A laser range finder on this forthcoming satellite, which is scheduled to be placed in a polar orbit in 2002, should be capable of detecting subtle



FLORIDA looked quite different 20,000 years ago, during the last ice age. At that time, vast amounts of water remained locked within continental ice sheets to the north, and sea level was nearly 120 meters lower than today (*top*). As the ice melted, the coastlines retreated inland to their present positions (*black line*). Future melting of ice in West Antarctica may yet raise sea level an additional five meters, inundating large areas (*bottom*).



WILLIAM F. HAXBY

SOUTHEAST ASIA during the last ice age included a huge tract of land along what is now the Sunda Shelf. That terrain connected the mainland of Asia with the islands of Indonesia, forming one great continental mass (*top*). Should the West Antarctic ice sheet melt, the resulting five-meter rise in sea level would flood river deltas, including the environs of Ho Chi Minh City and Bangkok (*bottom*), substantially altering the present coast (*black line*).

changes in the overall volume of snow and ice stored at the poles. (Curiously, a similar laser instrument is now on its way to Mars and will be charting changes in the frozen polar ice caps on that planet well before scientists are able to perform the same feat for the earth.) During the first decade of the 21st century, then, scientists should finally learn whether the Antarctic ice cap as a whole is releasing water to the sea or storing water away in deep freeze.

Further insight into the stability of West Antarctica's vast marine ice sheet may come sooner, after scientists drill deeply into the ice perched between two of the ice streams. The researchers planning that project (who have replaced their former moniker SeaRISE with the less alarmist acronym WAIS—for West Antarctic ice sheet) hope to recover ice, if it indeed existed, dating from the exceptionally warm 5e interval of 120,000 years ago. Finding such a sample of long-frozen West Antarctic ice would, in Mosley-Thompson's words, "give you some confidence in its stability."

Until those projects are completed, however, scientists trying to understand sea level and predict changes for the next century can make only educated guesses about whether the polar ice caps are growing or shrinking. The experts of the Intergovernmental Panel on Climate Change, a body established in 1988 by the World Meteorological Organization and the United Nations Development Program, have adopted the position that both the Antarctic and the smaller Greenland ice caps are most likely to remain constant in size (although they admit the possibility of substantial errors in their estimate, acknowledging that they really do not know whether to expect growth or decay).

Up or Down?

Whatever the fate of the polar ice caps may be, most researchers agree that sea level is currently rising. But establishing that fact has been anything but easy. Although tide gauges in ports around the world have been measuring sea level for many decades, calculating the change in the overall height of the ocean is a surprisingly complicated affair. The essential difficulty is that land to which these gauges are attached can itself be moving up or down. Some regions, such as Scandinavia, are still springing back after being crushed by massive glaciers during the last ice age. Such postglacial rebound explains why sea level measured in Stockholm appears to be falling at about four millimeters a year, whereas it is rising by one and a half millimeters a year at Honolulu, a more stable spot.

In principle, one could determine the true rise in sea level by throwing out the results from tide gauges located where landmasses are shifting. But that strategy rapidly eliminates most of the available data. Nearly all the eastern seaboard of North America, for instance, is still settling from its formerly elevated position on a "peripheral bulge," a raised lip that surrounded the depression created by the great ice sheet that covered eastern Canada 20,000 years ago. What is more, local effects—such as the buckling that occurs at the edges of tectonic plates or the subsidence that ensues when water or oil is pumped from the ground—dominate in many tide gauge records, even in the tropics. In Bangkok, for instance, where residents have been tapping groundwater at a growing rate, subsidence makes it appear as if the sea has risen by almost a full meter in the past 30 years.

Fortunately, geophysicists have de-

ROBIN LIGHTY

NEAR-SURFACE DWELLING CORALS of the species *Acropora palmata* help to determine past changes in sea level. By drilling into coral reefs and recovering ancient samples of this species from deep under the seabed, scientists have been able to reconstruct how sea levels rose as the last ice age ended.

vised clever ways to overcome some of these problems. One method is to compute the motions expected from postglacial rebound and subtract them from the tide gauge measurements. Using this approach, William R. Peltier and A. M. Tushingham, then both at the University of Toronto, found that global sea level has been rising at a rate of about two millimeters a year over the past few decades. Many other investigators, using different sets of records from tide gauges, have reached similar conclusions.

Further confirmation of this ongoing elevation of the ocean's surface comes from four years of measurements performed by the TOPEX/Poseidon satellite, which carries two radar altimeters aimed downward at the ocean. Because the position of the satellite in space is precisely known, the radar measurements of distance to the sea below can serve as a spaceborne tide gauge. The primary purpose of the TOPEX/Poseidon mission is to measure water circulation in the ocean by tracking surface undulations caused by currents. But the satellite has also been successful in discerning overall changes in the level of the ocean.

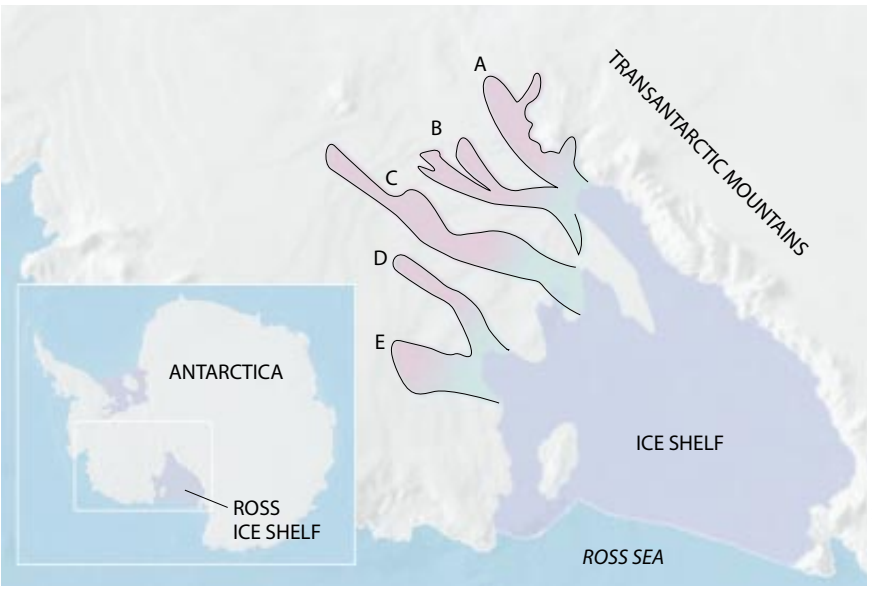
"When you average over the globe, you get much less variability than at an individual tide gauge," explains R. Steven Nerem of the Center for Space Research at the University of Texas at Austin. His published results from the TOPEX altimeter, which indicated that global sea level was rising at almost four millimeters a year—twice the rate previously determined—were, as it turns out, affected by a bug in the software used to process the satellite data. A subsequent analysis appears to confirm the land-based assessment of two millimeters a year in sea-level rise. "Of course, this estimate changes every time I put in some more data," Nerem admits, "but the current number is completely compatible with the estimates that have come from 50 years of tide gauge records."

Looking Backward

With few exceptions, scientists believe they have established a reliable value for the rate of recent rise in sea level: two millimeters a year. But the key question still facing these researchers—and civil planners—is whether this trend will hold steady or begin to accelerate in response to warming climate. Geologists have helped address this problem by tracing how sea level has fluctuated in the past, in response to prehistoric climate changes.

Columbia's Fairbanks, for example, has studied one species of coral that grows near the surface of the sea, particularly in and around the Caribbean. By drilling deeply into coral reefs in Barbados and locating ancient samples of this surface-dwelling species, he and his colleagues were able to follow the ascent of sea level since the end of the last ice age, when tremendous quantities of water were still trapped in polar ice caps and the oceans were about 120 meters lower than they are today.

Although his coral record shows episodes when the sea mounted by as much as two or three centimeters a year, Fairbanks notes that "these rates are for a very different world." At those times, 10,000 to 20,000 years ago, the great ice sheets that had blanketed much of North America and Europe were in the



MICHAEL GOODMAN

ICE STREAMS, channels where glacial ice moves rapidly toward the sea, had been seen as signaling the collapse of the West Antarctic ice sheet. But recent investigations have revealed that one major ice stream leading into the Ross Sea (ice stream C) stopped moving more than a century ago, perhaps because it lost lubrication near its base.

midst of melting, and the ocean was receiving huge influxes of water. The more recent part of the sea-level record indicates a progressive decline in the rate of ascent, with the height of the ocean seemingly stagnating in the past few millennia. Thus, the current climatological regime appears inclined toward relatively stable sea level.

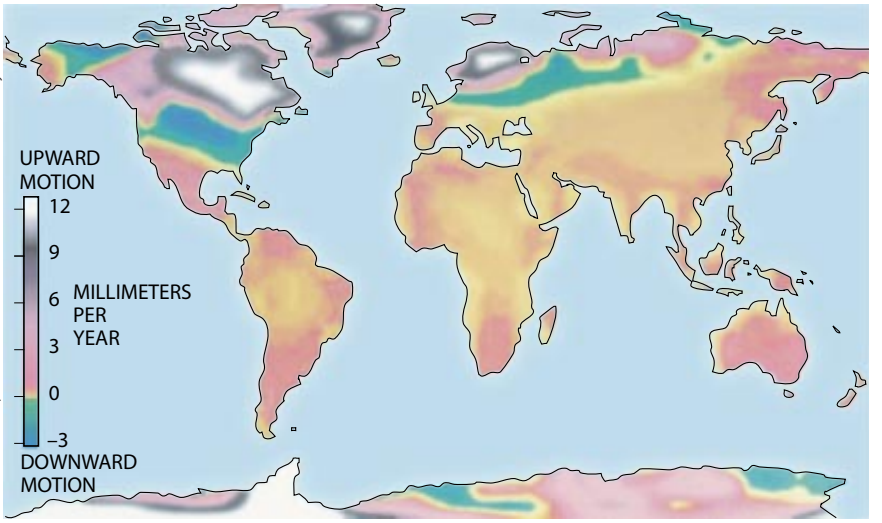
But this reassuring picture is called into question by John B. Anderson, a marine geologist at Rice University. The data collected by Fairbanks and his colleagues are "not accurate enough to see the kinds of events predicted by the glaciological models," Anderson contends. There were at least three episodes of sudden sea-level rise in the past 10,000 years, he elaborates, but these are invisible in the coral record simply because "there's a five-meter error bar associated with that method."

Anderson and his co-workers have garnered evidence from such places as Galveston Bay in the Gulf of Mexico, where sediment cores and seismic soundings reveal how that estuary responded to rising sea level since the last ice age. A steady increase in sea level would have caused the underwater environments that characterize different parts of the estuary to move gradually landward. But the geologic record from Galveston Bay, Anderson says, shows "very dramatic" features that indicate sudden flooding of the ancient strand.

The most recent episode of sudden sea-level rise that Anderson discerns occurred about 2000 B.C., when global climate was presumably similar to present conditions. His work indicates that sea level may have jumped considerably in just a few centuries. But so far Anderson has been unable to establish just how large a rise occurred.

Archaeologists should be able to help track ancient changes in sea level with further examination of coastal sites submerged by rising seas. Numerous analyses done so far in the Mediterranean, which span only the past 2,000 years, indicate that sea level has risen an average of only two tenths of a millimeter a year. Unfortunately, those studies give little insight into whether the ocean may have suddenly mounted 4,000 years ago. Nor is the archaeological work yet adequate to discern exactly when sea level began to quicken in its rise, ultimately reaching the modern rate of two millimeters a year.

Despite many such troubling gaps in the scientific understanding of how sea level has varied in the past and how it could change in the future, the experts of the Intergovernmental Panel on Climate Change have provided some broad guidelines for what the world might expect by the end of the next century. The panel's forecasts for sea-level rise range from 20 centimeters to almost one meter. The low end of these estimates corresponds, in essence, to the rate of sea-level rise that has probably been occurring for the past century or two—since before humanity began releasing carbon dioxide and other greenhouse gases into the atmosphere with abandon. That is to say, the next century might see only a continuation of the natural rise in sea level that has long been tolerated. The high-end estimate of the panel represents a substantial acceleration that could plausibly happen but so far has not been evidenced.



POSTGLACIAL REBOUND, the slow recovery from the deformation caused by weighty ice sheets, accounts for the vertical movement of the land in many parts of the world. These shifts, which have been continuing since the last ice age ended, affect relative sea level at the coastline in a manner that varies from place to place. Such movements can confound tide-gauge records obtained from coastal sites and thus complicate efforts to track the overall change in global sea level.

Weathering the Future

Of course, responsible international authorities must take the full range of possibilities into account in planning for the future. Although the fivefold uncertainty in the amount of sea-level rise might trouble some, John G. de Ronde, the head of hydraulic modeling at the Ministry of Transport and Public Works in the Netherlands, seems unruffled by it. Whatever the eventual trend in global sea level, he is confident that his country can cope: "Sea-level rise—you can measure that, you can see it and do something about it."

Although the necessary expenditures might seem enormous, de Ronde reports that the cost of improving Dutch dikes and other waterworks to accommodate 60 centimeters of sea-level rise over the next century amounts to no more than what people there now pay to maintain their bicycle paths. He shows greater concern for poor, land-scarce coastal nations and for an aspect of future climate that is much more difficult to forecast than sea level: changes in the frequency and intensity of violent storms. "You would need 20 years to see a change in statistics," de Ronde notes, "then a bad storm could happen the next day."

So as long as the West Antarctic ice sheet remains reasonably behaved, the real question facing residents of coastal regions may be how greenhouse warming affects local weather extremes and the size of damaging storm surges. Yet for those kinds of changes, scientists are especially hard put to offer predictions. Perhaps with further research and more refined computer models, climatologists will eventually be able to pinpoint where conditions will deteriorate and where they will improve. But such precise forecasts may, in the final reckoning, prove to be unreliable. It may just be as de Ronde says, imparting a lesson that nature keeps forcing on him and his colleagues: "We have to live with things we don't know exactly." SA

by Ian Stewart

Juniper Green

About a year ago Ian Porteous, a mathematician at the University of Liverpool, told me about an elegant game. His son, Richard Porteous, invented it to teach children about multiplication and division. The game is called Juniper Green, after the school at which Richard taught. It is fun to play, and the search for a winning strategy is quite challenging.

To play Juniper Green, you should make 100 cards, numbered 1 through 100. Lay them face up on the table in numerical order, say, 10 rows of 10 cards each, so that it will be easy for players to locate the desired card. Here are the rules:

1. Two players take turns removing one card from the table. Cards removed are not replaced and cannot be used again.

2. Apart from the opening move, each number chosen must either be an exact divisor of the previous player's choice or an exact multiple.

3. The first player who is unable to choose a card loses.

There is one final rule to make the game worth playing. Recall that a prime number has no divisors other than itself and 1. It so happens that if a player picks a prime larger than 50, then the next player loses. Suppose Alice plays against Bob, with Alice going first. She plays 97; Bob must play 1. Now Alice plays another big prime—say, 89. At this point Bob has used up card 1 and is stuck. To prevent this spoiling strategy, we have:

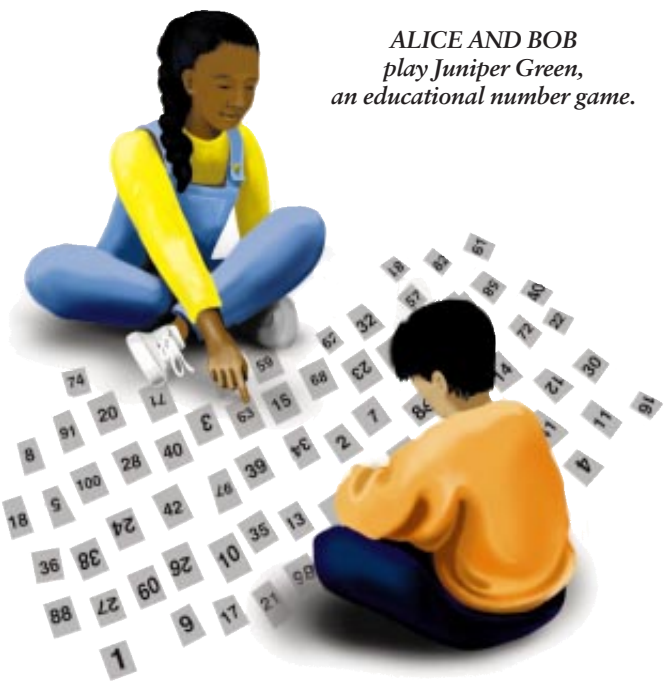
4. The opening move in the game must be an even number.

Even though the game starts with an even number, big primes still influence play. In particular, if any player picks card 1, then he or she loses, assuming the opponent is awake. Say Bob chooses 1, and Alice responds with a big prime—97. (Note that 97 must be available, because it can be chosen only if the previous player chooses 1.) Then Bob has nowhere to go. So the game effectively ends when a player is forced to choose card 1.

The chart below shows a sample game, played without much regard for good tactics. I would suggest that at this point you stop reading, make a set of cards and play the game for a while. Although I'm not going to give away the winning strategy—I'll put it in a subsequent Feedback section so as not to spoil your fun—I will analyze the same game when there are only 40 cards, numbered 1 to 40. The analysis will give you some broad hints on the 100-card game as well. Very young children might use a pack numbered 1 to 20. For brevity, I will call the Juniper Green *n*-card "JG-*n*" and find a winning strategy for JG-40.

Some opening moves, of course, lose rapidly. For example:

MOVE	ALICE	BOB
1	38	
2		19
3	1	
4		37
5	LOSES	



ALICE AND BOB play Juniper Green, an educational number game.

JENNIFER C. CHRISTIANSEN

MOVE	ALICE	BOB	COMMENTS
1	48		Even number, as required by rule 4
2		96	Doubles Alice's choice
3	32		One third of Bob's choice
4		64	Bob is forced to choose a power of 2
5	16		So is Alice
6		80	
7	10		
8		70	
9	35		Halve
10		5	Only choices are 7, 5 (or 1 and lose)
11	25		
12		75	Only 50 and 75 available
13	3		
14		81	
15	9		Only 27 and 9 available
16		27	Bad move!
17	54		Forced because 1 loses
18		2	Forced
19	62		Inspired variant on big prime tactic
20		31	Forced
21	93		Only choice but a good one
22		1	Forced, and loses, because …
23	97		Big prime tactic

The same goes for an opening move of 34. Some other numbers are also best avoided. For instance, suppose that Alice is unwise enough to play 5. Then Bob strikes back with a vengeance by picking 25. Alice has no choice but to play 1; however, this move is bound to lose. (Note that 25 must still be available, because it can be chosen only if the previous player plays 1 or 5.)

Alice's obvious tactic is to force Bob to play 5 instead. Can she do this? Well, if Bob plays 7, then she can play 35, and Bob has to play 1 or 5, both of which lose. Good, but can she force Bob to play 7? Yes: if Bob has chosen 3, then Alice can play 21, and that forces a reply of 7. Fine, but how does she make Bob play 3? Well, if he plays 13, then Alice plays 39. Alice can go on in this manner, building hypothetical sequences that force Bob's reply at every stage and lead to his inevitable defeat.

But can she maneuver Bob into such a sequence to begin with? Early in the game the moves have to involve even numbers, so the card numbered 2 is likely to play a pivotal role. Indeed, if Bob plays 2, then Alice can play 26, forcing Bob into the trap of playing 13. So now we come to the crunch. How can Alice force Bob to play 2?

If Alice opens with 22, then Bob either plays 2 and gets trapped in the long sequence of forced moves outlined above, or he plays 11. Now Alice has the choice of playing 1 and losing or going to 33. When she picks 33, 11 has already been used up, so Bob is forced to 3, and so Alice can win. The moves below summarize Alice's strategy: the two sets of columns deal with the two alternatives Bob can pick. (Assume throughout that all players avoid 1.)

MOVE	ALICE	BOB	ALICE	BOB
1	22			
2		11		2
3	33		26	
4		3		13
5	21		39	
6		7		3
7	35		21	
8		5		7
9	25		35	
10		LOSES		5
11			25	
12				LOSES

There is at least one other possible opening move for Alice that forces a win: 26. The same kind of game devel-

ops but with a few moves interchanged as in the list below.

MOVE	ALICE	BOB	ALICE	BOB
1	26			
2		13		2
3	39		22	
4		3		11
5	21		33	
6		7		3
7	35		21	
8		5		7
9	25		35	
10		LOSES		5
11			25	
12				LOSES

The crucial features here are the primes 11 and 13. If the opening move is twice such a prime (22 or 26), Bob has to reply either with 2—at which point Alice is off to a win—or with the prime. But then Alice replies with thrice the prime, forcing Bob to go to 3—and she's away again. So Alice wins because apart from two times the prime, there is exactly one other multiple that is under 40, namely, 33 or 39. These "medium primes," which amount to between one third and one quarter of the number of cards, allow Alice to win.

Does any opening choice other than 22 or 26 also lead to a win? That's for you to find out. Moreover, you are now in a good position to analyze JG-100—or even the ambitious JG-1,000. Is there a first-player strategy to force a win?

Finally, the time has come to open up the problem in its full generality. Consider JG-n for any whole number n. Because no draws are allowed, game theory implies that either Alice—who goes first—can have a winning strategy or Bob can, but not both. Suppose n is "primary" if Alice has a winning strategy for JG-n and "secondary" if Bob does. Can you characterize which n are primary and which are secondary?

For very small n, a few quick calculations indicate that 1, 3, 8 and 9 are primary, whereas 2, 4, 5, 6 and 7 are secondary. What about $n = 100$? Completely general n? Can anyone find any patterns? Or solve the whole thing? SA

FEEDBACK

Much of the mail I got on the interrogator's fallacy [September 1996] demonstrated how easy it is to get confused about conditional probabilities. So I'll try to clarify the points that caused the most difficulty. Most readers had trouble with the preparatory example. We were told that the Smith family has two children and that one of them is a girl. What is the probability that both are girls? (Assume boys and girls are equally likely, which may not be the case in reality. Also, when I say "one is a girl," I do not mean that only one is: I mean that at least one is.)

The big bone of contention was my ordering the children by birth. There are four types of two-child family: BB, BG, GB, GG. Each, I said, is equally likely. If one child is a girl, we are left with BG, GB and GG. Of these, only one gives two girls. So the conditional probability that if one is a girl, so is the other, is $1/3$. On the other hand, if we are told "the eldest child is a girl," then the conditional probability that they are both girls is now $1/2$.

Some of you said that I shouldn't distinguish BG and GB. Why don't we just toss two coins to check? The coins represent the sexes, with the right probabilities ($1/2$ each). If you're lazy, like me, you can simulate the tosses on a computer with a random-number generator. For one million simulated throws, here's what I got:

Two heads	250,025
Two tails	250,719
One of each	499,256

Try it for yourself. If BG and GB are the same, you should get 333,333 in the last category.

The other main argument was that whether or not we know that one child is G, the other is equally likely to be B or G. It is instructive to see why this reasoning is wrong. When both children are girls, there is no unique notion of "the other"—unless I specify which girl I am thinking about (for example, the elder). The specification destroys the assumed symmetry between Bs and Gs and changes the conditional probabilities. In fact, the statement "the eldest child is a girl" conveys more information than "at least one child is a girl." (The first implies the second, but the second need not imply the first.) So it ought not to be a surprise that the associated conditional probabilities are different. —*I.S.*

by Shawn Carlson

Algorithm of the Gods

I used to spend my days (and I do mean my days) hunting for supernovae. The astrophysics group I worked for dusted off an old 30-inch telescope, then used only for teaching, and converted it into a fully automated research instrument. When night arrived, this computer-controlled marvel woke up, checked its systems and set about the business of discovery. On clear nights it scanned hundreds of galaxies, searching for objects that appeared as bright stars not detected in earlier images. Sometimes it found them.

It was wonderful! And I didn't feel too guilty about not freezing all night in a remote observatory. I had toiled in cyberhell for months teaching the telescope's computer how to decide which galaxies to image and in what order it should observe them. Because large excursions from horizon to horizon sent the telescope's 40-year-old drive system into shock, it was vital that the feeble old veteran be moved as little as possible. That meant ordering the galaxies into a sequence that, totaled over the whole night, required the telescope to move through the smallest possible angle. Computer aficionados will recognize my galaxy conundrum as a variant of the classic traveling salesman problem, in which a huckster seeks an itinerary that will let him travel the smallest possible distance through a list of cities.

The problem of minimizing the telescope's motion appeared intractable. There are nearly 10^{375} different ways to sort 200 galaxies—a fairly typical evening's caseload for our telescope. (For you math types, 10^{375} is 200 factorial.) To find the one way of ordering the galaxies for a search that put the absolute least strain on the telescope, we would have had to check every possible ordering. Unfortunately, this job could not be accomplished even by all the world's supercomputers working day and night for *sextillions* of years.

For most real-world problems, a solution that comes within a few percent of the ideal one is quite acceptable. Fortunately, computer scientists have devised an algorithm that can find such solutions to many seemingly impossible problems. This amazing algorithm enables ordinary laptop computers to come up with these solutions in just a few minutes, making it a powerful addition to any amateur scientist's tool kit.

Called simulated annealing, this algorithm is a remarkable melding of human cleverness and natural efficiency. A mathematical physicist named Nicholas Metropolis and his co-workers developed the procedure back in 1953, but it has only recently come into wide use. Metropolis's procedure was later used to find useful solutions to traveling-salesman-type problems by mimicking on a computer the natural process by which the crystal lattices of glass or metal relax when heated. This process is called annealing.

Although the procedure is modeled on annealing, the relevant fundamentals are the same, and perhaps a bit more easily explained, for crystal growth. The molecules in a solution of hot sugar water wander about randomly. If the temperature drops quickly, the sugar molecules solidify into a complicated jumble. But if the temperature drops slowly, they form a highly ordered crystal that can be billions of times larger than the individual molecules.

With each molecule not only immobile but also at its lowest possible energy level in the crystal's lattice, this crystal is in its minimum energy state. (It corresponds, in my problem, to the galaxy ordering that demands the least movement from the telescope.) The system naturally progresses toward this minimum in a rather unexpected and remarkable way. The molecules are naturally distributed over a range of kinetic energies. As the temperature cools, the average kinetic energy drops. But some individual molecules remain in high-energy states, even when most are moving slow enough to bind to the crystal. When the lower-energy molecules get "hung up," they often bind in states with excess energy rather than in the lowest-energy states where they belong.

The higher-energy molecules, howev-

SLIM FILMS

GALAXY SEARCH was made possible by a heavenly algorithm.

Algorithm of the Gods Revealed

Here is a procedure for implementing simulated annealing.

PSEUDOCODE	NOTES
Basic Program Algorithm	
{	
Setup()	Create initial list and set needed variables
for (i = 1; i <= 100; i = i + 1)	Try up to 100 different temperatures
{ numSuc = Anneal ()	Anneal list at this temperature; return the number of successful alterations made
if(numSuc == 0) break	If there were no improvements found, we're done
temperature = temperature *0.9	Reduce temperature by 10 percent
}	
PrintResults()	
}	
Setup Algorithm (creates the initial list and sets the initial temperature)	
{	
CreateInitialList (list)	
energy = GetEnergy (list)	
temperature = energy/number of items in the list	
runLimit = 100 * number of items in the list	
sucLimit = 10 * number of items in the list	
}	
Anneal Algorithm (anneals the list at one temperature to find the best solution)	
{	
numSuc = 0	Number of successful changes to the list
for (I = 0; i <= runLimit; i = i + 1){	Do up to "runLimit" trials at current temperature
GetSegment (start, end, insertPoint)	Randomly select a section of the list to alter
alteration = PickAlteration()	Randomly decide to reverse the segment or move it
Edif = EnergyDif (alteration)	Calculate energy change if this alteration is made
answer = Oracle (Edif, temperature)	Decide if current list will be replaced by the new list
if (answer == YES){	If the Oracle algorithm said to alter the list …
AlterList ()	… alter the list permanently
numSuc = numSuc + 1	Another success!
}	
if (numSuc >= sucLimit) break	If there have been enough successes, get out of this loop so you can lower the temperature
}	
return numSuc	
}	
Oracle Algorithm (decides whether to accept a proposed new list)	
{	
if (Edif < 0) return YES	Always keep a new list if it has lower energy than the old list
if (random () < exp(-Edif/temperature)) return YES	Next, use the Boltzmann factor to decide if a higher energy list should be kept Note, random() returns a random number between zero and one
return NO	If all else fails, reject the list
}	

er, can "knock" these trapped molecules out of these overly energetic bound states and into states of lower energy. This energy transference from molecule to molecule allows the molecules to redistribute themselves as the fluid cools, thereby nudging the growing edges of the crystal in such a way that the molecules settling into them can find the minimum energy state. This orderly crystal growth occurs only during a slow cooling because a lot of time is needed for the molecules to find the lowest-energy state.

So what does all this have to do with the traveling salesman problem? To use Metropolis's procedure, you must be able to describe your problem as a search for a sequence. In the traveling salesman problem, for example, the problem is to determine the best order in which to visit the cities on a list. With a little cleverness, a great many problems can be formulated in this way. It is also necessary for you to be able to generate a number that tells how well any given sequence works; the better the solution, the smaller this number must be. This number is analogous to the energy of the crystal in the crystal-growth example. For my supernovae search problem, the sequence was the order of galaxies searched; the quantity analogous to energy was the total angle through which the telescope had to move.

The box at the left outlines the algorithm. It works by calculating the energy levels represented by different sequences, or "paths." If a new sequence has a lower energy than the previous one, the program always adopts it. Returning to the crystal-growth example, a lower-energy path corresponds to one or more molecules finding their way into a position of lower energy in the lattice. But what about a higher-energy path? Here is where it gets interesting. The program does not immediately reject higher-energy paths; after all, the dislodging of a molecule trapped in a higher-energy state in a lattice is an example of a higher-energy path, and such occurrences are the heart of the procedure.

Yet not all higher-energy paths are likely to nudge the system into a lower-energy state. To determine which ones do, the procedure uses the so-called Boltzmann probability distribution. This factor determines the probability of finding a system, such as a molecule or a group of molecules, with a certain energy E at a given temperature T. When applied to simulated annealing, this probability turns out to be the number e (a constant, equal to about 2.7183, that comes up often in physics and other fields) raised to the power $(-\Delta E/kT)$, where k is Boltzmann's constant, which relates temperature to energy, and ΔE is the energy difference between the two paths.

A clever trick allows the list to be altered without requiring the energy to be

recalculated from scratch every time. The alteration begins by randomly selecting some subsection of the list. Then, either the order of the subsection's elements is reversed, or the subsection is moved and reinserted somewhere else in the list at random. In either case, the energy associated with the subsection does not change. The energy changes only where the subsection joins the rest of the list.

The box on the opposite page contains pseudocode that outlines the necessary procedures. The equivalent C code can be downloaded from the Society for Amateur Scientists's World Wide Web site.

Simulated annealing isn't the only algorithm that mimics nature to solve complex problems. So-called genetic algorithms simulate evolution at the genetic level to create cyberorganisms that are themselves solutions to research problems [see "The Amateur Scientist," July 1992]. Neural networks—which simulate the activity of neurons in the brain to store information, learn from experience and do calculations—are another field of intense research.

All this brings up a fascinating point. Nature is far more clever than humans will ever be. Simulating on a computer nature's methods of organizing and creating has already produced extraordinarily powerful tools to fell some of our own most vexing computing problems. Despite this, only a handful of nature's solutions have yet been duplicated on a computer. There simply have to be more out there to borrow from. The tricky part is in recognizing which systems to model and in realizing the kinds of problems that our simulations can solve.

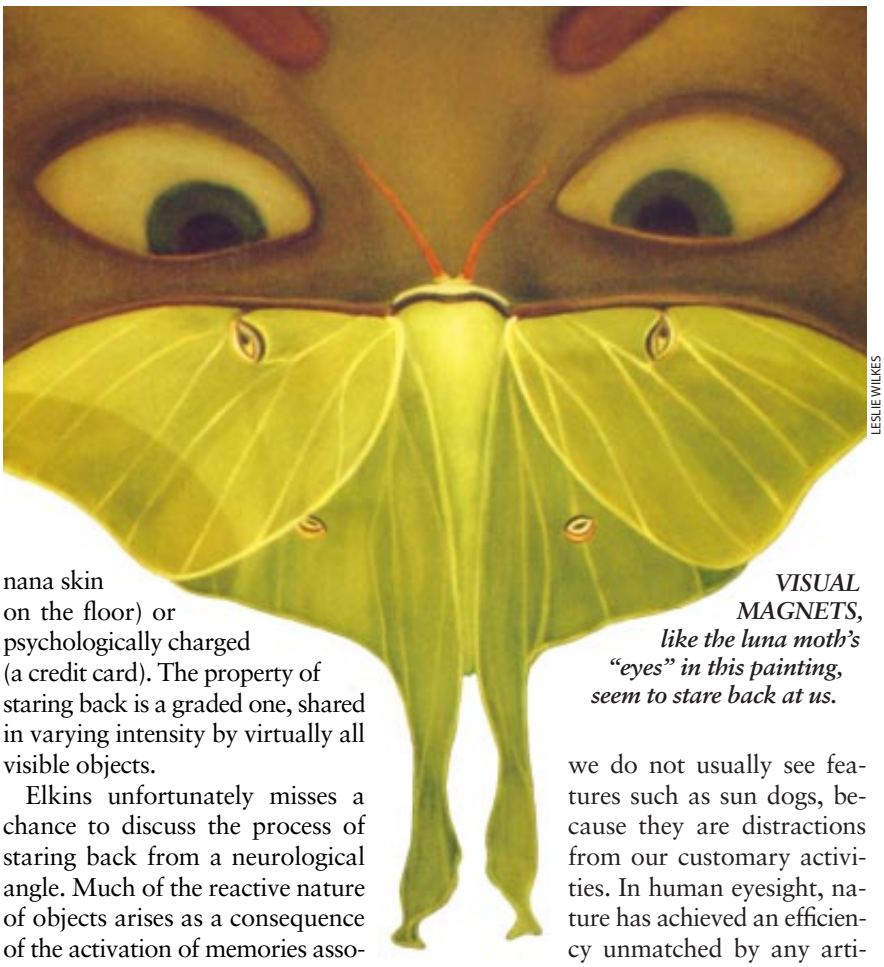
So keep your eyes open! Perhaps, while contemplating ripples of turbulence in cigarette smoke, investigating how individual bees organize themselves into a hive or studying the simultaneous turns of a flock of birds, you will discover the next major innovation in computer problem solving. SA

To download all the C code you'll need to implement the simulated annealing algorithm, visit the Society for Amateur Scientists's World Wide Web site at http://www.thesphere.com/SAS/ For more information about other amateur scientist projects, visit the Web site or call (800) 873-8767 or (619) 239-8807.

VISION REVIEWED

Review by Luciano da F. Costa

The Object Stares Back: On the Nature of Seeing
BY JAMES ELKINS
Simon & Schuster, 1996 ($24)



LESLIE WILKES

***VISUAL MAGNETS,** like the luna moth's "eyes" in this painting, seem to stare back at us.*

Second to no machine in its performance, human vision is—or at least seems to be—comprehensive, effortless and instantaneous. There is a tendency to consider it pure in its simplicity, to think of the image we see as a direct impression of the world outside ourselves. Yet vision is an elaborate process that demands about half the overall capacity of the primate brain's cortex. And even with that complexity (indeed, often because of it), vision is in fact limited in many aspects. The dynamic and often contradictory nature of seeing is the organizing theme of this interesting, but sometimes gloomy book, which covers many issues not usually considered in texts on visual science.

James Elkins, an art historian by training, sets out by denying the popular concept of vision as a passive activity—that we are "just looking." In reality, our eyes are constantly and actively seeking something, whether we are visiting an art museum or just watching the clouds roll by. Furthermore, seeing is not entirely under our control. When and where our gaze settles next is to a great extent determined by our surroundings and by what we had been looking at before.

The notion of vision as an active process is easily grasped; Elkins's idea that objects "stare back" is not so straightforward, because Elkins does not advance a conclusive or exact definition of this concept. It is left to the reader, as he or she progresses through the many instances and arguments presented in the book, to formulate a version of the concept. Perhaps the simplest explanation provided by Elkins is through the notion that many objects possess "eyes," that is, distinctive visual features that draw our attention. Such eye-endowed objects include those that are particularly appealing (a tempting piece of pie, for example), potentially harmful (a banana skin on the floor) or psychologically charged (a credit card). The property of staring back is a graded one, shared in varying intensity by virtually all visible objects.

Elkins unfortunately misses a chance to discuss the process of staring back from a neurological angle. Much of the reactive nature of objects arises as a consequence of the activation of memories associated with that object, as they are retrieved and integrated with our visual perception, often producing some motor reaction. Hence, it is not properly the object itself but rather its representation stored in our brain, with all its associated connotations, that looks back at us.

Another intriguing issue raised in *The Object Stares Back* is the inconstancy of vision—more specifically, the many objects that we usually fail to see. Elkins documents quite effectively our peculiar tendency to overlook certain things: the most extraordinary phenomena (multiple rainbows, sun dogs, meteors and so on) may take place in the sky and yet go unnoticed by almost everybody. Obviously, what we see and what we overlook is influenced by our interests, habits, background and even mood. Also partially invisible are those pictures that are too physically or psychologically intense, such as the sun, genitals and images of death. Our visual system functions as a filter designed to satisfy our basic needs in our typical environment; we do not usually see features such as sun dogs, because they are distractions from our customary activities. In human eyesight, nature has achieved an efficiency unmatched by any artificial visual system.

In the course of human evolution, visual breadth did not always guarantee evolutionary success. Neanderthals, who possessed a large occipital region dedicated to visual processing, became extinct, whereas we, with our more limited visual capabilities but increased capacity in the frontal region, prevailed. It seems reasonable to speculate that the increased reasoning and planning abilities conferred by the enlarged frontal cortex—even at the expense of better vision—may have improved *Homo sapiens'* chances for survival. Evolutionary biology offers reasonable explanations for many other peculiarities of our visual system. It is a pity that Elkins does not address them in greater depth.

Just as there are some types of objects that tend to go unnoticed, there are also those that especially attract our visual perception. Bodies and faces, the most prominent of these, each earn an entire chapter in *The Object Stares Back*. As Elkins observes, bodies and faces are so

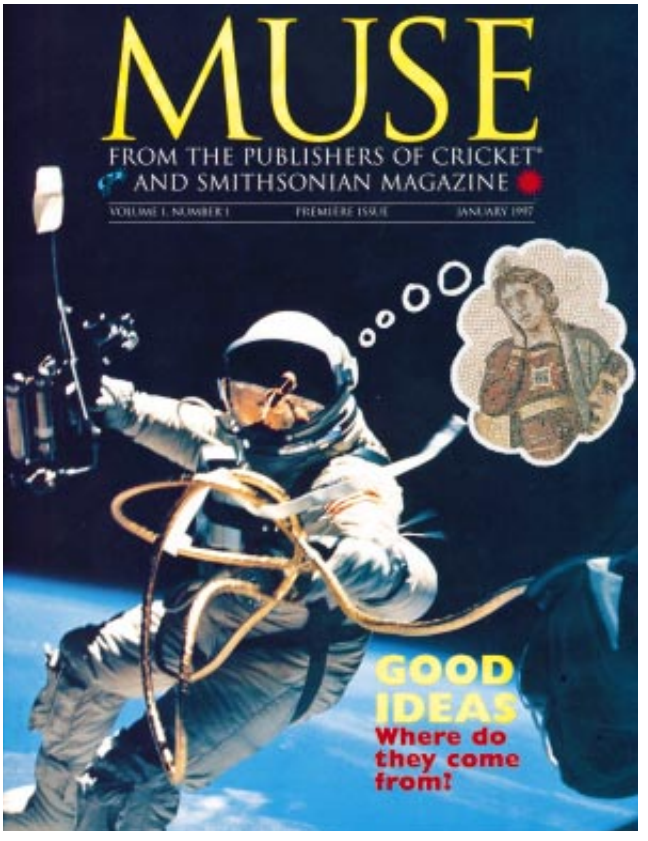
special that we often try to see them in cars, buildings, abstract artistic objects or even in random natural formations (take, for instance, the infamous "face on Mars"). Some of this response is possibly hardwired into the brain. And there is concrete physiological evidence indicating that some neurons in the primate cortex are particularly responsive to the visual stimuli associated with observing a face.

One of the most paradoxical concepts presented concerns a blurring of the distinction between vision and blindness. Although we are rarely aware of it, only a small part of our retina, the fovea, is capable of high-resolution vision. The severe constraints implied by foveal vision can be easily verified by performing the following classic experiment from psychophysics. Hold the page 20 to 30 centimeters (eight to 12 inches) away and stare at the asterisk in the following group of numbers and letters.

2nq2hhs48awqpoiug93hd7hh38bf
30gu84ng0e84nc957gn40fjv8n6
1h374hc08h73*e5ndfg8h74h5fd
0jn58fn30as81h203akoqw893w
g983h49hsdfkypq8w34885af33rp2rb

ON THE NEWSSTAND

Muse
Cricket Magazine Group, in collaboration with the Smithsonian Institution
(Bimonthly, $22 for six issues; call (800) 827-0227)



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION; ART RESOURCE/NEW YORK

Step aside, Euterpe, Calliope and Terpsichore; make way for Chad, Bo and Aeiou, muses of hardware, factoids and software, respectively. These updated characters are featured players in *Muse,* a new science magazine for young readers. The first issue appears promising, containing short, fast-paced articles on mummification, hieroglyphic writing, shortwave radio and the possible discovery of ancient life on Mars. Concerned adults and educators may look to *Muse* as a helpful tool in reversing the ongoing decline in scientific literacy and science enrollment. Children can just look forward to enjoyable reading. —*Paul Wallich*

BRIEFLY NOTED

THE SCIENTIFIC 100: A RANKING OF THE MOST INFLUENTIAL SCIENTISTS, PAST AND PRESENT, *by John Simmons. Citadel Press, 1996 ($29.95).* The very act of creating such a ranking is an invitation to conflict. Few might deny Isaac Newton (*right*) his place atop the list. But who could dare presume to deduce that the historical legacy of Euclid slots him between Gregor Mendel and Hans Bethe or that physiologist Claude Bernard (number 13) trounces Archimedes (dead last at 100)? The reader's cries of outrage are, of course, entirely the point. Disputing the author's order entails plunging headlong into the achievements of 100 great minds and mulling the vicissitudes of fame.

FANFARE FOR EARTH, *by Harry Y. McSween, Jr. St. Martin's Press, 1997 ($23.95).* We are all made of stardust, but the story of how supernova debris became planets and people is neither simple nor fully understood. Harry McSween, a geologist by trade, begins his story with the accretion and evolution of the earth and follows it to the relatively recent development of its thin skin of living creatures. His narrative traces both planetary history and the history of the sciences that have enabled us to understand where we came from.

SPERM WARS: THE SCIENCE OF SEX, *by Robin Baker. BasicBooks, 1996 ($25).* Wholeheartedly embracing the notion of science as a candle illuminating the dark, Robin Baker charges into the bedroom to make sense of the often secretive aspects of human sexuality. The format is unconventional, to say the least: 37 fictional scenes of carnal behavior alternate with the author's bold interpretations. Female orgasm allows control over sperm retention, he argues, whereas males produce a vast oversupply of sperm in each ejaculation because most of the cells are decoys or hunters intended to fend off competitors from another partner. As a researcher, Baker turns out to be a bit of a tease: he offers little insight into his lab work and no references for those who are ready to commit to something a little deeper.

Continued on page 127

Now, without moving your eyes, try to identify how many neighboring characters you can clearly discern.

No need to despair if you have recognized only two or three characters—that is actually the standard performance. Our vision appears comprehensive because we can scan our surroundings and integrate the observed details into our memory. The process determining where we look next is of course biased toward those visual features that are of the most interest—or most capable of "looking back," in Elkins's terminology.

In exploring the frail border between vision and blindness, Elkins considers a remarkable phenomenon called blindsight, in which patients having damaged visual cortices are still able subconsciously to perceive simple visual features. He goes rather far out on a limb and interprets the act of drawing as a dialogue with blindness. Because artists may have no definitive pictures in their head before they start to draw, the final work only emerges as the artist painstakingly dominates the blindness represented by the blank canvas. Theoretical though it sounds, this concept does take on a certain power when one views unfinished masterpieces such as Michelangelo's *Captives,* who seem to be struggling with the blindness represented by the rough surface of the unfinished part.

In the end, Elkins's interdisciplinary account of vision manages to cover a lot of territory while demanding no prerequisites from the reader. It also contains some memorable ideas. In the afterword, he cites a peacock as the ultimate instance of "vision made visible": the animal includes visual features that look back (the eyespots in their plumage), others that trap our visual attention (the convergent plumage pattern) and things that cannot be seen (the large feathers in the middle of the plumage). After reading *The Object Stares Back,* you will not be able to look at a peacock again without recalling that there is more to the world than meets the eye.

LUCIANO DA F. COSTA is a lecturer and researcher with the Cybernetic Vision Research Group at the University of São Paulo in Brazil.

WHO SAW THE FACE OF GOD?

Review by Donald Goldsmith

The Very First Light: The True Inside Story of the Scientific Journey Back to the Dawn of the Universe
BY JOHN C. MATHER
AND JOHN BOSLOUGH
BasicBooks, 1996 ($27.50)

Somewhere between 10 and 15 billion years ago, a flash of radiation marked the beginning of the universe. This radiation filled the cosmos with energy, part of which soon transformed itself into the matter we see today. The expansion of the universe steadily lengthened the wavelength and lowered the energy of every photon in the sea of radiation until, after about 300,000 years, the photons of the cosmic radiation had grown so weak that they no longer interacted with the other particles. This "decoupling" of radiation and matter allowed atoms to form and led to the evolution of the modern universe: galaxies, stars and ourselves. The

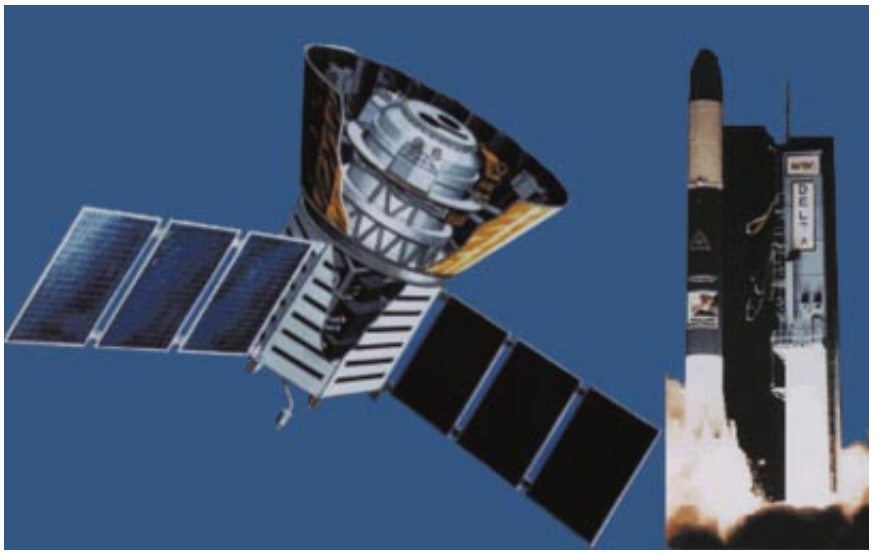
THE ILLUSTRATED PAGE

An Inordinate Fondness for Beetles
BY ARTHUR V. EVANS
AND CHARLES L. BELLAMY
PHOTOGRAPHY
BY LISA CHARLES WATSON
Henry Holt and Company, 1996 ($40)

Beetles rarely elicit from us the feelings of sympathy we easily afford cute and cuddly vertebrates," the authors lament. So they have advanced an agenda of "beetlephilia," a scientific appreciation of the importance of beetles to the global ecosystem and a personal feeling that, by gosh, beetles sure are fascinating. They build a good case. Beetles—more precisely, insects belonging to the order Coleoptera—make up a hefty 20 percent of all known biological species and display a dazzling array of behavioral and morphological adaptations. The book's playfully artistic photographs give those facts and figures a rare visual grounding. An image of a disarticulated *Megasoma actaeon* (*right*), for instance, provides a swift, unforgettable lesson in the almost magical efficiency of beetle anatomy. —*Corey S. Powell*

"Each beetle resembles a unique machine."

LISA CHARLES WATSON



NASA GODDARD SPACE FLIGHT CENTER

COBE SATELLITE* (left; at launch, right) *yielded the most detailed information we have about conditions immediately after the big bang.

cosmic radiation, meanwhile, grew ever weaker but continued to permeate all of space, a relic of the fierce brilliance of the big bang.

This scenario, briefly outlined in the opening chapters of *The Very First Light,* was first envisioned during the early 1950s by Ralph Alpher, George Gamow and Robert Herman, who predicted that the cosmos must still be suffused with what astronomers now call the cosmic background radiation (CBR). More than a decade later, in 1965, Arno Penzias and Robert Wilson of AT&T Bell Laboratories serendipitously detected the CBR. Their work won them a Nobel Prize and provided stunning confirmation that the big bang is a scientifically accurate description of the birth of the universe, at least in its present phase.

The discovery of the CBR spurred astronomers to obtain two crucial sets of observations that would reveal some of the basic details of how the universe was born; the technical efforts, scientific collaborations and occasionally bitter disputes behind that quest form the heart of the book.

The first key observation was to measure the spectrum of the cosmic radiation to determine whether it matched the ideal-radiator shape predicted by nearly all cosmological theories. The second goal, even more challenging, was to find small variations in the amounts of radiation arriving from different directions in space. These differences would have arisen from tiny local inequalities in the density of matter during the epoch of decoupling. Theorists believed such variations were the "seeds" that led to the formation of galaxies and clusters of galaxies within a billion years or so after the big bang. To achieve these twin goals, astronomers needed to rise above the earth's distorting atmosphere. John C. Mather, a researcher at the National Aeronautics and Space Administration Goddard Space Flight Center, and his colleagues conceived a sophisticated, expensive satellite observatory—the Cosmic Background Explorer (COBE)—and persuaded NASA to build it, to launch it and to analyze its data. The task took 15 years but ended in complete success, ushering in a new era in cosmological understanding.

In *The Very First Light,* Mather, who became the project scientist for COBE, has collaborated with science writer John Boslough to tell the satellite's full story, reaching all the way back to the project's conceptual roots in the early 1970s. As the authors recount, COBE traveled a rocky road to reach the earth's orbit. It was originally designed for launch by the space shuttle into a pole-to-pole orbit, which is essential for accurate measurements of the CBR.

After the *Challenger* disaster in 1986, however, NASA abandoned plans to use the shuttle for polar-orbit launches. Under immense pressure to reengineer COBE before the entire project was canceled, Mather worked long hours with teams of scientists and engineers to re-

BRIEFLY NOTED

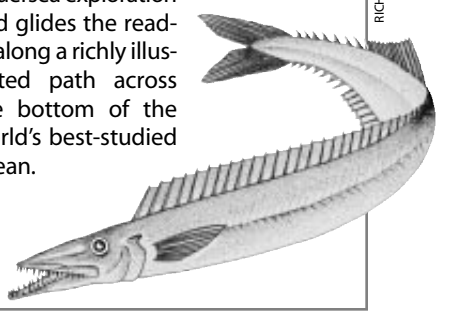
Continued from page 125

THE CAMBRIDGE ILLUSTRATED HISTORY OF MEDICINE. *Edited by Roy Porter. Cambridge University Press, 1996 ($39.95).*

Illness and attempts to treat it are essential parts of humanity's evolutionary heritage. Medicine has shaped our culture even as it has been shaped by it. Countless paintings, engravings and even a cuneiform description of epilepsy from 650 B.C. record the fascination that disease and attempts to cure it have held for artists and chroniclers. In 10 well-written chapters, Roy Porter and his collaborators examine the changing form of medicine and the growing body of technical successes that it has achieved. They also ponder an ironic paradox: even as medical science advances, there appears to be an increase in public concern about health and growing dissatisfaction with health care. The empathy and compassion that were once physicians' staple tools may have become outmoded, but no drug or operation seems to have effectively replaced them.

DEEP ATLANTIC, *by Richard Ellis. Alfred A. Knopf, 1996 ($35).*

The earth's territory 1,000 fathoms below the waves is less well known to us than are the surface features of the moon or Mars. Despite the enormous pressure and the temperatures barely above freezing, the region apparently supports abundant life. And bizarre life it is, judging from the specimens that weighted nets, dredges and occasional submersible forays have brought back. Creatures from the hadal regions (named after the ancient underworld) may be brightly colored even though they live in such utter darkness that many of them have no eyes. Deep-sea predatory fish look like something out of a nightmare or cartoon. Richard Ellis, a marine artist, sketches the history of undersea exploration and glides the reader along a richly illustrated path across the bottom of the world's best-studied ocean.



RICHARD ELLIS

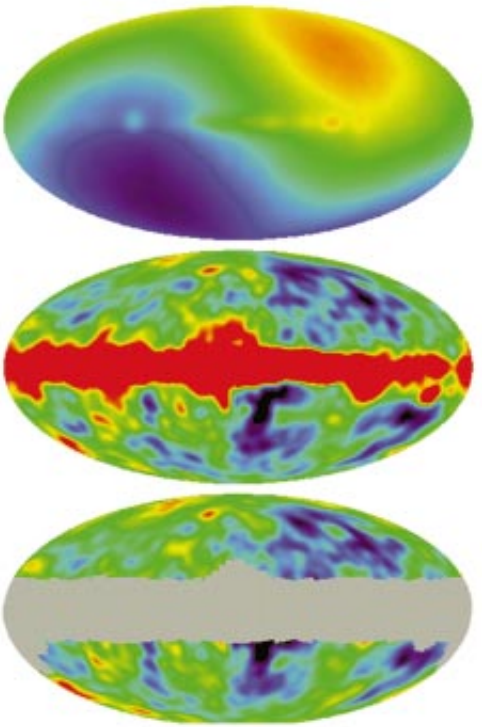
duce the weight of the satellite by half (so that it could fit onto a Delta rocket) without sacrificing its key observational capabilities.

Mather was not only the chief scientist for the COBE satellite but also the principal investigator for one of its three detectors, the experiment to measure the spectrum of the cosmic radiation. Before COBE's launch in November 1989, some scientists had reported detecting baffling deviations in the spectrum, which conventional cosmological theories were at a loss to explain. So when Mather stood before a packed house at the American Astronomical Society's meeting in January 1990 to display the first COBE results, he was settling a high-stakes controversy. COBE's measurement exactly conformed to the big bang model, fitting the standard "blackbody" spectrum so perfectly that it might have been copied from a physics textbook. More than 1,000 astronomers burst into spontaneous, heartwarming applause; the authors describe it as "a moment of supreme epiphany."

Then came the still more difficult task: COBE's second key instrument, the differential microwave radiometer (DMR), sought to find the subtle evidence of the seeds of long-vanished galaxy formation. It took more than two years of computer analysis and statistical techniques to sort through the data in search of the tiny differences in intensity that would verify theorists' predictions of how galaxies began to form. George Smoot of Lawrence Berkeley Laboratory, the principal investigator for the DMR, spearheaded the task.

On April 23, 1992, Smoot announced at a meeting of the American Physical Society that the long-awaited galaxy seeds had been found. After his talk, he and other COBE scientists faced a media corps hungry for news on an otherwise slow day. Smoot's throwaway line, "If you're religious, it's like looking at God," reverberated far and wide; before the week was out, a leading literary agent was marketing Smoot's book proposal to 17 countries. The media focus on Smoot arose in part because he had apparently arranged for his institution to issue a press release without the usual consultation with NASA or anyone else but, even more, because the media needed a hero to connect with COBE's immense but abstruse scientific discovery. It is also easy to speculate that Smoot, who had once found his co-investigator receiving most of the credit for painstaking observations of the cosmic radiation they had jointly made from a U-2 spy plane, was in no mood to lose a second chance for glory.

Along with the rest of the COBE team, Mather was justifiably outraged by Smoot's hogging of the second big COBE story. The penultimate chapter of *The Very First Light* presents the "true inside story" of what Mather considers to be Smoot's betrayal of the agreements among the COBE scientists concerning how they would make announcements and claim credit. To set the record straight, Mather and Boslough carefully describe the contributions of unsung COBE heroes, including Ray Weiss, a brilliant experimental physicist; Ned Wright, who performed heroic data analyses; and Nancy Boggess, an astronomer at NASA headquarters who nursed COBE onward through many crises.



NASA GODDARD SPACE FLIGHT CENTER

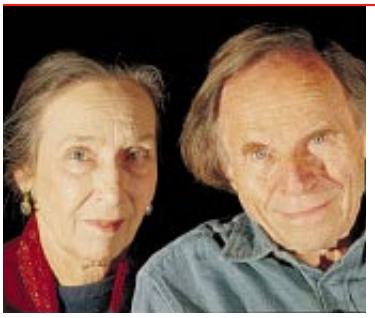
***COBE SKY MAPS** show the raw microwave background* **(top)**, *processed to remove large-scale effects* **(middle)** *and local emissions* **(bottom)**, *revealing the primordial fluctuations.*

This section includes passages in which Mather, who is one of the sweetest scientists one may encounter, seems to engage in overkill. For example, he quotes Boggess's reaction to Smoot's statement that NASA had made him the principal investigator for the DMR experiment because of his previous work on the CBR. "That was a lie," Boggess said: NASA wanted to give this position to a more senior investigator, Dave Wilkinson, "but I knew that Dave would never do it, so I ended up picking [Smoot] almost by default." This non sequitur underlines how different bureaucratic infighting looks from within and from without. Even if Smoot were NASA's third or fourth choice as principal investigator, was it a lie for him to say that NASA picked him for his experience?

The book's final chapter discusses science after COBE. (Mather is now the chief scientist for the Next Generation Space Telescope, the planned successor to the Hubble Space Telescope.) A new family of instruments—ground-based, balloon-borne and eventually on other satellites—will provide more detailed maps of the CBR, necessary to refine our models of the early evolution of the universe.

By the turn of the millennium, we should be ready for a new book that will describe how scrutiny of the cosmic background radiation has unlocked the secrets of the long-vanished epochs when galaxies began to form. For now, those readers who seek a cogent overview of the cosmic radiation without much sociological insight will do best with Marcus Chown's new *Afterglow of Creation*; those who want to learn about the CBR and Smoot's career can enjoy *Wrinkles in Time,* which Smoot wrote with Keay Davidson. But those who want the complete history of COBE and its observations of the CBR will want to read *The Very First Light,* which effectively describes how it felt to be at the center of the greatest effort in observational cosmology of the late 20th century.

DONALD GOLDSMITH is an astronomy writer in Berkeley, Calif. His most recent book, The Hunt for Life on Mars, *has just been published by E. P. Dutton.*



WONDERS

by Philip and Phylis Morrison

Molecular Crayons and Mustard Seed Avalanches

Hardly a week passes without bringing its dramatic image of some molecular scene. One recent tour de force of the modern nano-scene studios was an atomic abacus, the counting beads ranked in parallel grooves, and the entire device built of neatly distinct molecules and atoms. Such images are the product of a scanning probe microscope. It uses no focused beam of photons or particles; instead direct physical contacts are mapped as atom after atom is probed in turn. The brightness or darkness of each picture element depends on the strength of an interaction between an atom and the probe end; it may be a tiny current tunneling between the two or the localized force between the surfaces as the probe delicately taps away. Such pictures magnify distances within the minuscule scene by a few million times.

It took us a while to realize that images so made are not unknown at our own scale. Who has not seen an ancient relief carving in stone beautifully rendered in black on flat paper, the highlights and recesses felt out and recorded by rubbing a suitable crayon over the whole scene? The atomic images popular today are a kind of atomic rubbing, made with a fine crayon indeed.

So far the markers used have been less than the best—a metal wire etched at hazard to a jagged crystalline point or the smooth but blunt end of a microfabricated silicon lever. But lately, wonderful nanotubes—carbon atoms linked into a fullerene latticework—have been put to the task. Made in bulk in a carbon arc, they are amazingly thin, strong and stiff, a fraction of a micron long, with a rounded tip a dozen atomic widths across. A single "crayon" is stuck by adhesive to the silicon probe, which is now only a handle to be steered deftly under the optical microscope. Test images show the virtues of this probe: a set of submicron grooves etched in metal appears under the cruder silicon tip as V-shaped valleys with wavy surfaces, but the carbon tube reaches deeper, to show the walls as smooth, vertical cliffs and the flat valley bottom textured on the scale of a few atoms.

The virtuoso display of the true atomic granularity has supported a close look at matter that is granular on our own gross scale. Loose millimeter grains piled up in good number offer a tempting stand-in for the huge arrays of real, invisible but cohesive atoms. They have economic importance, too, for commerce transports such grains by the billions of tons every year, notably our staple foods, the seeds of wheat, rice and corn. What agriculturists and engineers have worked at for a long time has now become a fascinating challenge for the physicists.

Hundreds report using stand-in atoms at millimeter scale—one experiment used polenta!

Dozens of labs worldwide study this kind of incoherent matter, both in motion and at rest under gravity, using clever bench-top experiments and elaborate numerical simulation.

A few thousand mustard seeds piled on a slightly tilted table resemble a model crystal, rather uniform spheres locally ordered. But tilt the barely stable pile just a little more, and a sudden surface avalanche pours downslope, leaving the deeper-lying seeds entirely undisturbed. No real fluid acts like that!

Certainly, surface is newly important in so small a sample of "atoms." Pour water into a tall cylinder, and the pressure at the bottom will steadily increase with water level. For granules, the bottom pressure soon reaches a limit and

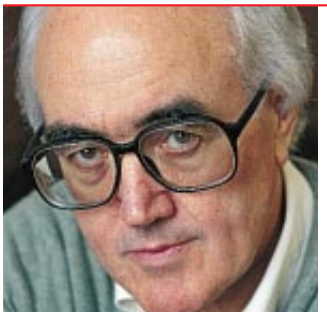
DUSAN PETRICIC

grows little more under greater depth. Grains feel friction and send forces sideways to share the weight between bottom and walls. That is the basic theory of the hourglass, explained a century ago: sand flows more or less uniformly through the orifice even as the level of sand above decreases. There are hundreds of reports using stand-in atoms at millimeter scale: grains of sand, mustard seeds, beads of glass and metals are in the current physics literature. One experiment used polenta!

The real temperature of the grain material is not directly relevant, for the thermal motions of atoms within the grains do not affect the motion of a grain as a whole. Friction surely does, and internal energy losses dominate the repeated collisions between grains. The lossy grain motion diffuses swiftly into abrasion, heat, even sound, and the energy of motion is all but gone after a few dozen collisions. When an atom gains or loses energy of motion, it has merely passed it to a partner. For real atoms rebound perfectly until a quantum jump occurs, an event rare at modest temperatures. In the time a moving seed requires for 1,000 collisions with neighbors or walls, an air molecule will collide and rebound a trillion times. Big, slow grains have no time to search out all the opportunities open in the swifter world of atoms.

Recently, in a marvelously direct ex-

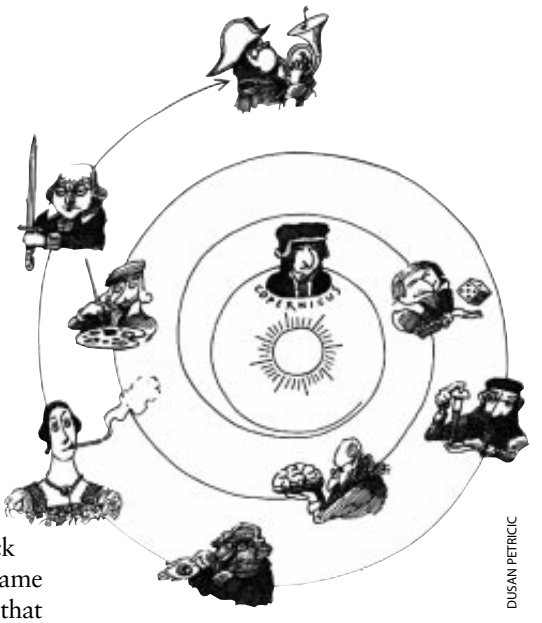
Continued on page 131



CONNECTIONS

by James Burke

Revolutionary Stuff



DUSAN PETRICIC

I was enjoying a recent partial solar eclipse in London and thinking about how after Copernicus came out with *De revolutionibus orbium coelestium,* in which he made the shocking assertion that the earth moved in orbit just like the other planets, it really *was* for his contemporaries, as they often said, that "the world turned upside down." Because if you put the sun instead of the earth at the center of everything, you rocked the entire boat: the old "fixed" order of things (and the church that said so); man as the center of the universe (and the church that said so); the heavens that were beyond investigation (and the church that said so).

No wonder Andreas Osiander (Lutheran mathematician and religious fanatic) tried to persuade Copernicus to write a smoke-and-mirror preface saying it was all just astronomers' mathematical fiction. Otherwise, Osiander said, there was a good chance Copernicus would be in deep and potentially fatal doo-doo with Rome. But since Copernicus was dying anyway, what did he care? In the event, while Copernicus's editor, Rheticus, was out of town (Nuremberg, where the work was being printed), Osiander, temporary replacement editor, slipped in his own preface, with the "fiction" message. By the time the thing blew up (Rheticus went ballistic), it was too late. And *De Revolutionibus* was off the hook enough to survive the censor. More or less.

In 1543 Vesalius's book was a boffo success, triggering an epidemic of grave robbing.

Osiander was a priest who dabbled in astrology and mathematics, and at one point he corresponded with an Italian, Gerolamo Cardano, who shared his interests. Cardano was quite a guy. From being in trouble with the Inquisition, he then became a pal of the Pope. He also wrote more than 200 works on everything from music to philosophy to algebra to gambling. It was his luck with the dice (possibly because he came up with the first law of probability) that enabled him to pay his way through college. By 1540 he was already making a name as a math popularizer and algebra genius, dedicating his great work on the latter subject (*Ars Magna*) to his editor, Osiander.

Cardano was also the second-best doctor in Europe and made one of the first detailed studies of asthma (that took him off for a strange adventure in Scotland, but more of that in another column). We know he met the *best* doctor in Europe, because he cast the latter's horoscope. As a result of which it's said that Andreas Vesalius was born in Brussels at 5:45 on December 31, 1514. Vesalius advanced the state of medicine from potions of boiled puppy, lily leaves and minced earthworms to modern anatomy with his new show-and-tell book called *On the Structure of the Human Body* (1543), which literally took humans apart: brain, blood vessels, nerves, bones, muscles. The work was made easier thanks to a helpful judge in Padua, Italy (where Vesalius was professor), who supplied the author with fresh corpses of executed criminals more or less to order. The book was a boffo success, triggering an epidemic of grave robbing by medical student wannabes.

Part of the reason this new "what you see is what you get" approach made such an impact was because of its artwork, done by the studio of a new rising star in the elite Venetian world of portrait painting: Titian. And what Titian was all about (as any art historian will tell you) was the most fantastic skin-tone work anybody had ever seen. He even went so far as to make Madonnas and Venuses look like real, flesh-and-blood women.

Titian's stuff was so lifelike that people doffed their hats when they passed his 1545 picture of Pope Paul III. So in no time he was turning down commissions right and left from queens, cardinals, dukes, princes and other such biggies. But there was one particular offer he just couldn't refuse: to paint the Holy Roman emperor Charles V, who was in Augsburg at the time, having just won a battle with the Lutheran princes, and who wanted a little commemorative number done. Titian sat him on a horse in full parade armor (the suit he'd worn to watch the recent battle). And you might conclude, on viewing the finished work in Madrid's Prado Museum, that the emperor was screwed. Well, the thing on his armor might be a wing nut, but either way, that's how they fixed plate armor onto you.

Augsburg, being a metalworking center, was the home of the screw. And one of the local goldsmiths was a fellow called Max Schwab, who sometime after 1550 got an invite to send one of his fancy balance presses to the Louvre in Paris to make some not so fancy coins for Henry II. These had a reduced precious-metal content, the idea being that devaluation would help shore up Henry's tottering finances and also leave enough for his wife, Catherine de Médicis, to spend on her diplomatic mega-

buffets. At one of which she might well have passed around a new, recreational drug she'd been sent by the French ambassador to Portugal.

If I tell you his name was Jean Nicot, you'll be there ahead of me. Tobacco went through European high society (and then the rest) like an addiction waiting to be taxed. Soon enough, when James I of England upped the customs duty on it more than 30 times, it became the first of many examples of a harmful but fiscally remunerative commodity. So, before you knew it, mercantilism was the new buzzword. Tobacco sales started pouring cash into national coffers, and the new European trick became setting up colonies to make even more green stuff from the green stuff.

Unfortunately, with a navy of a few dozen rotting hulks, that left 17th-century France potentially out of the get-rich game. Until a new controller-general of finance, Jean-Baptiste Colbert, took over and turned the economy around with everything from tax incentives for explorers (which is when French Africa started) to a budding domestic transportation network. Including the Canal du Midi (still there for holiday boating), for which he engaged the services of a military engineering genius named Sébastien Le Prestre de Vauban, who did one of the aqueducts.

Vauban was a mover and shaker. He predicted what the population of Canada would be in 2000 A.D. (51 million) and wrote on beekeeping, silk manufacture, pig farming and taxation. He built major fortresses all around the French frontier and invented the socket bayonet. He also came up with a totally new kind of siege tactic. We call it trench warfare: dig a trench, fill it with firepower so as to cover the men digging another trench nearer the enemy walls. Go on doing that until you're right under the walls. Then undermine them with explosives and blow them up. Unless you've undermined enemy morale so much they give up before you have to.

Which is just what happened on October 19, 1781, when General Cornwallis and his troops surrendered the fort of Yorktown in Virginia and marched out, signaling the victory of the Americans over the British. And you know what the band played as they left? A little march entitled "The World Turned Upside Down." SA

Wonders, *continued from page 129*

periment, a few thousand millimeter-size glass beads were photographed packed into a small, clear box. A fluid was added that matched the refractive index of the glass very well, so that the beads lost all contrast. Viewed through a pair of crossed polarizers, the scene was dark and bland, no beads to be seen. Then a few pounds of pressure were applied to the top of the sample by a small piston. Pressure-stressed glass rotates polarized light, so a number of long chains of beads showed up. The chains twisted their way awkwardly through the container. Most weight was borne by a few strings of tightly contacting beads, with no semblance of the uniformity of fluid pressure. Maybe over a long time the beads might relax toward uniformity, or will that appear only in the average behavior over many trials?

Granular motion itself is in no way a faithful model of the thermal world. When you shake together beads of a few different sizes, they often unmix rather than mix. Often the bigger ones migrate to the free surface. Once there, it is hard for them to fall back down, because the space below is filled by smaller beads. Or vibrate a box full of a dozen layers of beads, and at the right range and rate of vibration, the wave-marked surface layer is decorated by little standing jets of beads in regular array. There grains rise up and fall back with a rhythm fixed by the vibration; each site alternates between a geyser a few millimeters high and a little local crater.

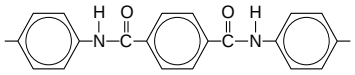
Frictional grain motions hug walls and only grudgingly spread. The inescapable loss of energy on rebound induces neighboring grains to cluster after rather few collisions. The unexpected order that the strange sandpiles show at our scale comes from the external energy fed in to meet losses all but absent among real atoms. Available energy is always capable of partial conversion into new order. Just what that order will be may indeed have no single general answer. Surprises will continue, as each rich new system sports its own wonders. (Try the unmixing experiment in your own kitchen.)

We owe the simplicities of mixing to quantum laws. They hold for granular fountains and landslides, too, but when each rubbing grain holds a few thousand trillion atoms to share collisional energy, atomic simplicity is long delayed. SA

STOPPING BULLETS

DU PONT

STEPHANIE KWOLEK recently received the National Medal of Technology for her discovery at Du Pont in 1965 of a solvent that would dissolve Kevlar so that it could be spun into a yarn. When spun, the molecules in the yarn line up in straight, rigid chains (*at right*).



by Brian Scott

There is no such thing as a bulletproof vest. For more than 3,000 years, soldiers have attempted to stop pointed objects from penetrating the skin. But a sharp-enough point made of a hard-enough material delivered at high-enough velocity will defeat the most intricate chain mail or a weave of the most high-technology fiber.

Polymer chemistry, however, has achieved a measure of success in making materials that can stop many of the bullets found in the most common handguns. At the same time, the wearer of garments made from such plastics no longer need feel like a knight in armor: the materials weigh little enough to be fashioned into an overcoat or a dress jacket. Until the mid-1970s, clothes that could resist bullets required so many layers of nylon, silk, leather or metallic materials that their bulkiness often caused police to avoid them.

The first of these new bullet-resistant materials was made out of poly (*para*-phenylene terephthalamide), known by its trade name of Kevlar. This polymer resembles nylon, except that the type of hydrocarbon structure present in nylon is replaced by aromatic rings. The ring structure prevents the polymer from bending, which lends the material its rigidity. (Other companies have also fashioned bullet-resistant plastics.)

Kevlar found its first use as reinforcement for radial tires. In 1971, however, the National Institute of Justice recognized the potential of a polymer 16 times stiffer than the nylon of previous bullet-resistant vests, one that would allow vests or other garments to be made using less material.

The thinnest recommended vests are made of about 20 layers of fabric stitched together. They can absorb and disperse the energy of a bullet from a nine-millimeter handgun traveling at 1,200 feet a second. These workaday garments ensure that the skin underneath the vest does not depress more than 1.7 inches. Although still enough to bruise, that amount of pressure is usually too little to cause serious internal injury. Adding layers to a vest can stop higher-powered bullets.

Plastic body armor has proved its worth. In the past 20 years, about 2,000 police officers wearing Kevlar vests have taken a bullet and survived.

BRIAN SCOTT is a research associate with Du Pont. Kevlar® fiber is a registered trademark of Du Pont.

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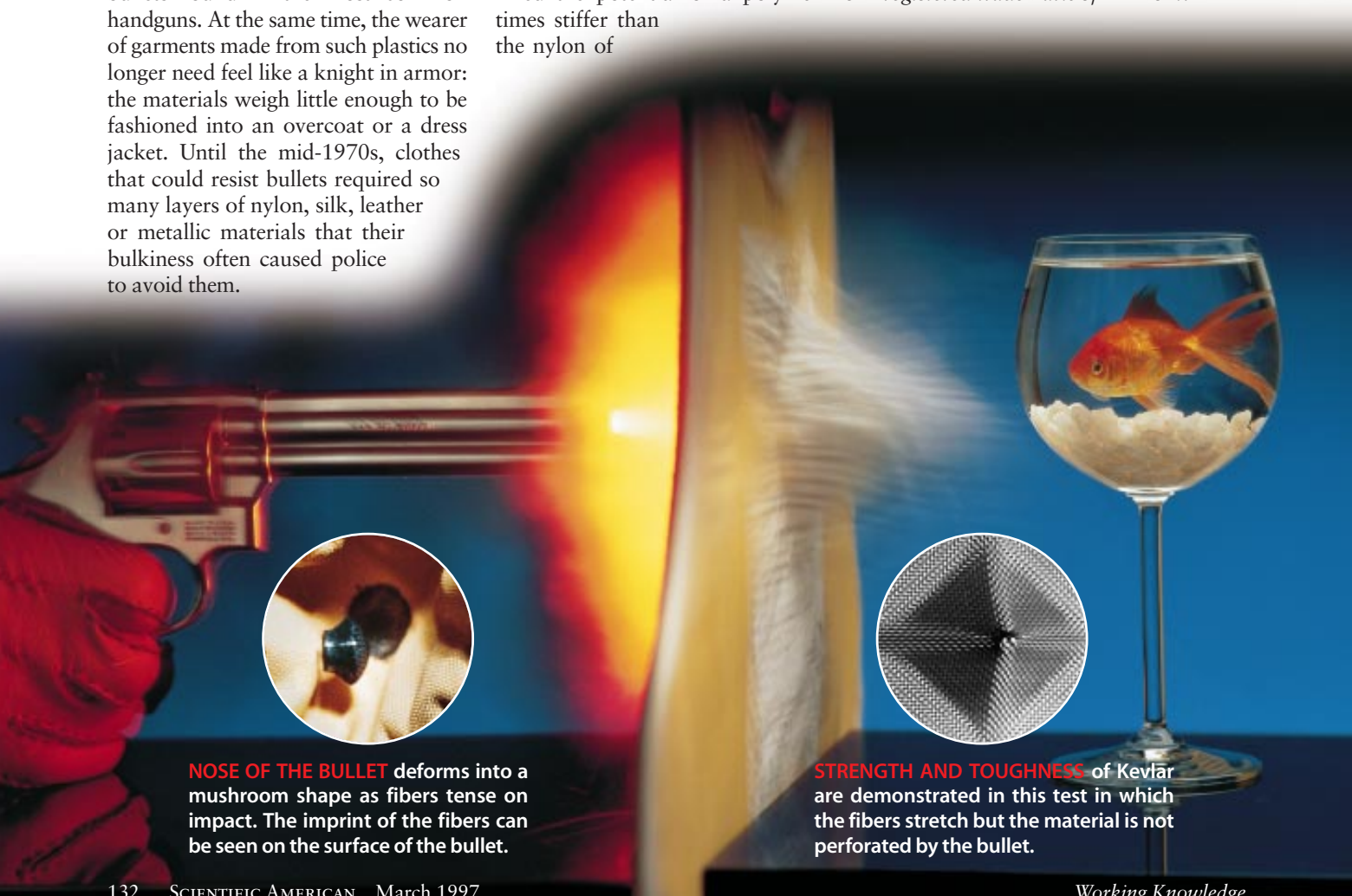

NOSE OF THE BULLET deforms into a mushroom shape as fibers tense on impact. The imprint of the fibers can be seen on the surface of the bullet.

STRENGTH AND TOUGHNESS of Kevlar are demonstrated in this test in which the fibers stretch but the material is not perforated by the bullet.