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Dangers from new viral plagues.
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Secrets of quantum computing.

***Three suns** and their planets orbit in a complex gravitational dance.*

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DEPARTMENTS

THE COVER depicts the view over the rim of a planet in orbit around a star that is part of a triple system. Arrangements of two, three or even four members include a large number of the stars that are like our sun. Yet astronomers have only recently learned that such groupings also exist among stars that are still early in their evolution. Observations indicate that multiple systems are at least as common for newly emergent stars as for more mature ones (see "Companions to Young Stars," by Alan P. Boss, page 134). Painting by Alfred T. Kamajian.

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LETTERS TO THE EDITORS

Clearing the Smoke

I would like to commend you for publishing "The Global Tobacco Epidemic," by Carl E. Bartecchi, Thomas D. MacKenzie and Robert W. Schrier [SCIENTIFIC AMERICAN, May]. The article reveals all too clearly the formidable task facing the American Cancer Society and other organizations and individuals determined to reduce tobacco's toll on public health and well-being. The Society has played a leading role in research on the health consequences of tobacco use and in advocating stronger tobacco-control measures. Articles such as yours strengthen the resolve of our staff and volunteers to continue pursuing these vitally important goals.

MICHAEL F. HERON
American Cancer Society
Atlanta, Ga.

You have completely destroyed the credibility of your publication by allowing Bartecchi, MacKenzie and Schrier to spew their diatribe. The antismoking movement's "smoking cost" frauds have been exposed by the Congressional Research Report "Cigarette Taxes to Fund Health Care Reform," whose existence the authors have concealed. The majority of the supposed "400,000 smoking deaths" are founded on willful epidemiological malpractice. The authors falsely blamed ulcers and stomach cancer, which were really caused by *Helicobacter pylori,* on smoking. *H. pylori* and *Chlamydia pneumoniae* have also been impressively implicated as causes of heart disease, to such a degree that smoking becomes nonsignificant.

CAROL THOMPSON
Smokers' Rights Action Group
Madison, Wis.

The authors reply:

The Congressional Research Report to which Thompson refers was requested by Representative Scotty Baesler of Kentucky, along with several other tobacco-state lawmakers. The report based its calculations of the cost of smoking on many controversial assumptions—for example, that Social Security and pension savings brought about by the premature death of 419,000 American smokers every year should be counted as a benefit that offsets the health care costs of smoking. A report that treats premature death as a benefit and addiction as an "information problem" cannot be taken seriously.

The conservative estimate of 400,000 smoking deaths cited in the article came from researchers at the U.S. Department of Health and Human Services and the Carter Presidential Center. A pilot study in the *British Heart Journal* has suggested a possible association between *Helicobacter pylori* and coronary heart disease, but the findings are very preliminary. In contrast, the cardiovascular toxicity of tobacco smoke is solidly established in the medical literature. Thompson, like the tobacco industry in general, takes a kernel of truth and puffs it up to the ridiculous.

Complexity Reconsidered

In his article "From Complexity to Perplexity" [SCIENTIFIC AMERICAN, June], John Horgan displays a stunning misunderstanding of the Santa Fe Institute and of research on complex systems. The Santa Fe Institute (SFI) is a multidisciplinary research and education center devoted to creating a network of scientists pursuing emerging syntheses in science. Examples abound of what researchers associated with SFI call complex adaptive systems: economies, ecological systems, the immune system, the brain and human culture. Many researchers believe it is productive to compare the common features of these systems and to search for common principles. I know of no serious researcher who believes there will be a common master theory of complex adaptive systems (what Horgan calls a "unified theory") that will explain all their features. SFI's value as a research center does not depend on such a speculative program.

L. M. SIMMONS, JR.
Santa Fe Institute
Santa Fe, N.M.

What an illuminating and interesting (and I don't mean "interesting" in being complex) article John Horgan has written in the June *Scientific American.* Science journalism at its best!

EDWARD O. WILSON
Harvard University

Bell Curve, Continued

In your May 1995 issue you published a response by Leon J. Kamin that quotes me out of context, implying that my belief that modern science is opening the door to eugenic policies hides a predilection for genocide. The sentence Kamin quotes is taken from a chapter, "Sir Arthur Keith and Evolution," in which I summarize Keith's possibly accurate view that human evolution had sometimes involved the total displacement of an earlier population by a more highly evolved one.

Kamin has sought to cite this sentence not as a description of Keith's opinion as to how evolution sometimes occurred but to imply that I advocate genocide as a policy! Nothing could be further from the truth. I believe that evolution has endowed *Homo sapiens* with a rich degree of genetic diversity, and I would be very apprehensive of any chain of events that might cause humankind to be reduced to a single subspecies, whether by genocide or panmixia.

ROGER PEARSON
Institute for the Study of Man, Inc.
Washington, D.C.

CLARIFICATIONS AND ERRATA

The article "Lost Science in the Third World" [SCIENTIFIC AMERICAN, August] reported several assertions made during interviews and later confirmed by Luis Benítez-Bribiesca, editor in chief of the journal *Archives of Medical Research*, regarding the Science Citation Index, a database produced by the Institute for Scientific Information (ISI). According to the ISI, it has never required that any journal, person or institution purchase an ISI product to qualify for inclusion in its indexes.

Furthermore, the ISI notes that it has never made a decision about indexing a journal until after at least three issues have appeared. No statement in the article is meant to imply that the extent to which a journal's articles are cited is the sole criterion for inclusion in an ISI product.

Also, the $10,000 subscription price mentioned for the index is the approximate current price, not the price during the 1970s. The Editors regret any misunderstanding resulting from ambiguities or misstatements in the article.

50, 100 AND 150 YEARS AGO

OCTOBER 1945

"A recent proposal would put transmitting equipment on airplanes and would broadcast television and FM from an altitude of six miles, where the limitations of ultra short-wave transmission almost vanish. Eight 'Stratovision' stations could replace about 100 ground relay stations. When the technical possibilities and costs are balanced, it appears that the 'brain-child of a wild-eyed dreamer' is actually a view of the not far distant future as seen by a group of realistic engineers."

"The anticipated use of plastics in smaller boats is tantamount to a minor revolution in boat building. In the past skilled craftsmen painstakingly built sea-worthy boats from teak, mahogany, and brass. None dared to challenge tradition. But with Pearl Harbor came the need for small craft to be constructed by the thousands with no sacrifice of sea-worthiness. Under the stimulus of this emergency the boat industry began to adopt plastic laminates for hulls, superstructures and decks."

"On transoceanic flights the crews have available to them every known navigational aid. Drift of the plane, caused by side winds, is checked by the use of thin glass flasks containing pulverized aluminum which, when dropped from an airplane, break on striking the ocean surface and produce a bright silvery slick visible for miles."

"Ray Russell, industrial designer, has conceived and built a Quadratic Drive car. A hydraulic system eliminates the clutch, transmission, drive shaft, axles and brakes. The engine drives a hydraulic pump that forces fluid through flexible couplings to all four wheels, in each of which is mounted a hydraulic motor. Braking power is applied through regulation of the speed of the hydraulic fluid."

OCTOBER 1895

"There has lately passed from our midst one of the greatest of all great men. Louis Pasteur has done more to ameliorate the condition of the race than any one man, living or dead; his healing touch will be felt to the end of time. Physicians were wrestling blindly with a foe that they could not see, and that was manifest to them only by its fatal effects. Pasteur has thrown the clear light of science upon this foe, and he has put into the hands of the physician a sure means for its extermination."

"The telephone newspaper organized at Pesth, Hungary, has now been working successfully for two years. It is called the Telephone Hirnondo, or Herald, costs 2 cents, like a printed paper, and is valuable to persons who are unable or too lazy to use their eyes or who cannot read. A special wire 168 miles long runs along the windows of the houses of subscribers, and within the houses long, flexible wires make it possible to carry the receiver to the bed or any other part of the room. To fill up the time when no news is coming in, the subscribers are entertained with vocal and instrumental concerts."

Jardine's electric time check receiver

"Gold in plenty may be found in the sands of the Volador River in South America; but the mosquitoes are so thick and terrible there that all attempts to rifle the sands of their gold have so far failed. One Italian laughed at the idea of mosquitoes driving any one away from a place where gold could be picked up almost by the handful. His party of six endured for less than half an hour the awful torture, and then left. They found their way back to Rio Hacha with difficulty, for the eyes of five were so badly swollen that they were blind."

"An automatic device for receiving the checks or tickets of employees in manufacturing establishments, offices, etc. [*shown in illustration*], has been patented by Charles K. Jardine of Oban, Scotland. Pivoted in the box is a lever carrying a plate with the words 'early,' 'late,' 'closed.' "

OCTOBER 1845

"The current of the Gulf Stream has generally been attributed to the waters of the Mississippi, especially as it was observed that the water of the stream was several degrees warmer than that of the ocean in its vicinity; and although this reason was unsatisfactory to every geography-reading schoolboy, yet no more rational theory was discovered till recently. It now appears that the water of the Pacific flows by a subterranean channel to the Atlantic. The high temperature of the water of the Gulf Stream is now readily accounted for by a knowledge that if this subterranean channel is three or four thousand feet deep, it must pass through earth, the temperature of which is far above the boiling point of water."

"It is estimated that the power of steam in Great Britain is equal to the labor of 170,000,000 men, in a population of only 28,000,000."

"Incredible as it may appear to our skeptical readers, it is nevertheless a fact that a selfacting helm, or an artificial helmsman, has been invented on rational principles, that will guide a ship to any required point of the compass. This is effected by means of an electro magnetic engine, which is connected with the rudder and operates upon the least variation of the needle of the compass."

Hidden Scars

Sexual and other abuse may alter a brain region

Many women and men who have been subjected to severe physical or sexual abuse during childhood suffer from long-term disturbances of the psyche. They may be invaded by nightmares and flashbacks—much like survivors of war—or, conversely, may freeze into benumbed calm in situations of extreme stress. Two recent studies find that survivors of child abuse may also have a smaller hippocampus relative to control subjects. If substantiated, the discovery could fill out the profile of an abuse survivor and help define what constitutes abuse.

STEPHEN SHAMES *Matrix*

CHILDHOOD ABUSE, whether physical or sexual, leads to psychological disturbances in up to 40 percent of survivors. It may also cause changes in brain structure.

Changes in the hippocampus—the part of the brain that deals with short-term memory and possibly the encoding and retrieval of long-term memory—could, researchers suggest, be wrought by hormones flooding the brain during and after a stressful episode. Such alterations are presumably reflected in the psychological aftermath of trauma. Between 10 and 20 percent of adult survivors of abuse are believed to suffer from dissociative disorders or from post-traumatic stress disorder (PTSD); the estimate is uncertain because survivors who do not seek counseling are hard to identify.

Dissociation and PTSD are not sharply separated and often alternate in the same individual. Dissociation, often employed by children who cannot escape from the threat of abuse, is a means of mentally withdrawing from a horrific situation by separating it from conscious awareness. The skill allows the victim to feel detached from the body or self, as if what is happening is not happening to her or him. People with PTSD tend to relive violent memories. They are easily startled, avoid cues that remind them of the original experience and become intensely agitated when confronted with such stimuli.

The two studies of brain changes associated with abuse both used magnetic resonance imaging to measure hippocampal volumes and found the most significant deficits on the left side. Murray B. Stein of the University of California at San Diego compared 22 women who reported severe childhood sexual abuse with 21 control subjects and detected an average volume reduction of 5 percent of the left hippocampus. PTSD and dissociative symptoms were more pronounced in those abuse survivors with a smaller hippocampus.

J. Douglas Bremner and Dennis S. Charney of Yale University matched a control with each of 12 men and five women who had experienced severe abuse and suffered from PTSD. The researchers found a 13 percent reduction in left hippocampal volume. Given the small number of subjects in the studies, and the disparity in their psychological profiles and genders, the similarities in the results came as more of a surprise to the scientists than did the differences. Neither study has yet been peer reviewed.

Bremner also found that the abuse survivors had impaired short-term verbal memory. The result echoes his earlier finding showing impairment of verbal memory in Vietnam veterans with PTSD; the veterans had smaller hippocampal volumes as well. Tamara Gurvits and Roger Pitman of the Veterans Administration Medical Center in Manchester, N.H., reported recently that the left hippocampus was smaller by 26 percent and the right hippocampus by 22 percent in seven Vietnam veterans with PTSD.

The neurochemical mechanisms that might alter the hippocampus remain far from transparent. The brain responds to intense stress by causing adrenaline, noradrenaline, cortisols, opiates and several other hormones to be released into the bloodstream. The chemicals alter neuronal connections and seem to mediate psychological reactions: enhanced noradrenaline levels cause PTSD sufferers to experience flashbacks. The hippocampus is particularly sensitive to high levels of cortisols, which circulate for hours or days after stress. Robert M. Sapolsky of Stanford University

has found that in rats, glucocorticoids circulating for months kill neurons and reduce hippocampal volume.

But prolonged stress leads, if anything, to chronically depleted cortisol levels in humans. John W. Mason of Yale has demonstrated that PTSD patients have extreme levels of key hormones: anomalously low cortisol coupled with high adrenaline, noradrenaline and testosterone. Low cortisol is linked with emotional numbing; spasms of high cortisol coincide with disturbing memories.

Nevertheless, argues Frank W. Putnam, Jr., of the National Institute of Mental Health, childhood stress may lead to initially high and damaging cortisol levels. His ongoing study of about 80 girls, recruited in 1987 within six months of disclosing sexual abuse, reveals initially high plasma cortisol. Although the mean cortisol levels are decreasing from year to year, the total amount of cortisol the victims are subject to may be above average.

"The thermostat is broken," explains Rachel Yehuda of the Bronx Veterans Affairs Medical Center: the feedback systems that control hormone levels appear to be dysfunctional. Putnam suggests that stress floods the brain with cortisol; the brain, in turn, resets the threshold at which cortisol is produced, so that it ultimately circulates at a dramatically low level. But the system remains hypersensitive.

There is, however, one other explanation for the observed hippocampal volume deficits. Both MRI studies were dominated by survivors who suffered from PTSD or dissociation. Therefore, the results strictly apply only to those victims in whom these disorders developed. In particular, Stein emphasizes, those born with a smaller hippocampus could be more vulnerable to acquiring PTSD or dissociation if subjected to extreme stress. (Prior child abuse, it turns out, is a risk factor for development of war-related PTSD in Vietnam veterans.)

If the neurophysiology is mysterious, its interface with psychology is more so. David W. Foy of Pepperdine University notes that within days or weeks of a traumatic experience, therapy seems beneficial in dispelling PTSD. This period, Bremner speculates, could reflect the timescale over which the hippocampus organizes experiences into a person's worldview. Although some functions of the hippocampus are known, its mechanics are poorly understood.

Psychiatrists contend that if repeatedly invoked in childhood, dissociation prevents memories from being integrated into consciousness and can lead to an altered sense of self. Many normal children play with imaginary companions; abused children can use such creative resources to a pathological extent, in extreme cases falling prey to multiple personality disorder (MPD). Adults may continue to use dissociation as a coping mechanism. Once dissociation or PTSD develops, the majority of psychological symptoms and the hormonal profile are very resistant to treatment.

Ninety-seven percent of psychiatrists believe in dissociative disorders, which have a strong presence in the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV).* But their link with MPD, and their implicit provision of a mechanism for memory suppression, has made them controversial. PTSD, too, has detractors: the condition was defined for diagnosing Vietnam veterans. "It's not the same clinical picture in 10-year-old girls," Putnam points out. Several clinicians argue for a classification for dissociation and PTSD as related specifically to child abuse.

Thus, the findings, although helping to ground psychology in biology, raise more questions than they answer. "The last thing we want is for clinicians to be telling patients, 'You have a smaller brain,' " Yehuda warns. "There is a knee-jerk reaction: big brains good, small brains bad." The real story is more complex, but no more so than humans themselves. —*Madhusree Mukerjee*

Seeing the Forest for the Trees

Biologists crane to see the canopy

As scenic overlooks go, the Wind River canopy crane doesn't really rate. Dangling from the crane's jib in a steel cage 245 feet off the ground, you can't see the jagged crater of Mount St. Helens just 40 miles to the north or the snowy pinnacle of Mount Hood to the south. You can't see the brooding basalt ramparts of the Columbia River Gorge, into which the Wind River drains. You can't even see Wind River.

But you can lean out and grab the drooping crown of Western hemlock #3064, which is suffering from a nasty infection of dwarf mistletoe. And you can visit the nuthatches nesting in the broken spire of fir snag #1014. You can nab a few bald-faced hornets or sample the nutrient-rich runoff from the upper reaches of red cedars; you can monitor the gaseous effusions of the highest epiphytes or launch plumes of pink smoke and watch turbulence carry them into the gaps and canyons of treetop topography.

Ecologists are planning to do all this and more now that the world's tallest canopy-crane research facility is up and running. Located in the Gifford Pinchot National Forest in the southern Cascade Range of Washington State, the crane will provide researchers with unprecedented top-down access to the apex of

JERRY F. FRANKLIN

WIND RIVER CANOPY CRANE allows biologists unprecedented access to the Northwest forests.

this old-growth conifer forest. The arboreal laboratory should help answer questions about life in the region's protected forests and its managed stands.

"Mark, you want to cozy us on up to this Doug-fir top?" From the swaying gondola, site director David C. Shaw of the University of Washington communicates by handheld radio with crane operator Mark Creighton to position the craft and its four snug passengers inches from the fir in question. The canopy is a shaggy green riot broken by the gray strokes of dead boughs and the glint of aluminum ID tags (eventually, Shaw says, individual branches will be marked with bar codes). Shaw points to dense tufts of pale yellow festooning the expiring fir: wolf lichen, *Letharia vulpina.* "We knew this was probably here," he says, "but until now, we couldn't see it up close and personal."

Since June dozens of scientists have cozied up to the 1,179 trees in the gondola's six-acre scope. Representatives of disciplines ranging from climatology to plant physiology are studying organisms and processes inaccessible to the platforms and towers researchers have relied on in the past. The canopy is the final frontier in forestry research, and although the Wind River crane is the third such facility to be erected—a 134-foot crane was set up in Venezuela earlier this year and a 138-foot crane has operated in Panama since 1990—it is the first of its kind in temperate forest.

But if the forest is temperate, the political climate definitely is not. Locals besieged by logging industry cutbacks defeated plans to put the crane on the Olympic Peninsula, where the amiable likeness of the project's founder, Jerry F. Franklin of the University of Washington, was seen on WANTED posters. Research conducted at the Wind River site is likely to be used to implement the controversial plan for managing Northwest forests that was recently approved by President Bill Clinton.

"We need to know more about the kind of structures to retain in our managed forests, and this is one of the places we can do that," Franklin explains. How will such findings be received outside the scientific community? The answer to that question, he says, is not at all clear-cut. *—Karen Wright*

Beyond Neptune

Hubble *telescope spots a vast ring of icy protoplanets*

Astronomers have long suspected that the solar system's suburbs, which begin on the far side of Neptune, might be a busy place. But only recently have telescopes begun to reveal just how densely populated those outer boroughs really are.

Data trickling in from the *Hubble Space Telescope* and other sources suggest that the solar system is encircled by a vast disk of icy comets, some of which are hundreds of kilometers across, called the Kuiper belt. Pluto and its moon, Charon, which are 1,200 and 600 kilometers wide, respectively, may merely be the largest members of the belt.

The belt is the probable home base of such comets as Shoemaker-Levy 9, which collided with Jupiter in spectacular fashion last year. Further research on this region may yield clues about the conditions that preceded the birth of planets in the inner solar system. "This represents a wonderful laboratory for studying how planets formed," says Harold F. Levison of the Southwest Research Institute in Boulder, Colo., one of the *Hubble* team.

The belt's namesake is Gerard P. Kuiper, who proposed in 1951 that the solar system might be ringed by a disk of debris—similar to the rings of Saturn—that never coalesced into full-fledged planets. Levison notes that another astronomer, K. E. Edgeworth, had advanced a similar theory two years earlier. But Kuiper, who was already one of the world's leading planetary scientists, received—and accepted—all the credit for the prediction.

Astronomers began discerning Saturn-like disks around other stars, notably Beta Pictoris, in the 1980s, but only recently have telescopes become powerful enough to spot individual fragments surrounding our own star, the sun. The first sighting occurred three years ago. Using a 2.2-meter telescope on Mauna Kea in Hawaii, David C. Jewitt of the University of Hawaii and Jane Luu of the Harvard-Smithsonian Center for Astrophysics found an object roughly 100 kilometers across beyond Pluto.

Since then, Luu, Jewitt and others have counted 30 or so more objects of similar size. These results suggest that tens of thousands of such "planetesimals" may be orbiting the sun. The findings also spurred other investigators to wonder whether the Kuiper belt might harbor many smaller, comet-size objects too small for the Hawaiian telescope to discern.

To test this hypothesis, Levison and three colleagues—F. Alan Stern of the Southwest Research Institute, Anita L.

Cochran of the University of Texas at Austin and Martin J. Duncan of Queen's University in Ontario—pointed the *Hubble* at a relatively uncluttered piece of sky in the constellation Taurus. The group managed to see, barely, 30 or so objects that are 12 to 20 kilometers across. The Manhattan-size objects are thought to have the same constitution as comets: an icy core with a sooty coating that reflects little light. Levison compares the detection of these black snowballs to spotting a 100-watt lightbulb 20 times farther away than the moon.

Extrapolating from their findings, the *Hubble* workers have estimated that at least 200 million similar objects, and possibly as many as five billion, are circling the solar system. Cochran expects additional observations will reveal the orbits of the objects and their full range of sizes. Do they steadily decrease in number as their size increases—following a power law—or come in only a few basic sizes?

Cochran also hopes to get some sense of the thickness of the belt and possibly its full breadth. "We're only seeing objects in the inner belt," she says. Some analysts have estimated that the distance between the belt's inner and outer edge may be 500 times greater than the distance from the earth to the sun.

The data gathered so far support the thesis that the Kuiper belt is the source of most short-period comets, those that orbit the sun in 200 years or less, according to Duncan. Short-term comets generally orbit within the same plane occupied by the planets and by the Kuiper belt itself, he explains.

Another class of comets—notably Halley's, which last swung by the earth in 1986—penetrates the solar system from all regions of space. These comets may come from the Oort cloud, a spherical nebula of comets thought to have been catapulted out of the inner solar system billions of years ago. Theorists have estimated that the Oort cloud is 1,000 times farther from the sun than is the Kuiper belt.

Unlike the Kuiper belt, the Oort cloud remains far beyond the vision of astronomers—for now. "Every time we think we have hit a limit," Cochran notes, "we find a new technology that takes us even further." —*John Horgan*

Why So Blue?

HUBBLE SPACE TELESCOPE

Psychologists are not the only ones trying to figure out what's normal. In their efforts to understand the overall makeup of the universe, astronomers are trying to decipher a new image from the *Hubble Space Telescope* (*left*). The picture offers clinching evidence that bright, well-defined elliptical and spiral galaxies—objects such as those in our own Milky Way—are actually in the cosmic minority. Instead irregularly shaped, blue objects seem to predominate.

Rogier Windhorst of Arizona State University led the team that generated this view of the mysterious "faint-blue galaxies." Their hue indicates that these galaxies abound with young, hot stars; the irregular shapes suggest, in some cases, that the galaxies are very dynamic, colliding and interacting with one another. Windhorst's team finds that the faint-blue realms are most common at distances of three to eight billion light-years away, corresponding to a time when the universe was about one half its present age. These galaxies still contained infant stars and undefined structures long after their brighter cousins settled down into stable systems. Clearly, there is more than one pace of galactic evolution.

Even more puzzling, the faint-blue structures seem to have mostly vanished by the present. Did they self-destruct, or did they simply fade away? Observations from giant, ground-based telescopes, now under way, will help flesh out the life histories of the real "normal" galaxies. —*Corey S. Powell*

High Tension

Researchers debate EMF experiments on cells

In the nearly two decades since the link between exposure to low-frequency electromagnetic fields (EMFs) and childhood leukemia was first proposed, people have puzzled over whether this ubiquitous form of radiation could affect human health. Over the years scientists investigating the possibility have produced a vast body of literature and an intense debate, but no consensus has emerged. On one side are physicists who point out that effects of low-frequency fields from power lines, home electrical wiring and appliances should be negligible compared with the thermal energy in living tissue. On the other are epidemiologists who have found troubling statistical correlations and biologists who have occasionally observed changes in cells exposed to weak electromagnetic fields.

Straddling the divide, a group from the California Institute of Technology and Oregon State University recently proposed that the presence of tiny magnetic particles could explain how cells can be affected by such weak fields. But instead of being embraced for presenting an idea that might reconcile laboratory observations with sound physical theory, the team is receiving attacks from both sides.

The idea of Atsuko K. Kobayashi, Joseph L. Kirschvink and Michael H. Nesson, which appeared in correspondence to *Nature* this past March, challenges the efforts many biologists have taken to detect and quantify biological changes using cell cultures. Those experiments sometimes produced alarming results: weak, low-frequency electromagnetic fields seemed to cause alteration in the flow of calcium across cell membranes, in gene expression and in

RONALD WILLIAM MAY *Gamma Liaison*

POWER LINES and the electromagnetic fields they generate have been the subject of intense scrutiny because some believe they put human health at risk.

the growth rate of breast cancer cells.

Because cell cultures allow both field exposure and biological response to be quantified, these findings should have helped answer the questions surrounding low-frequency fields once and for all. Instead the many in vitro studies have themselves proved extremely controversial within the scientific community. In one case, changes in the expression of a proto-oncogene in human cells exposed to electromagnetic fields were reported, but two other groups found the result impossible to replicate.

Kobayashi and her colleagues offered a hypothesis that might help solve at least some of these riddles. For many years the workers had examined biologically generated magnetite. This mineral is a highly magnetic iron oxide and will quickly align itself to the ambient magnetic field. Rocks made of magnetite were used by the ancients to make compasses, and, curiously, tiny amounts of this substance can be found in the tissues of certain animals. The group's previous investigation of such "biogenic magnetite" helped to elucidate how some creatures can sense the earth's extremely weak magnetic field and use it to navigate.

In the course of their work with the vanishingly small quantities of magnetite found in animal tissues, Kobayashi and her co-workers developed a

FIELD NOTES

3 Rms, Ocean View

Sitting in about 20 meters of water off Key Largo, it's a Jules Verne fantasy come true. The big algae-covered tube, officially known as the Aquarius Undersea Laboratory and Habitat, is like an ungainly extension of the reef, surrounded by schools of grunts, chub and jacks. Literally, there's no place like this home: the main lock combines a kitchen, communications room and a bedroom. There's a little nook with a table, a big round porthole with a gorgeous blue ocean view.

The habitat is the centerpiece of the National Oceanic and Atmospheric Administration's efforts to study reefs, marine creatures and water quality in the economically important and heavily stressed sanctuary surrounding the Keys. Missions last 10 days, during which the aquanauts spend up to nine hours daily in the water at depths down to 29 meters. In the 29 missions completed since it was first deployed in St. Croix in 1988, the habitat has helped scientists study the feeding, growth and illnesses of corals; the behavior of fish that feed on plankton; and the relation between reef development and climatic change. "Aquarius gives scientists the gift of time," explains Sylvia A. Earle, ocean explorer, marine biologist and aquanaut, who has participated in seven such missions in earlier habitats. "Otherwise you're a stopwatch biologist: you zoom in and zoom out."

The small quarters sometimes make the researchers themselves want to zoom out. The six-person station is comfortable but cramped—like a camper with lots of electronics and gauges built into the walls. Three days into a 10-day stay, the four aquanauts inside the habitat when I visit seem to be in great spirits. I ask what they miss the most. "Sunlight and beer," says David B. Carlon of the University of New Hampshire without hesitation. "You can add my wife in there," he quickly puts in. Visible through the porthole, placing tiny coral recruit samples in chambers, is Peter J. Edmunds of California State University. Edmunds and company are studying certain stages in the early life of corals, such as how the current-borne juveniles of some species manage to anchor themselves to the sea bottom.

DAN BURTON

Compared with other government-sponsored research, programs such as Edmunds's are a bargain. The entire budget for Aquarius is $1 million this year. (In contrast, one space shuttle mission can cost anywhere from $600 million to $1 billion.) Nevertheless, for 12 of the past 13 years the Department of Commerce, following the presidential administration's lead, has tried to eliminate the allocation; only the intercession of Congress has kept Aquarius alive. "Hundreds of millions of dollars are being spent to look at the ocean from above, and hundreds of millions have been proposed for ships to look at the ocean from the surface," Earle says. "And the administration repeatedly has recommended zero funding [for the facility and similar undersea research] to look at the oceans from within."

Down in the habitat, such realities seem far away. Attracted by the light or the shiny glass, several huge barracuda swim slowly by the porthole as Carlon and I chat. "It's almost like an aquarium," Carlon notes. "But *you're* in the fishbowl." —*Glenn Zorpette*

keen appreciation that magnetic contaminants were common in the laboratory. They could even be traced to factory-fresh plastic flasks and test tubes, as well as to liquids used for cell culture. "We have found that none of these materials is free of ferromagnetic particulate contamination," they state plainly.

Common as they are, the contaminating particles are also tiny—smaller than can be seen with a light microscope—and cannot be easily perceived. Indeed, their detection and analysis require specialized equipment, such as a cryogenic magnetometer. Hence, it is perfectly reasonable that most biologists testing cells exposed to electromagnetic fields would not be aware of the potential for invisible magnetic grains to attach to the cells and mechanically disturb them as the particles oscillate in the applied fields.

The hypothesis proposed by Kobayashi and her colleagues is straightforward, but it is unclear whether magnetite as a contaminant does explain any of the reported disturbances to cells. Critics raise two arguments. Some, such as Jeffrey D. Saffer and Sarah J. Thurston of Pacific Northwest Laboratory, suggest that the very premise is wrong. According to their comments in a subsequent issue of *Nature,* "it is not necessary to invoke magnetite as an explanation for these effects, which in fact may not exist." Taking the opposite tack are those who firmly believe electromagnetic fields can directly cause biological changes. Richard A. Luben of the University of California at Riverside, for instance, calls magnetite contamination "a highly dubious hypothesis."

As unpopular as the new idea is, it has been embraced by at least one key administrator at the National Institute of Environmental Health Sciences, the body that funds much of the study in this area. Dan C. Van der Meer manages a $65-million effort to understand electromagnetic fields and human health, a program mandated by Congress in 1992. He says the institute has been supporting the work on magnetite and is encouraging these researchers to share their ideas with other scientists concerned with the influence of electromagnetic fields.

Still, tests needed to demonstrate the action of magnetite in specific cell culture experiments have not yet been presented, and until they are, many people will remain highly critical. But after so many years of heated debate, perhaps this reaction should be expected; as Van der Meer explains, "That's the nature of EMF research—it's been fractious from the get-go." *—David Schneider*

Giving Your All

ANDREW C. MASON

***MALE AUSTRALIAN REDBACK SPIDER* (tiny) *prepares to copulate with and be consumed by the female* (large).**

That female spiders of the species *Latrodectus mactans* sometimes eat the male after copulation has been known since the 1930s, causing them to be called black widows. But in the case of *L. hasselti,* otherwise known as the Australian Redback spider, the male is even more likely to be eaten—apparently because he asks for it. In 1992 Lyn M. Forster of the University of Otago in New Zealand observed that after the male inserts one of his two sexual organs (or emboli) into the female, he backflips onto her jaws. Copulation proceeds while she slowly masticates his abdomen and injects enzymes. At the end of a possible second copulation, the male is already half-digested, whereupon the female wraps him in silk and concludes her repast.

Ethologists have since wondered what end might be served by such an extreme antisurvival trait. The male spider has no more than 2 percent of the female's mass and so cannot offer much nutrition to his offspring; in the 35 percent of cases in which the female refuses to eat the male, she lays the same number and weight of eggs.

Maydianne C. B. Andrade of Cornell University now offers an explanation based on competition for paternity between two male spiders. A male can copulate for a longer time if he allows himself to be eaten, ensuring that more sperm is transferred. Also, if the female eats the male, she is more likely to reject a second suitor—and his sperm. Thus, cannibalized males father most of the female's offspring.

The situation is compounded by the short life of the male—two to four months after maturation, compared with up to two years for females, at least in the laboratory. Even if he escapes being eaten, the male is unlikely ever to find another female. The male Australian Redback spider is therefore compelled to put all his resources into the one chance he gets to reproduce. *—Madhusree Mukerjee*

A Pox on the Pox

New vaccine raises hopes and doubts

Earlier this year—nearly 40 years after the country learned that the first of two polio vaccines would end the epidemics that were crippling the nation—researchers reported that they could conquer another childhood scourge: chicken pox. But unlike the announcement that polio could be prevented, which was hailed as a medical triumph, news of the chicken pox vaccine was greeted with a dose of skepticism.

Pediatricians raised concerns about whether immunization was needed for what is typically a mild childhood disease. "I just don't think we need this vaccine, especially when complications from chicken pox are so infrequent and rare," notes pediatrician Thomas F. Long of San Ramon, Calif. Others fretted about whether the immunity conferred by the vaccine would last a lifetime—as does the immunity granted by infection in childhood. And still others pointed to the huge cost of immunizing all American children.

In past months the vaccine's proponents and its manufacturer, Merck & Co., have sought to address these concerns. Merck points to a study in Japan that indicates that immunity does not wane for at least 10 years. Merck is also sponsoring a study of 15,000 children to determine the extent of long-term immunity. Even if results show that immunity diminishes by adolescence, there is always the prospect of a booster shot. And although the vaccine, called Varivax, does not work in 10 to 30 percent of kids aged 13 and younger, data indicate that immunized children acquire a milder form of the disease.

JOHN CHIASSON *Gamma Liaison*

SHOTS of polio, diphtheria-tetanus-pertussis and measles-mumps-rubella are required for public school admission. The chicken pox vaccine may join the list.

Other reports suggest that widespread use of the vaccine would be cost-effective. "Chicken pox can be an expensive disease," says Tracy A. Lieu of the Permanente Medical Group in Oakland, Calif. "People forget that parents have to take time off from work, and some children with chicken pox are hospitalized." By looking at work-loss estimates and medical costs, Lieu figures that mass immunization would save $5 for every $1 it costs.

The mounting evidence regarding cost and effectiveness recently led the American Academy of Pediatrics to recommend routine use of the vaccine. The Centers for Disease Control and Prevention, in slightly less enthusiastic language, has called on physicians to make the vaccine part of the childhood immunization schedule. If adopted by state agencies, the $39 to $49 vaccine could be required for admission into public school, just as immunizations against polio,

diphtheria-tetanus-pertussis and measles-mumps-rubella are.

But studies and recommendations notwithstanding, some researchers still see a chicken pox vaccine as nothing short of a gamble. If use of the vaccine becomes widespread, they argue, the few children who invariably slip through all vaccination programs face the possibility of contracting a far worse form of the disease in adulthood.

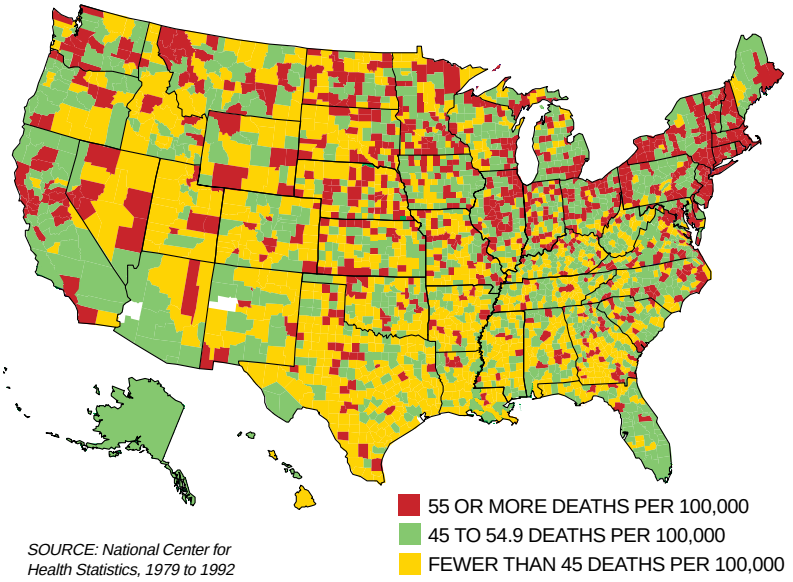
Currently, contracting chicken pox is a childhood rite of passage. In the vast majority of children the disease runs its course in about a week. The most common complication is infection from repeated scratching of one of the 300 or so little red marks. Of the approximately four million U.S. children who contract the disease every year, about 9,000 are hospitalized, and up to 100 die from complications. The disease is so ubiquitous that virtually all American adults are immune because of an infection when they were young.

But whereas chicken pox may provide only an uncomfortable holiday from school for children, it offers a sojourn into danger for adults. When the disease occurs in pregnant women during the first two trimesters, it can cause severe birth defects. In the last trimester, it may result in neonatal chicken pox, which kills as many as 30 percent of infected infants within a month of birth.

It is the severity of the disease in adults that gives rise to the remaining worry about the vaccine. "With fewer children actually contracting the disease in childhood because of the vaccine, the few unvaccinated kids may grow up with no immunity, because they will not have come into contact with the virus," explains Edward A. Mortimer, Jr., of the CDC. "If we don't implement this program in 100 percent of children, I can see the day when we may have a crop of adults with serious complications from chicken pox."

History demonstrates that even if immunization is mandatory, some children go unvaccinated. The CDC recently reported that although the number of cases of measles dropped to an all-time low of 948 in 1994, unvaccinated children compose 98 percent of those who became infected. "These are children whose parents have religious or philosophical objections to vaccines and who live in states that grant exceptions to the immunization rules," Mortimer notes. About 1 percent of all children, or nearly 550,000, are not immunized, according to the CDC. Children can avoid vaccinations in 17 states with a simple parental note claiming a philosophical objection; 48 states allow exemptions from vaccines on the basis of religious belief.

It is a point that even Thomas M. Vernon of Merck does not dispute. "From a public health perspective we have a very good record in immunizing children," he says. "The overwhelming majority of children receive all the vaccines currently mandated in immunization schedules. Does that mean that every single child is immunized? No, certainly there is a minority of children slipping through. And in the context of this vaccine all that means is that we will have to do a better job." —*John Carpi*



SOURCE: National Center for Health Statistics, 1979 to 1992

Deaths Caused by Breast Cancer, by County

Breast cancer is the most common cancer among American women, with about 180,000 new cases and 46,000 deaths annually. The ultimate cause, or causes, of the disease is unknown, but several risk factors have been identified. Women who are younger than 20 at the time they have their first child are less likely to get the disease than those who delay pregnancy until their thirties or those who never give birth at all. Women of high socioeconomic status are at greater risk than those of low status. Mormons tend to have low rates, whereas Jews tend to have high rates.

These three sets of risk factors contribute to the pattern on the map, which is based on age-adjusted data for white women ages 35 to 84. Areas with high breast cancer mortality are generally regions of low fertility with a high proportion of unmarried women older than 35, college graduates and people in professional jobs. These also tend to be places with an above-average concentration of Jews. The Southeast, one area of low breast cancer mortality, has a high teenage pregnancy rate and a considerably lower proportion of college graduates and professionals than the North. Mormons contribute to the low breast cancer mortality in Utah and parts of neighboring states.

One popular theory—that dietary fat promotes cancer—does not get support from the map. Consumption of fat in the Northeast is below the national average. Evidence for another theory—that alcohol use promotes breast cancer—is more or less consistent with the data: social pressures against drinking are much greater in the South than in other places. The controversial notion that environmental chemicals cause or promote cancer is also supported: the distribution of toxic-waste dump sites parallels fairly closely the sites of highest breast cancer mortality [see "Can Environmental Estrogens Cause Breast Cancer?" by Devra Lee Davis and H. Leon Bradlow, page 166].

Of the 50 most populous areas, Nassau County, outside New York City, averaged the highest breast cancer mortality rate for women—70 per 100,000 between 1979 and 1992—whereas Honolulu County had the lowest average rate—45 per 100,000. Counties of a million or more people had 58 deaths per 100,000 in that same period; counties of 100,000 to 999,999 averaged 54; those with a population of between 25,000 and 99,999 averaged 49; and those under 25,000 had 46. —*Rodger Doyle*

Endangered Again

Property-rights advocates and champions of biodiversity are gearing up for what could be a decisive political battle over the fate of the 1973 Endangered Species Act (ESA). The act, which provides legal protections for species that the secretary of the interior lists as endangered or threatened, is a lightning rod in what has become an argument over landowners' rights and habitat conservation. A concerted effort is expected this fall in Congress to remove some of the ESA's strongest provisions.

Ecologists generally support the law, which proponents say has stabilized populations of several hundred species. Both the bald eagle, which was recently delisted, and the peregrine falcon, which is scheduled for delisting, have been brought back from the brink of extinction because of protection afforded under the ESA. The Ecological Society of America has declared the legislation to be "a powerful and sensible way to protect biological diversity."

The National Research Council also gave the act a benediction when it reported this spring that it is "based on sound scientific principles" and "has prevented the extinction of some species and slowed the declines of others." Indeed, the research council specifically endorsed one of the act's most divisive provisions: its protection for distinct populations of animals that might belong to the same subspecies. That approach was justified, the council said, because the populations could be evolutionarily unique.

FRANS LANTING *Minden Pictures*

***PEREGRINE FALCON** is about to be taken off the list of endangered species.*

But these subpopulations may not be so special in the eyes of Representative Don E. Young of Alaska. The defenders of the ESA expect Young to introduce into the House an authorization bill that would defang it. The legislation would give the secretary of the interior the power to change the protections required for a listed species—thereby opening up what should be a science-based recovery plan to political vicissitudes. Earlier this year Senator Slade Gorton of Washington State introduced a bill that would work in a similar way.

The fuel for the political firestorm is the perceived threat to private-property rights that results from protecting the habitat of a listed species. In June the Supreme Court gave environmentalists a victory when it upheld federal authority to conserve critical habitats on privately held lands. That protection would be eliminated under the Gorton bill. The research council suggests that the federal government should have a right to make emergency designations of "survival habitat" to protect species in certain cases. But Capitol Hill observers say this idea will probably not go over well in the 104th Congress.

More likely to be successful, perhaps, are approaches advocated by the Keystone Center, a mediating organization that recently published a consensus report on incentives for private landowners to protect species. The center's approach is applauded by Gordon H. Orians of the University of Washington, president of the Ecological Society of America, who observes that environmentalists may have erred in the past by relying too much on command-and-control mechanisms for conservation.

The Keystone Center sees potential for reducing landowners' state tax burden in return for managing their lands in ways that benefit nature. For example, gifts of land containing habitats of an endangered species to conservation organizations could be encouraged by estate tax credits; landowners who entered into voluntary agreements to preserve species could be given income tax credits. Although such approaches reduce government revenues, they may allow protection of endangered species to move forward. —*Tim Beardsley*

A Tight Fit

Researchers pry open buckyballs in hopes of stuffing them

Ever since fullerenes were discovered in 1985, expectations have been high for these hollow, geodesic-dome-shaped molecules of pure carbon. Touted as possible conductors, superconductors, semiconductors, electrical insulators, drug delivery agents or environmental tracers, "buckyballs"—named after architect Buckminster Fuller—have captivated scientists.

Yet actually doing anything with them has proved difficult because of the inherent stability of the structures. The most tantalizing applications require modified fullerenes, particularly those with an atom or molecule inside. Workers have generally relied on brute force to fill buckyballs with a limited number of atoms. To expand the list, a gentler approach is needed.

In a recent paper in the *Journal of the American Chemical Society* entitled "There Is a Hole in My Bucky," researchers at the University of California at Santa Barbara announced that they can systematically produce an opened buckyball; another paper in *Science* will detail how they close it. The team has discovered how to make one of the 30 double bonds that interconnect the 60 carbon atoms in C_{60} more reactive than the other bonds. By attaching a nitrogen-methoxyethoxymethyl (or *N*-MEM) group to the cage, one nearby bond is weakened. A reactive type of oxygen known as singlet oxygen can then break this bond. The process takes about three hours, at room temperature.

To close the cage, researchers treat the buckyballs with acid, removing most of the *N*-MEM group. The nitrogen atom remains attached, however, and is incorporated into the fullerene structure, forming $C_{59}N$—what Fred Wudl, the leader of the group, calls the first example of a heterofullerene.

Being able to open and close buckyballs on command may point to new ways of getting chemicals in and out of the cage. Currently scientists rely on extreme measures to accomplish this task. Martin Saunders of Yale University explains that to force helium, for example, into a buckyball, his group raises the pressure of the gas to 3,000 atmospheres (the ambient pressure of air is usually one atmosphere) and heats the mixture to around 600 degrees Celsius (1,100 degrees Fahrenheit). In this state, a window forms in the cage, allowing helium to enter. But even under these conditions, less than 1 percent of the

buckyballs end up with anything inside them.

Despite the recent success in opening and closing the cage, a number of hurdles remain. "Contrary to early fantasies, the space inside the C_{60} molecule is rather small," Wudl notes. So no matter how well chemists guide the materials, they will be limited to inserting individual atoms or small molecules. Nevertheless, buckyballs with metal atoms inside may act as superconductors, and fullerenes that contain small radioactive elements can serve as tracers.

Richard E. Smalley of Rice University, who discovered fullerenes 10 years ago, explains that in addition to size limitations, chemical properties of various elements restrict what can be put inside buckyballs. The interior of the carbon cage prefers being negatively charged, so positively charged substances fit inside more naturally. Smalley envisions using this characteristic to load buckyballs: an opened fullerene mixed into a solution of positively charged ions may "insist that it gets filled."

All this work could benefit the growing field of "container" molecules, pioneered by Donald J. Cram of the University of California at Los Angeles. His group has designed some 200 of these compounds from scratch, controlling size, shape and reactivity. The containers can be tailored to fit a variety of possible applications. For instance, Cram has patented molecules that, by changing color when they take up sodium or potassium ions, signal the presence of those substances in blood or urine.

Cram sees fullerene research allowing scientists to gain similar control over buckyballs—essentially to use them "as a starting point for more complex structures." If his and others' predictions prove true, the recent hole in a bucky might well portend a wealth of new chemistry. *—Sasha Nemecek*

More Coral Trouble

Possibly because of their proximity to Miami's sprawl and to the northern limit of their habitat, corals in the Florida Keys have been afflicted for years with more than their share of maladies. Lately, though, an as yet unnamed disease has provoked more than the usual concern. "It's very new and very disturbing," says Esther C. Peters, a coral histologist and senior scientist at Tetra Tech, Inc., in Fairfax, Va.

The blight attacks one of the hardiest forms of coral, the elliptical star. "I've been observing these corals for 30 or 40 years and never saw one in the process of dying," says Eugene A. Shinn of the U.S. Geological Survey's Center for Coastal Geology in St. Petersburg, Fla. "Sometimes it's all you see living on a reef where all the other corals are dead." Although the extent and incidence of the disease are not known, a very quick survey on Conch Reef, one of the big reefs off Key Largo, showed that roughly 10 percent of the elliptical star corals were afflicted.

DAN BURTON

The new disease appears similar in some respects to the white band disease that devastated elkhorn and staghorn corals in parts of the western Atlantic, the Keys and the Caribbean from the late 1970s until the mid-1980s. As with that malady, tissue cells begin dying near the base of the corals. Soon the tissue itself

These Feet Were Made for Walking—and?

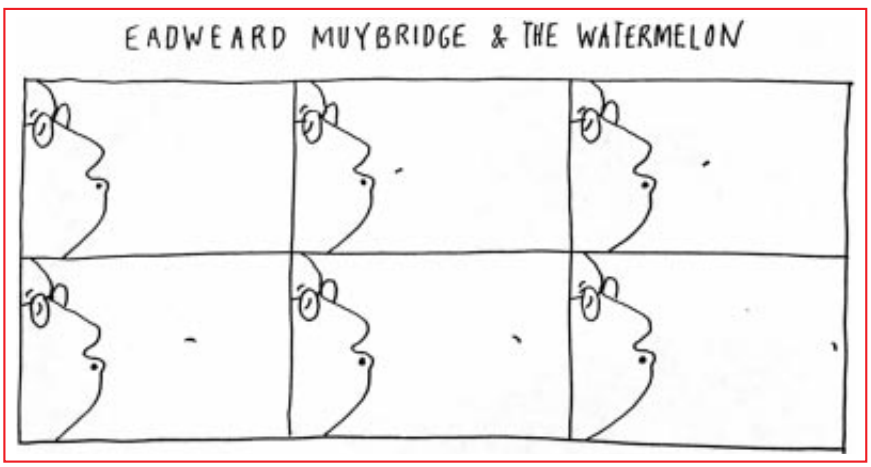
A new set of fossils may put hominids in the trees again

Sometime during the past few million years, our many great-grandparents came down from the trees and started to walk on the ground. Although there is no consensus about when exactly the switch happened, a recent scientific report about four well-preserved foot bones found in Sterkfontein Cave near Johannesburg has rekindled the long-standing dispute.

The report, published in *Science* by Ronald J. Clarke and Philip V. Tobias of the University of Witwatersrand, concludes that the owner of the bones—an australopithecine possessed of a humanlike heel and able to walk on two legs—had a big toe that diverged from the other toes, somewhat as a thumb diverges from the fingers. The reconstructed foot, dubbed "Littlefoot" and estimated to be about 3.5 million years old, looks like a chimpanzee's, the authors suggest, and so was probably used to help climb trees. Other foot bones from that time have been described in the literature before, but Littlefoot's bones are unusual in that they fit together exactly.

Yet even this perfect fit has not brought consensus. Clarke and Tobias's interpretation of Littlefoot is a kick in the shins for C. Owen Lovejoy of Kent State University and his associates, whose detailed studies of how australopithecines moved indicate that these early hominids were fully committed to walking. "It's wrong morphologically and in terms of the total anatomical complex," Lovejoy states of Clarke and Tobias's report.

The paper's details show, Lovejoy argues, that the creature in question could not have grasped with its big toe and that any splaying was a useless holdover from earlier times. Littlefoot's bones are, he says, "very similar if not identical" to other well-studied australopithecine remains. A set of preserved footprints 3.7 million years old indicate that some hominid creature at the



MICHAEL CRAWFORD

sloughs off, exposing the white calcium carbonate skeleton. The line between the exposed structure and the living tissue is quite sharp and moves upward over a period of days or weeks. If enough tissue is lost, the coral dies. Deborah L. Santavy of the U.S. Environmental Protection Agency says it is possible that the latest ailment may be bacterial in origin—as is believed to be the case with white band disease. A more conclusive diagnosis awaits testing of the first samples.

In addition to having yet another scourge on coral, researchers are troubled by the possibility that the new disease could begin affecting pillar corals. These spectacular corals, which are in the same family as the elliptical stars, are an important attraction for the recreational scuba divers who contribute significantly to southern Florida's estimated $1-billion-a-year tourist industry. Widespread losses "would be a real problem for the Keys," notes Steven L. Miller of the University of North Carolina's National Undersea Research Center in Key Largo. *—Glenn Zorpette*

time was walking with a humanlike gait.

Randall L. Susman of the State University of New York at Stony Brook counters that it stands to reason that "if they didn't climb trees they wouldn't have tree-climbing bones." Susman, who studies the behavior and functioning of living apes, believes australopithecines from this era walked on the ground but would on occasion climb trees using curved toes to grip the trunks.

Sitting on the fence somewhere between Susman and Lovejoy is Donald C. Johanson of the Institute of Human Origins in Berkeley, Calif. Johanson has reservations about whether Clarke and Tobias's find is as old as they suppose—the South African authors were forced to rely for their estimate on detailed comparisons of other bones found in the cave with bones from elsewhere in Africa. Johanson is likewise "not terribly convinced there is strong evidence of a highly diverged big toe." On the other foot, Johanson says he is "not opposed to the view that these creatures would have from time to time climbed in trees."

As the differing views are at least in part the result of different philosophical approaches, it is far from clear when the question can be settled. Several other early fossil hominids are now being studied by various researchers, but the word on the paleontology grapevine is that the confusion is likely to get worse before it gets better. The debate over whether the earliest hominids climbed trees rarely, sometimes or often promises to run on. *—Tim Beardsley*

THE ANALYTICAL ECONOMIST

Are Band-Aids Enough for Third World Debt?

Since the early 1980s, debt has stalked the international financial system—sometimes a specter on the horizon, other times Godzilla pounding on the door. Developing nations owe roughly $2 trillion to the developed world, and the prospects for paying all of it back are slim. Although the developing world as a whole is only about $35 billion behind in its interest payments, arrears on principal have grown to more than $90 billion, as seen in the latest World Bank figures.

When a bank lends money to a person or a company, and the debtor falls behind on payments, the bank can seize assets and sell them to compel repayment. Banks lending to nations, in contrast, have no such recourse. On the positive side, however, countries do not generally die or go out of business, so hope is almost never entirely lost.

The crucial issue now, according to Eduardo Fernandez-Arias of the Inter-American Development Bank, is not so much debt as debt service: the interest charges that a country must pay to keep its creditors happy. Most loans to developing countries have floating rates, adjusted every three months to reflect the changing price of money on the international market. A nation whose contract specifies the London interbank offered rate (LIBOR) plus 1 percent, for example, would have been paying about 7.5 percent in August. If world interest rates rise sharply, a nation's obligations can quickly exceed its means.

The solution for such shortfalls, paradoxically, is usually more loans—"rescheduling" agreements that advance a country additional money so that it can pay off old loans. The process is not just a shell game, Fernandez-Arias explains; new debt often carries fixed interest rates so countries can plan their economic development better. Such agreements shift the risk that interest rates will rise from the developing country to the lender, but both sides consider that preferable to default, which would force lenders to write off the original loan and would shut borrowers out of the market for future funds. Some rescheduling also involves below-market interest rates—as low as 2 or 3 percent.

To ensure that such largess is not just throwing good money after bad, rescheduling and other debt reductions may also have strings attached. "Structural adjustment loans" from the World Bank, for instance, require qualifying countries to reduce tariffs on imported goods and eliminate subsidies. Such adjustments have been blamed for a great deal of hardship and environmental damage. In Malawi the Overseas Development Institute reported that currency devaluation and agricultural "reforms" led to greater production of environmentally questionable cash crops such as tobacco, cotton and hybrid maize.

Advocates of structural adjustment point to the fact that the debt crisis has eased in recent years, at least in Latin America. Fernandez-Arias, however, says that according to his numbers, lower interest rates rather than economic efficiency explain almost all the improvement in developing countries' financial conditions. Revamping an economy under crisis conditions is "very inefficient," he declares.

In addition to reducing debt-service burdens, the near halving of rates since the mid-1980s has attracted investors by increasing their confidence in developing economies. A country that does not have to struggle with debt service can pay more attention to internal economic stability. On the other hand, even the slight rise in rates during 1994 was sufficient to trigger last winter's peso collapse and the bailout of Mexico.

If reductions in debt service rather than economic development have produced the relative calm of the past few years, could another upturn in worldwide interest rates lead to a global storm like that of the early 1980s? Maybe not. Many nations have managed to reduce their ratio of variable-rate debt to income, and fewer are borrowing to meet day-to-day needs. Investors also have become more cautious: much of the capital that has been flowing into developing countries in the past few years has been in the form of loans to private businesses, which do not have sovereign immunity, or direct investments in manufacturing plants. Such obligations are much more difficult to wipe out with a stroke of a finance minister's pen.

With luck, the resiliency of these new arrangements will not be put to the test any time soon. As long as world interest rates stay low, debtor nations have more breathing space than they did—and especially the world's largest debtor, the U.S. —*Paul Wallich*

Slash and Burn

Technology, energy and the environment head for the guillotine

With scarcely a murmur of protest from industry or the science and technology establishment, congressional budget axes are chopping into applied research funding with fervor. During the summer, deficit hawks secured approval in the House of Representatives for large cuts in scores of federal programs. Civilian technology development and all forms of environmental research fared particularly badly, with energy-related efforts not far behind. Finally, a congressional campaign to abolish the Department of Commerce stirred President Bill Clinton to threaten a veto.

The Republican majority is using a novel strategy to eliminate these programs—one that obviates debate. Usually, congressional authorizing committees determine the overall scope of programs; appropriations committees then determine exact funding. But the new majority is going straight to appropriations, eliminating or reshaping items by cutting their budgets. As a result, authorizing committees are becoming "practically a nonentity," comments Representative George E. Brown, Jr., of California, ranking minority member of the House Committee on Science: "It will come back to haunt us all before very long. We've had policy decisions with inadequate or no hearings, and they are going to be flawed."

One principal target is the National Institute of Standards and Technology, which used to be dedicated to physical standards and measures. Under Clinton, NIST's technology development role expanded, but many Republicans now see the institute's agenda as a form of corporate welfare. In July the House approved a 1996 budget that would eliminate the Advanced Technology Program—NIST's flagship initiative for which the administration had requested $491 million—and held at $81 million the Manufacturing Extension Partnership, for which the White House had sought $146 million.

Representative Robert S. Walker of Pennsylvania, chairman of the science committee, has long criticized the ATP. He points to a General Accounting Office report concluding that although participants in the program were happy to receive funds, 14 out of a sample of 26 said they would probably or definitely have pursued the technology research regardless. NIST counters that the accounting office did not look at all available evidence and that these collaborations take time to bear fruit.

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

DIAMOND TOOL MANUFACTURING programs at the National Institute of Standards and Technology may be cut.

Brown, a longtime science supporter, notes that the cutbacks in civilian technology are not being balanced by cuts in military development budgets. The House has voted to award defense projects a $1.4-billion increase over the past financial year, whereas it gave civilian research a $1.7-billion cut. "You could take half the increase in defense programs and put the money into civilian programs and have them all be stable or increasing," Brown states. And he slyly points out that although many of the anticipated cuts are explained by Republican philosophical opposition to subsidies, some projects favored by Walker—notably, hydrogen fuel development, reusable space launch vehicles and supersonic flight—are slated for substantial increases.

So far business has made only lukewarm efforts to fight for the technology programs, because most of its muscle has been directed at other big-ticket items: securing regulatory and tort law reform, and the never-ending campaign for a permanent research and development tax credit. The Coalition for Technology Partnerships—a lobbying group created to support the threatened items—has written to lawmakers that the Advanced Technology Program and a separate defense conversion program are "essential, cost-effective and timely." Yet congressional aides say the effort is half-hearted.

For their part, universities and scientific societies have been busy with diplomatic efforts on behalf of basic science. By maintaining a bipartisan stance, they have safeguarded the budgets of the National Science Foundation, the National Institutes of Health and research at the Defense Department.

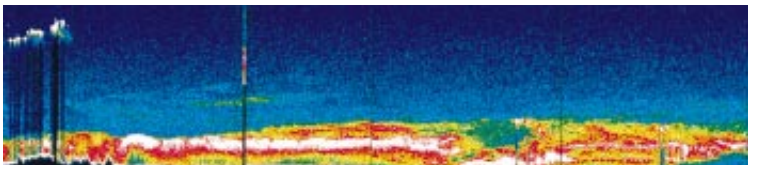
But other areas of research may soon go the way of technology as well. The Environmental Protection Agency stands to lose a third of its budget, including an initiative that supports commercial development of environmentally friendly technology, a new laboratory and all its research on global climatic change. The Partnership for a New Generation of Vehicles, which aims to develop energy-efficient cars in collaboration with the Big Three automobile manufacturers, might also be ended. The National Oceanic and Atmospheric Administration faces a 20 percent cut, and the National Aeronautics and Space Administration may lose 25 percent of its budget for Mission to Planet Earth, the government's major long-term environmental data-gathering effort.

In the end, budgets may prove to be only the first point of attack. A House plan to dismantle the Commerce Department would attempt to sell off parts of NIST and NOAA to the private sector—including 11 laboratories that perform basic environmental research—and relocate other parts, such as the National Weather Service. "We don't think that's remotely realistic," maintains one NOAA spokesperson. Some longtime observers of the Washington science scene doubt that a parallel initiative can prevail in the Senate, where policy making moves at a more measured pace. Nevertheless, omens point to a winter of discontent. —*Tim Beardsley*

An Acid Test

Sulfates are notorious for causing acidification and dense, yellow smog. Nowhere are they more keenly noticed than in Europe, where fish stocks continue to decline and tree bark to dissolve because of acid rain—even though sulfur emissions there have dropped about 30 percent since 1980. The lack of results has frustrated European scientists, who were powerless then to explain why stringent cleanup efforts failed.

Newly released images of pollution patterns may help. A novel application of Lidar—an imaging system like radar that reads echoes of laser light instead of radio waves—reveals an enormous sulfate plume stretching from the eastern American seaboard all the way to Europe. The finding shatters a long-standing theory that sulfur compounds produced in the U.S. rained down before crossing the Atlantic Ocean. "Material generated in one place is not confined to that place," says Lamont C. Poole of the National Aeronautics and Space Administration. "This has been speculated in the past, but this is the first time it has been confirmed in a quantitative sense."



AEROSOL HAZE of various intensities **(white, yellow, red)** ***stretches from Washington, D.C.*** **(far left),** ***1,500 miles out over the Atlantic*** **(far right).**

ATMOSPHERIC ENVIRONMENT SERVICE/NASA LANGLEY RESEARCH CENTER

For their part, scientists on the other side of the ocean are pleased with the explanation. There are certain parts of Europe "where acceptable levels of acidity were exceeded without *any* European contribution," notes Henning Wuester of the United Nations Economic Commission for Europe. Members of the commission signed a protocol last year to reduce sulfur emissions further; the U.S. participated in negotiations but did not sign.

Until Lidar was used last fall on board the space shuttle *Discovery,* scientists had only speculative computer models to trace the movement of the tiny sulfur compounds, often called sulfate aerosols. Lidar has tracked the Antarctic ozone hole—and a slightly modified Lidar could permit monitoring of global ozone levels. Lidar could soon open up a whole new era of remote sensing from space.

—Brenda DeKoker

Writing on the Fringe

Interfering electrons could lead to atomic data storage

Hard drives may one day take an atomic twist. Using ultrabrief laser pulses, physicists have demonstrated an ability to manipulate the position of an electron in an atom. Through such control, they expect to craft a kind of atomic video screen, with letters written directly on an atom.

The particular feat that Michael W. Noel and Carlos R. Stroud of the University of Rochester accomplished was the interference of an electron with itself. In physics, interference is typically demonstrated by passing a laser beam through two slits. The light waves emanating from each slit interfere, producing characteristic fringes of alternating light and dark bands on a viewing screen. The light areas correspond to the waves reinforcing each other (when the peaks of the waves line up); dark bands result when the waves cancel each other out (peak meets trough).

Electrons, too, can interfere: in quantum mechanics, particles can act like waves, and vice versa. But rather than have two separate electrons clash, Noel and Stroud coaxed one electron to get in the way of itself. They fired pulses lasting trillionths of a second to excite a potassium atom, turning the outermost electron into a "wave packet"—a bell-shaped envelope that denotes the general whereabouts of the electron.

Created near the core of the atom, the packet then performed a decidedly unquantum act: it began to orbit the nucleus in a way similar to planets revolving around the sun. At the furthest part of its orbit, the packet was about half a micron away from the core (typically, electrons are 1,000 times closer).

Once the wave packet reached its apogee, the workers fired another laser pulse, which formed a second wave packet near the core of the atom. In other words, the two laser pulses excited a single electron so that it had a probability of being located at two different places in one orbit.

Over time, these wave packets spread out as they orbited and interfered with each other. The workers fired a third laser pulse to detect the intensity peaks and dips on the orbit that correspond to interference fringes. Noel and Stroud found they could change the spacing of the fringes by adjusting the delay between the first two laser pulses.

Such fun with lasers may lead to the manipulation of chemical reactions and to new kinds of lasers, notes William E. Cooke of the College of William and Mary, who conducts similar experiments. It may also yield a better understanding of the foundations of quantum mechanics: because one electron is in two places at once, it is effectively an experimental realization of the famous Schrödinger's cat experiment, in which a feline that may have been poisoned is supposed to be alive and dead simultaneously. The cat remains in this odd state until an observation is made.

But there is also another possibility: data storage. "Generally, there's a great deal of information capacity in the atom," Stroud asserts. "We can arrange the electron probability distribution to suit ourselves." Data would be encoded in the electron's wave function, a mathematical equation that contains all there is to know about a particle. The number of bits stored would depend on the energy level to which an electron is excited, so in theory it can be unlimited, Cooke notes. For the moment, Noel and Stroud are aiming for 900 pixels to spell "optics" on an atom, representing the hue of the picture in terms of the phase of the wave function and the saturation as the amplitude.

Several problems plague this approach, perhaps more than those proposed in other quantum computing schemes [see "Quantum-Mechanical Computers," by Seth Lloyd, on page 140]. It is not clear how to create logic functions with electron distributions, and highly excited atoms are extremely fragile, Stroud cautions.

Most vexing of all, however, may be reading back the bits. Quantum mechanics dictates that a measurement will upset the delicate state of the atom and thereby destroy the encoded information. Any atom-based data storage may therefore be limited to write-once, read-once schemes or require clever measurement techniques, Noel remarks. "We're just at the beginning of finding out what we can do." *—Philip Yam*

SCALA/ART RESOURCE

PERSPECTIVE, seen in Leonardo da Vinci's* The Annunciation, *was introduced in the Renaissance and reflected a new worldview. Designers of cyberspace are confronted with a new world as well, and they too may radically shift our way of perceiving.

There's No Place Like Cyberspace

New worlds require new ideas, not old metaphors

Since William Gibson first coined the word "cyberspace," computer scientists have been trying to create the worlds he described: "a consensual hallucination—lines of light ranged in the nonspace of the mind, clusters and constellations of data. Like city lights, receding." The lure of a world with familiar landmarks but with the freedom and excitement only computers can bring seems irresistible. It may also be unobtainable: navigating a world of information is very different from navigating more familiar geographies. Just how different, researchers are slowly coming to realize.

For much of the past decade, the problems of creating cyberspace have been less absorbing to many scientists than those of coming up with virtual realities—that is, of pushing enough pixels about the screen to render realistic images. The challenges of making sense of vast quantities of information, however, run far deeper than simply achieving pretty pictures. A recent competition, sponsored by Britain's Design Council, to create a new version of the Houses of Parliament illustrates some of the concerns.

The winner of the competition proposed a virtual parliament. The judges were won over by the design student's argument that whatever its architectural merits, the existing Victorian Gothic building was in many ways a hindrance to the actual process of government. In the real building, the debating chamber overflows with members of Parliament on important debates, and there is only a tiny space for the public; in a virtual world the chamber could expand to include all who were interested. In theory, the builders of a virtual parliament could make available information now languishing in locked filing cabinets in musty offices at the end of inaccessible corridors. The question is how.

No doubt a virtual parliament could set information free. But reaching that information by taking a virtual walk down a long virtual corridor, to reach a virtually musty office filled with virtual filing cabinets—as some designers actually propose—would be an anticlimax. Alive though they are to the theoretical possibilities, neither design students nor computer scientists are bursting with ideas about how to make Gibson-style virtual worlds anything more than a gimmick. THOMAS, the program that is the virtual countenance of the U.S. Congress, presents a face that looks a lot more like a card from a library catalogue than any three-dimensional reality. Whatever its virtues for information retrieval, a catalogue card is not a place where debates can take place.

The heart of the dilemma is that the familiarity of the real world is inextricably intertwined with its limitations. Reassuring though it may be to navigate in terms of up, down, left and right, these concepts are at best arbitrary inside a computer—and sometimes downright misleading. As graphics improve, people's attention is inevitably shifting from pixel pushing to the harder problems of making worlds that seem natural and intuitive, although they convey information that has nothing to do with nature or intuition.

Even when the data in question relate to geography—or architecture, for that matter—creating cyberspace can be difficult. Researchers at Art+Com in Germany are trying to implement an idea that has been around for a long time. To make more accessible all the various information gathered by systems that monitor the earth—from infrared-imaging satellites to closed-circuit televisions in shopping malls—the program allows a user to fly around the world, zooming in on whatever view whets the curiosity. Although this ability sounds like a lot of fun, it also leaves many questions unanswered. Some requests don't fit into the metaphor—for example, how to move through time as well as space. Others fit it perfectly well—say, how to find a building in street-signless Tokyo.

So as they move into the realm of computerized information, researchers inevitably find themselves drawn away from virtual realism into the abstract symbols of which such worlds are more naturally constructed. Ben A. Shneiderman of the University of Maryland has created a system to help people shop for houses. Instead of whooshing down virtual suburban streets, he uses a fairly simple map. Many of the important dimensions of finding a house have nothing to do with geography—like price, number of bedrooms, style and so on. Shneiderman brought these dimensions into the abstraction of the map by creating controls that would let the user adjust the view to determine which houses would appear—three-bedroom, two-garage bungalows costing less than $100,000, or whatever.

At Xerox's Palo Alto Research Center, Stuart Card is working to make even the most abstract representation on a screen more comprehensible. Part of that task concerns things like timing, the constraints of which make events of the screen appear natural or not. Delay less than a tenth of a second, and most people will begin to lose a sense of sequence between two events. Delay much more than a tenth of a second, and motion appears downright jerky. Delay for more than a second, and most people get nervous waiting for something to happen (in conversation, a second's pause will usually elicit "uh-huh" or some other encouragement from the other half of the dialogue).

But Card's larger challenge is creating

A Tiny Gutenberg

More than 30 years ago researchers trying to create minuscule patterns on the surface of silicon wafers and other electronic substrates turned to photolithography. They exposed a "resist"—a photosensitive polymer—to light through a mask containing the pattern they wanted to transfer. They then used solvents to etch away unwanted material. Each layer in the final circuit may require as many as half a dozen steps of coating, exposure and etching.

Chemists at Harvard University are now performing the same operations more simply, with a subminiature printing press that works much as did those that displaced monastic scribes. Furthermore, Rebecca J. Jackman, James L. Wilbur and George M. Whitesides point out that the process works as well on curved surfaces (such as optical fibers) as it does on flat ones—a feat that has been almost impossible for photolithographers to accomplish because of the difficulty of focusing light rays passing through a mask at multiple distances simultaneously.

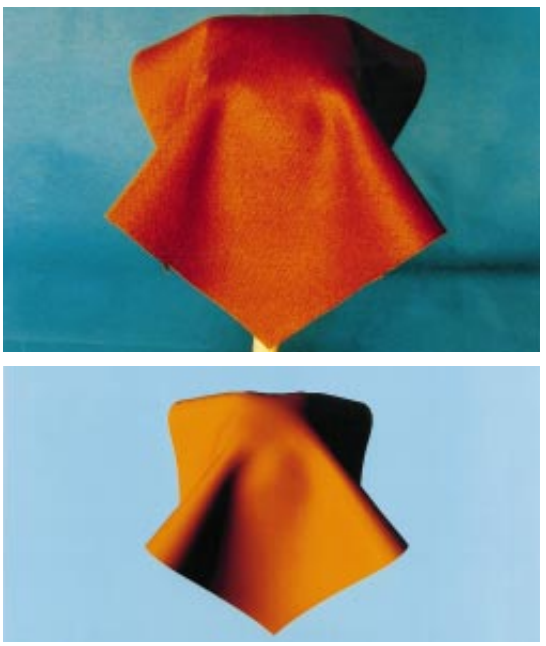
The "ink" is an alkanethiol, a sulfur-doped hydrocarbon, that spontaneously forms a monomolecular layer on the surface of a gold substrate. A flexible polymer printing plate (made by casting in a photoetched mold) transfers the material to anything that can be coated with a thin layer of gold. Once a pattern has been transferred, the monolayer can perform essentially the same function as a conventional photoresist, protecting the material underneath it from being etched away. Jackman, Wilbur and Whitesides have made patterns as small as a millionth of a meter with a simple handpress consisting of an etched polymer slab and a top plate to roll objects across it.

A great deal of work remains to be done to mechanize the microprinting process and integrate it with more conventional manufacturing methods, but it could make possible a range of new microelectronic devices by freeing designers from dependence on flat surfaces. It could also improve optics by imprinting complex diffraction gratings on the curved surface of lenses. *—Paul Wallich*

a sense of perspective on a computer screen—in the broadest sense of the word. Today's windows are incoherent. Each shows a small slice of a different view or program, with no sense of how (or if) one relates to the other. Nor do most programs give any sense of what is beyond the edges of the window. Some tricks used in establishing that perspective involve illusions of space. Card's "Table Lens," for example, makes part of a table or spreadsheet seem to zoom toward the viewer while the rest of the figures recede into partial legibility in the background.

What seems most to be missing is perspective in the larger sense of the word: a view that makes apparent the sweep of the issue at hand. The challenge for designers and computer scientists to come is to make squiggles on the screen that correspond to new ideas in the mind. Although nuclear physics and literature certainly offer a sense of perspective, it is unlikely to correspond to any of the perspectives once used by painters of trompe l'oeil and now borrowed by would-be creators of cyberspace.

No matter how much technology advances, hard problems will always require more than flying through columns of light. True, good representations can make hard problems easier to solve—just as spacetime diagrams helped physicists envision space and time together. But for abstract, symbolic thought, those representations are at least as likely to come in symbols or diagrams, incomprehensible to the uninitiated, as in a familiar landscape-based form. Indeed, probably more so: if the quandary can be solved with familiar ideas, there is no need to invent other ones or new symbols to represent them. And if the old symbols are borrowed to represent new ideas, confusion is likely to result. If there is a "nonspace of the mind," it must look like no space we have ever seen—if it is seeable at all. *—John Browning*



MUTHU GOVINDARAJ

Soft Wear

If a new dress or suit seems to look better on a hanger than on your body, it's not just because clothes are often designed for the sales rack. Predicting how fabric will drape over even a simple figure is genuinely hard: warp stretches one way, weft another; some threads tighten their twists of fibers while others loosen.

The job may now become easier—and the day when designers can create their latest chic entirely on a computer may arrive sooner—thanks to software developed by Bijian Chen and Muthu Govindaraj of Cornell University. The two textile engineers have hit on a modeling method that, provided with simple data on a fabric's stretchiness, weave and heft, seems to predict with reasonable speed and accuracy how a cloth will fall and fold over a shape.

Although the researchers developed the program on Cornell's IBM supercomputer, they claim it runs just fine on more affordable workstations. Don't run out to get your body shape scanned, however—unless you are very fat or very thin. So far the model has been tested only on spheres and tables. *—W. Wayt Gibbs*

DRAPE OF FABRIC over a table* (top) *was accurately predicted* (bottom) *by researchers using a computer-modeling technique.

PROFILE: GEORGE F. R. ELLIS

Thinking Globally, Acting Universally

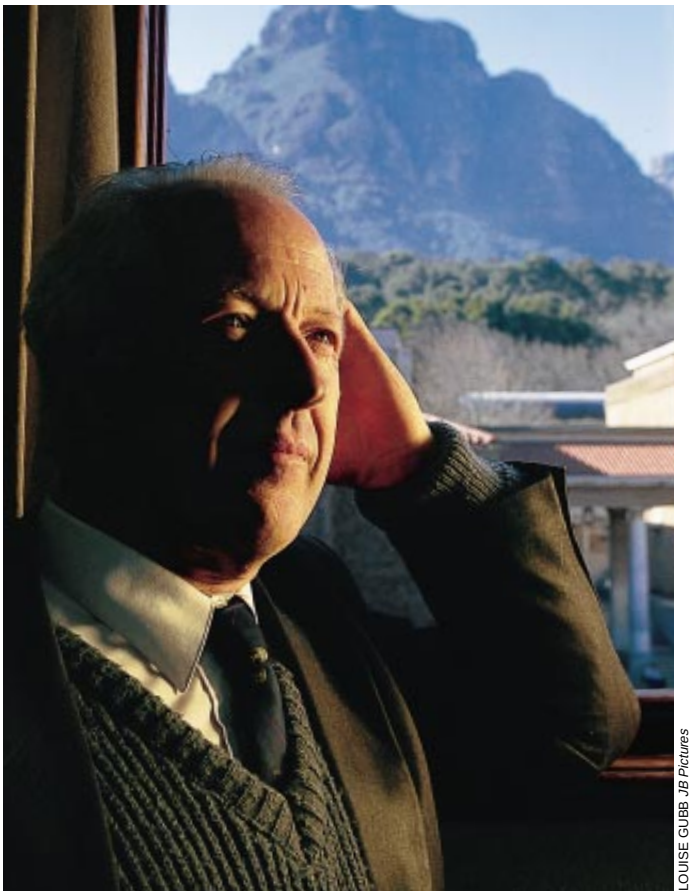
For as long as humans have lain on their backs and stared into the speckled depths of space, they have postulated theories to explain the mysterious patterns we see out there. Cosmologists tend to be better at picking the right theories from the fanciful ones. But few have applied that talent to the less celestial spheres of human activity as consistently and effectively as George F. R. Ellis, whose unusual ethical philosophy has driven him to supplement his theoretical work in South Africa with parallel careers as a Quaker philanthropist, antiapartheid activist and policy guru.

A heavy streak of altruism has probably run in Ellis since childhood. Growing up in Johannesburg, he took his moral instruction from a father whose antigovernment articles got him fired as editor of the city's chief liberal newspaper and a mother who helped to found the Black Sash, an organization of white women voters that aggressively fought apartheid for 40 years.

The ethic of community service had evidently taken root by the time he left the University of Cape Town (U.C.T.) for graduate study at the University of Cambridge. As he honed his theoretical skills with some of the giants in the field—attending relativity lectures by Fred Hoyle and working with fellow student Stephen W. Hawking on new mathematical techniques invented by Roger Penrose—Ellis explored his moral side as well. He took many theology courses and spent his spare time restoring cottages and churches in England, Austria and Holland. Observing that "whenever there was poverty, prisons or peacemaking, you'd find Quakers," he abandoned the Anglican Church for the Society of Friends. The influence was profound: the Quaker tenets of confronting injustice through rational dialogue and advocating tolerance for those with different beliefs would emerge as patterns throughout Ellis's career.

Life in Cambridge, Ellis says, "was pleasant but too parochial." With his first marriage souring, Ellis decided to return to South Africa. U.C.T. had invited him to head the department of applied mathematics, which would allow him to cast his intellectual net much more widely than just relativity and gravitation theory, into such areas as biology. Then there was apartheid: "I wanted to see if I could make a bit of a difference," he says.

Soon Ellis was presenting slides he had taken of children starving in the Ciskei homeland to groups at churches, universities and community centers. The money he helped to raise established an orphanage and a milk distribution program. As a member and later chairman of the Quaker Service Fund, Ellis supported development projects initiated by Stephen Biko, the black organizer whose murder by police a few years later would make him a symbol of the struggle against apartheid. Efforts to alert the public about the squalid conditions of the squatter camps that were quickly growing around Cape Town led Ellis to co-author a volume that criticized the government's futile, and increasingly violent, attempts to remove the squatters. Ellis proposed site and service schemes to meet the most basic housing needs of all low-income people. "The housing minister at the time rejected the suggestions out of hand," Ellis says. "But about five years later they basically became public policy."



LOUISE GUBB *JB Pictures*

SOUTH AFRICAN COSMOLOGIST George F. R. Ellis proposes a natural law of morality—and lives by it.

In the interim, Ellis pursued the strategy of marshaling information as a weapon against violence. "The government was trying to hide what was happening," he recalls. "It's a bit like Germans after World War II who said they never knew about the death camps and so on. Our philosophy was that people in South Africa would never be able to say they didn't know. So the South African Institute of Race Relations [of which Ellis was regional director] put out reports on deaths in detention, forced removals and other injustices."

As the violence escalated in the late 1980s, however, the job of observing became harder to bear. "At one point, the police organized a group of black vigilantes to attack a squatter settlement," Ellis says. "They systematically burnt down a couple of thousand houses every day, so that over the course of two weeks they made 70,000 black people homeless. And every day I would look out from my office window and see the smoke going up from that. We tried all sorts of things: getting mediators, calling the police, calling cabinet ministers. But the police were acting in collusion with these attackers, providing them with transport and weapons. So there was absolutely nothing we could do about it. And I kind of despaired at that point."

In 1988 Ellis left South Africa for the International School of Advanced Studies in Trieste. He threw himself into his theoretical work, visiting Queen Mary College in London and the University

of Texas at Austin and serving as president of the International Society of General Relativity and Gravitation and publishing numerous papers on the evolution and density of the universe.

But contributing only to science apparently failed to satisfy his sense of duty. By 1990 Ellis was back at U.C.T. and had redoubled his efforts to expose a conspiracy by forces intent on scuttling peace efforts. "We had an historic speech by [South African President] de Klerk when he released Nelson Mandela [leader of the African National Congress]," Ellis recounts. "The ANC was unbanned, and the government was supposed to be negotiating. The kind of undeclared war which it had been waging was supposed to be coming to an end. Yet we then saw a rising wave of violence with no real explanation. The government called it 'black on black' violence and essentially said that this is just the way blacks are. But the people on the ground who were seeing what was happening became more and more convinced it was being fomented" by a "Third Force" composed of parts of the military, police and security forces and sanctioned at the highest levels.

Ellis began collecting evidence and publishing it in letters to the local newspapers. But then "the national director of the Institute for Race Relations started putting out statements saying that there was no evidence of any Third Force activity," Ellis recalls. "I felt I had to do something about this, because as far as I could see, it simply wasn't true."

In a series of articles, Ellis argued that "a strictly judicial style of inquiry is very limited in its…ability to attain an understanding of what is happening when a dirty-tricks campaign is in operation, with evidence being 'lost' or destroyed and high-ranking officers committing perjury at judicial inquiries…. A broad-ranging causal analysis…based on a scientific approach of hypothesis testing is far more useful and…reliable."

So, quasiscientifically, Ellis laid out the evidence. He showed that his hypothesis was both more likely than the alternatives and consistent with the South African military's history of waging illegal, covert wars in Angola and Mozambique. Based on the observed pattern—an act of terrorism each time negotiations moved forward, steadily increasing in brutality—he predicted how the violence would continue.

It was a theory most whites did not want to hear. "A lot of my peers thought that I was going way out on the edge," Ellis says. "What was happening was so horrific it was mind-boggling: gangs with guns were getting on the black commuter trains to Johannesburg and killing people. And they organized it so that at the next station there would be people waiting on the platform with guns so that those who jumped off the train would be shot down as they tried to run away. People found it hard to believe this could be planned by the military." In the past year, confessions and testimony from the trial of a high-level military officer have confirmed that Ellis was more or less right all along.

Clifford Moran, dean of science at U.C.T., observes that the same distinctive talent that enabled Ellis to persuade people of Third Force activity now makes him "the leading thinker in science policy formulation in this country." Ellis, Moran says, "has the amazing ability to absorb an enormous amount of knowledge from across a wide field of endeavors and put it all together in some sort of synthetic framework."

"The foundational line of true ethical behavior…is the degree of freedom from self-centeredness."

As president of the Royal Society of South Africa, Ellis last year drafted a 300-page discussion document that serves as just such a foundation for the future of research in the rapidly changing country. He suggested four major guidelines for prioritizing funding: the government should support science that is of high quality, exploits current strengths, redresses racial and gender inequalities, and can be applied to the country's development. More remarkable is the fact that his analysis, which has garnered much support in the new government, seems to undermine the rationale for continuing to fund his own highly theoretical work in cosmology.

Lately that work has taken on a familiar pattern: drawing connections among disparate facts and ideas in order to change people's perception of what is real and what is possible. Within cosmology, Ellis has been exploring alternatives to the so-called standard model. According to many in the field, this theory posits that the big bang was followed by a period of rapid inflation, yielding a universe near "critical density"—that is, with just about enough matter to recollapse eventually in a big crunch. Ellis says his aim is to counter a recent trend "of researchers being very dogmatic, almost to the point of dis-

counting the astronomical evidence."

In a controversial article in *Nature* last year, Ellis and a colleague reviewed all the observations that might indicate the true density of the universe. They concluded that "no strongly convincing case can be made for a critical-density Universe." On the contrary "an open Universe [one that continues to expand for all eternity] should be preferred," even though that assumption may conflict with current inflationary theories.

"People need to be aware that there is a range of models that could explain the observations," Ellis argues. "For instance, I can construct you a spherically symmetrical universe with Earth at its center, and you cannot disprove it based on observations." Ellis has published a paper on this. "You can only exclude it on philosophical grounds. In my view there is absolutely nothing wrong in that. What I want to bring into the open is the fact that we are using philosophical criteria in choosing our models. A lot of cosmology tries to hide that."

Ellis himself has been delving into the philosophical territory that lies beyond cosmology. In a speech delivered last year at the Center for Theology and the Natural Sciences in Berkeley, Calif., he argued that observations of human behavior—including the behavior of those who claim that all moral systems are arbitrary cultural artifacts—indicate that a universal moral law does exist. "The foundational line of true ethical behavior, its main guiding principle valid across all times and cultures, is the degree of freedom from self-centeredness of thought and behavior, and willingness freely to give up one's own self-interest on behalf of others," Ellis proposed. He calls the principle *kenosis,* a Greek word for self-emptying.

Science itself could explain such a universal ethic only as a result of evolution, he says. But because evolutionary pressures apply to populations, rather than individuals, and favor the strong at the expense of the weak, this hypothesis is patently incorrect, according to Ellis. The only other option, he argues, is that "this moral law has comparable status to that of physics. There is an ethical underpinning to the universe as well as a physical one." How did it get there? That, he says, is like asking why any physical law is the way it is. One answer—the one he believes is correct—is that a benevolent Creator arranged things just so intelligent beings could experience *kenosis.* In explaining this particular pattern—something he will do at length in a forthcoming book—Ellis may not be right. But cosmologists do have a better record than most on such matters. —*W. Wayt Gibbs*

Emerging Viruses

Hemorrhagic fever viruses are among the most dangerous biological agents known. New ones are discovered every year, and artificial as well as natural environmental changes are favoring their spread

by Bernard Le Guenno

In May 1993 a young couple in New Mexico died just a few days apart from acute respiratory distress. Both had suddenly developed a high fever, muscular cramps, headaches and a violent cough. Researchers promptly started looking into whether similar cases had been recorded elsewhere. Soon 24 were identified, occurring between December 1, 1992, and June 7, 1993, in New Mexico, Colorado and Nevada. Eleven of these patients had died.

Bacteriological, parasitological and virological tests conducted in the affected states were all negative. Samples were then sent to the Centers for Disease Control and Prevention (CDC) in Atlanta. Tests for all known viruses were conducted, and researchers eventually detected in the serum of several patients antibodies against a class known as hantaviruses. Studies using the techniques of molecular biology showed that the patients had been infected with a previously unknown type of hantavirus, now called Sin Nombre (Spanish for "no name").

New and more effective analytical techniques are identifying a growing number of infective agents. Most are viruses that 10 years ago would probably have passed unnoticed or been mistaken for other, known types. The Sin Nombre infections were not a unique occurrence. Last year a researcher at the Yale University School of Medicine was accidentally infected with Sabià, a virus first isolated in 1990 from an agricultural engineer who died from a sudden illness in the state of São Paulo, Brazil.

Sabià and Sin Nombre both cause illnesses classified as hemorrhagic fevers. Patients initially develop a fever, followed by a general deterioration in health during which bleeding often occurs. Superficial bleeding reveals itself through skin signs, such as petechiae (tiny releases of blood from vessels under the skin surface), bruises or purpura (characteristic purplish discolorations). Other cardiovascular, digestive, renal and neurological complications can follow. In the most serious cases, the patient dies of massive hemorrhag-

PATRICK ROBERT SYGMA

es or sometimes multiple organ failure.

Hemorrhagic fever viruses are divided into several families. The flaviviruses have been known for the longest. They include the Amaril virus that causes yellow fever and is transmitted by mosquitoes, as well as other viruses responsible for mosquito- and tick-borne diseases, such as dengue. Viruses that have come to light more recently belong to three other families: arenaviruses, bunyaviruses (a group that includes the hantaviruses) and filoviruses. They have names like Puumala, Guanarito and Ebola, taken from places where they first caused recognized outbreaks of disease.

All the arenaviruses and the bunyaviruses responsible for hemorrhagic fevers circulate naturally in various populations of animals. It is actually uncommon for them to spread directly from person to person. Epidemics are, rather, linked to the presence of animals that serve as reservoirs for the virus and sometimes as vectors that help to transfer it to people. Various species of rodent are excellent homes for these viruses, because the rodents show no signs when infected. Nevertheless, they shed viral particles throughout their lives in feces and, particularly, in urine. The filoviruses, for their part, are still a mystery: we do not know how they are transmitted.

Hemorrhagic fever viruses are among the most threatening examples of what are commonly termed emerging pathogens. They are not really new. Mutations or genetic recombinations between existing viruses can increase virulence, but what appear to be novel viruses are generally viruses that have existed for millions of years and merely come to light when environmental conditions change. The changes allow the virus to multiply and spread in host organisms. New illnesses may then sometimes become apparent.

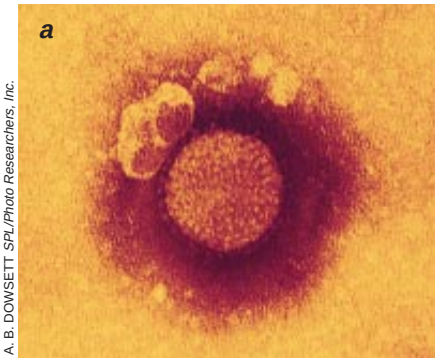
Improvements in Diagnosis

The seeming emergence of new viruses is also helped along by rapid advances in the techniques for virological identification. The first person diagnosed with Sabià in São Paulo (called the index case) was originally thought to be suffering from yellow fever. The agent actually responsible was identified only because a sample was sent to a laboratory equipped for the isolation of viruses. That rarely happens, because most hemorrhagic fever viruses circulate in tropical regions, where hospitals generally have inadequate diagnostic equipment and where many sick people are not hospitalized. Even so, the rapid identification of Sin Nombre was possible only because of several years of work previously accumulated on hantaviruses.

Hantaviruses typically cause an illness known as hemorrhagic fever with renal syndrome; it was described in a Chinese medical text 1,000 years ago. The West first became interested in this illness during the Korean War, when more than 2,000 United Nations troops suffered from it between 1951 and 1953. Despite the efforts of virologists, it was not until 1976 that the agent was identified in the lungs of its principal reservoir in Korea, a field mouse. It took more than four years to isolate the virus, to adapt it to a cell culture and to prepare a reagent that permitted a diagnostic serological test, essential steps in the study of a virus. It was named Hantaan, for a river in Korea. The virus also circulates in Japan and Russia, and a similar virus that produces an illness just as serious is found in the Balkans.

A nonfatal form exists in Europe. It was described in Sweden in 1934 as the "nephritic epidemic," but its agent was not identified until 1980, when it was detected in the lungs of the bank vole. Isolated in 1983 in Finland, the virus was named Puumala for a lake in that country. Outbreaks occur regularly in northwestern Europe. Since 1977, 505 cases have been recorded in northeastern France alone. The number of cases seems to be increasing, but this is probably because doctors are using more biological tests than formerly, and because the tests in recent years have become more sensitive.

Thus, it is only for about a decade that we have had the reagents necessary to identify hantaviruses. Thanks to these reagents and a research technique that spots antibodies marking recent infections, scientists at the CDC in 1993 were quickly on the track of the disease. The presence of specific antibodies is not always definite proof of an infection by the corresponding pathogen, however. False positive reactions and cross-reactions caused by the presence of antibodies shared by different viruses are possible. A more recent technology, based on the polymerase chain reaction, permits fragments of genes to be amplified (or duplicated) and sequenced. It provided confirmation that



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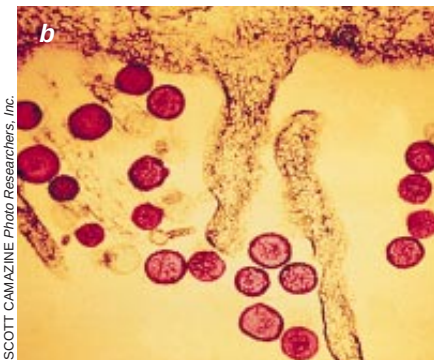

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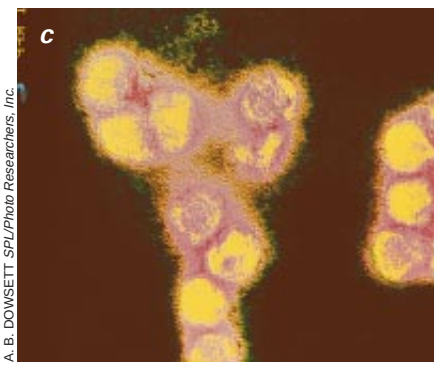

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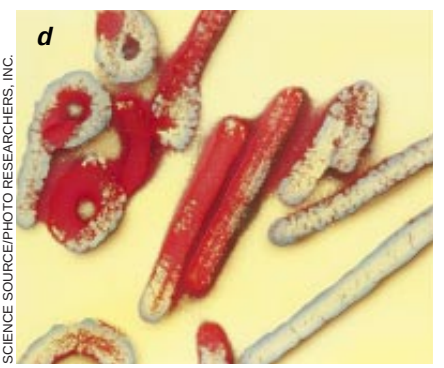

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HEMORRHAGIC FEVER VIRUSES vary greatly in appearance under the electron microscope. Lassa (*a*), found in Africa, is an arenavirus, a kind that is typically spherical. Hantaviruses (*b*) cause diseases of different varieties in many regions of the world. Tick-borne encephalitis virus (*c*) is an example of a flavivirus, a group that includes yellow fever and dengue. Ebola (*d*) is one of the filoviruses, so called because of their filamentous appearance. The images have been color-enhanced.

ZAIREAN RED CROSS members bury victims of the Ebola virus in Kikwit earlier this year. At least 190 died in the epidemic. Poor medical hygiene and unsafe funeral practices helped to propagate the infection.

the patients were indeed infected with hantaviruses. The identification of Sin Nombre took no more than eight days.

The Infective Agents

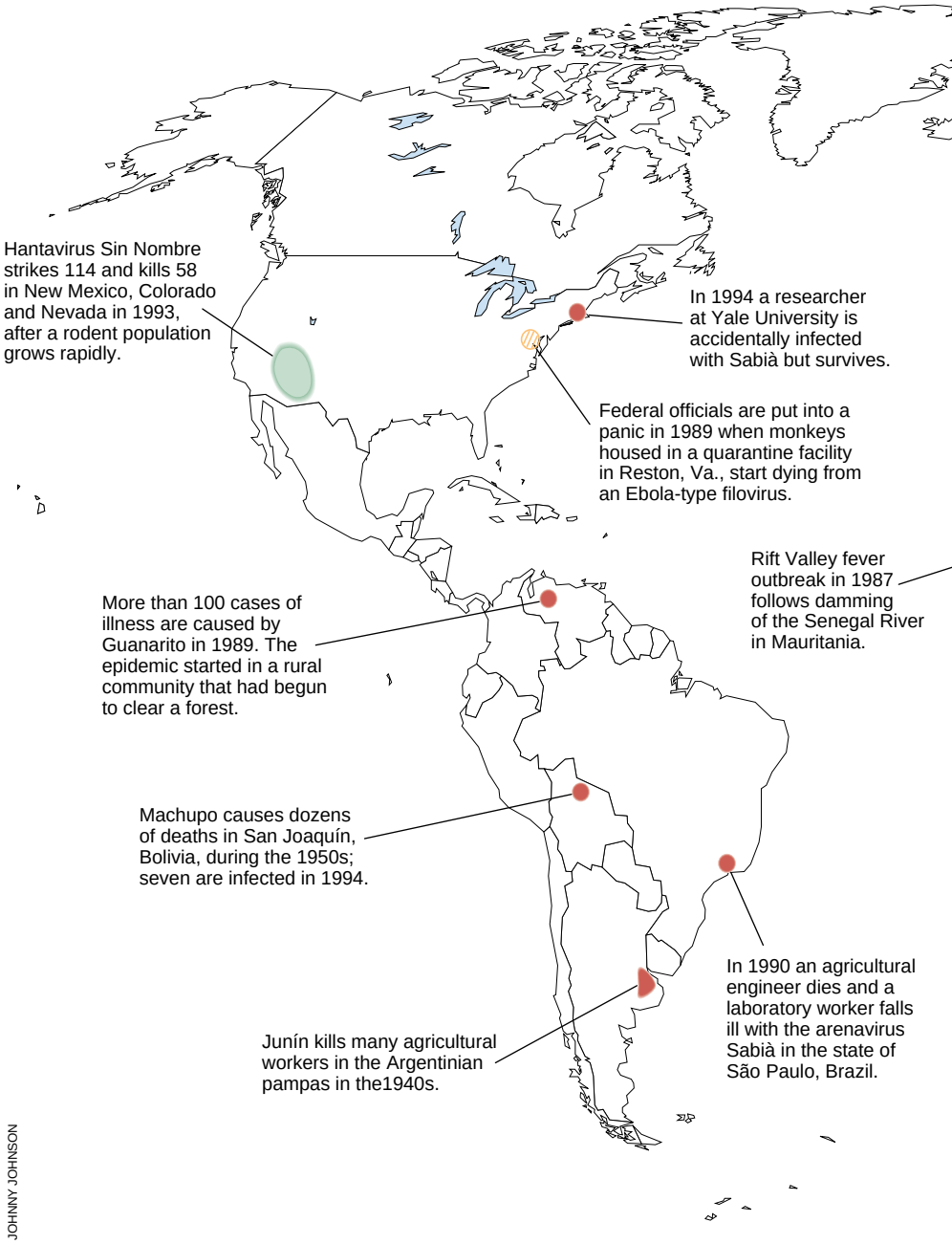
The primary cause of most outbreaks of hemorrhagic fever viruses is ecological disruption resulting from human activities. The expansion of the world population perturbs ecosystems that were stable a few decades ago and facilitates contacts with animals carrying viruses pathogenic to humans. This was true of the arenavirus Guanarito, discovered in 1989 in an epidemic in Venezuela. The first 15 cases were found in a rural community that had started to clear a forested region in the center of the country. The animal reservoir is a species of cotton rat; workers had stirred up dust that had been contaminated with dried rat urine or excrement—one of the most frequent modes of transmission. Subsequently, more than 100 additional cases were diagnosed in the same area.

Other arenaviruses responsible for hemorrhagic fevers have been known for a long time—for example, Machupo, which appeared in Bolivia in 1952, and Junín, identified in Argentina in 1958. Both those viruses can reside in species of rodents called vesper mice; the Bolivian species enters human dwellings. Until recently, an extermination campaign against the animals had prevented any human infections with Machupo since 1974. After a lull of 20 years, however, this virus has reappeared, in the same place: seven people, all from one family, were infected during the summer of 1994.

Junín causes Argentinian hemorrhagic fever, which appeared at the end of the 1940s in the pampas west of Buenos Aires. The cultivation of large areas of maize supported huge populations of the species of vesper mice that carry this virus and multiplied contacts between these rodents and agricultural workers. Today mechanization has put the operators of agricultural machinery on the front line: combine harvesters not only suspend clouds of infective dust, they also create an aerosol of infective blood when they accidentally crush the animals.

The arenavirus Sabià has, so far as is known, claimed only one life, but other cases have in all probability occurred in Brazil without being diagnosed. There is a real risk of an epidemic if agricultural practices bring the inhabitants of São Paulo into contact with rodent vectors. In Europe, the main reservoirs of the hantavirus Puumala—the bank vole and yellow-necked field mouse—are

Global Reach of Hemorrhagic Fever Viruses



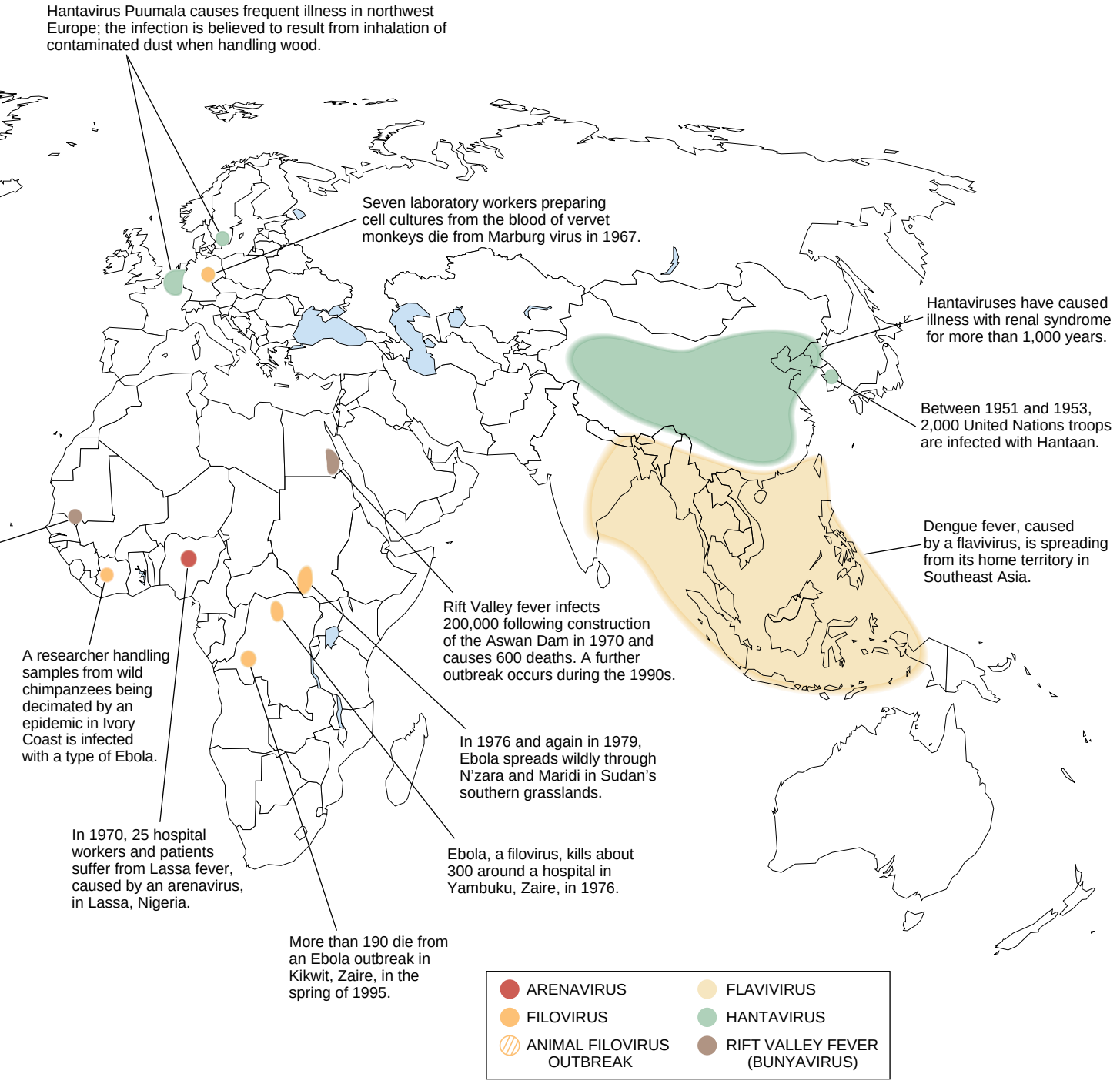
JOHNNY JOHNSON

woodland animals. The most frequent route of contamination there is inhalation of contaminated dust while handling wood gathered in the forest or while working in sheds and barns.

Humans are not always the cause of dangerous environmental changes. The emergence of Sin Nombre in the U.S. resulted from heavier than usual rain and snow during spring 1993 in the mountains and deserts of New Mexico, Nevada and Colorado. The principal animal host of Sin Nombre is the deer mouse, which lives on pine kernels: the exceptional humidity favored a particularly abundant crop, and so the mice proliferated. The density of the animals multiplied 10-fold between 1992 and 1993.

Transmission by Mosquitoes

Some bunyaviruses are carried by mosquitoes rather than by rodents. Consequently, ecological perturbations such as the building of dams and the expansion of irrigation can encourage these agents. Dams raise the water table, which favors the multiplication of



the insects and also brings humans and animals together in new population centers. These two factors probably explain two epidemics of Rift Valley fever in Africa: one in 1977 in Egypt and the other in 1987 in Mauritania.

The virus responsible was recognized as long ago as 1931 as the cause of several epizootics, or animal epidemics, among sheep in western and South Africa. Some breeders in contact with sick or dead animals became infected, but at the time the infection was not serious in humans. The situation became more grim in 1970. After the construction of the Aswan Dam, there were major losses of cattle; of the 200,000 people infected, 600 died. In 1987 a minor epidemic followed the damming of the Senegal River in Mauritania.

Rift Valley fever virus is found in several species of mosquitoes, notably those of the genus *Aedes*. The females transmit the virus to their eggs. Under dry conditions the mosquitoes' numbers are limited, but abundant rain or irrigation allows them to multiply rapidly. In the course of feeding on blood, they then transmit the virus to humans, with cattle acting as incubators.

Contamination by Accident

Although important, ecological disturbances are not the only causes of the emergence of novel viruses. Poor medical hygiene can foster epidemics. In January 1969 in Lassa, Nigeria, a nun who worked as a nurse fell ill at work. She infected, before dying, two other nuns, one of whom died. A year later an epidemic broke out in the same hos-

pital. An inquiry found that 17 of the 25 persons infected had probably been in the room where the first victim had been hospitalized. Lassa is classed as an arenavirus.

Biological industries also present risks. Many vaccines are prepared from animal cells. If the cells are contaminated, there is a danger that an unidentified virus may be transmitted to those vaccinated. It was in this way that in 1967 a culture of contaminated blood cells allowed the discovery of a new hemorrhagic fever and a new family of viruses, the filoviruses.

The place was Marburg, Germany, where 25 people fell ill after preparing cell cultures from the blood of vervet monkeys. Seven died. Other cases were reported simultaneously in Frankfurt and in Yugoslavia, all in laboratories that had received monkeys from Uganda. The monkeys themselves also died, suggesting that they are not the natural reservoir of Marburg virus. Four cases of natural infection with Marburg have been reported in Africa, but neither the reservoir nor the natural modes of transmission have been discovered. What is clear is that Marburg can propagate in hospitals: secondary cases have occurred among medical personnel.

In 1976 two epidemics of fever caused by a different virus occurred two months apart in the south of Sudan and in northern Zaire. In Zaire, around Yambuku Hospital, by the Ebola River, 318 cases were counted, and 280 persons died. Eighty-five of them had received an injection in this hospital. The epidemic led to the identification of a new virus, Ebola.

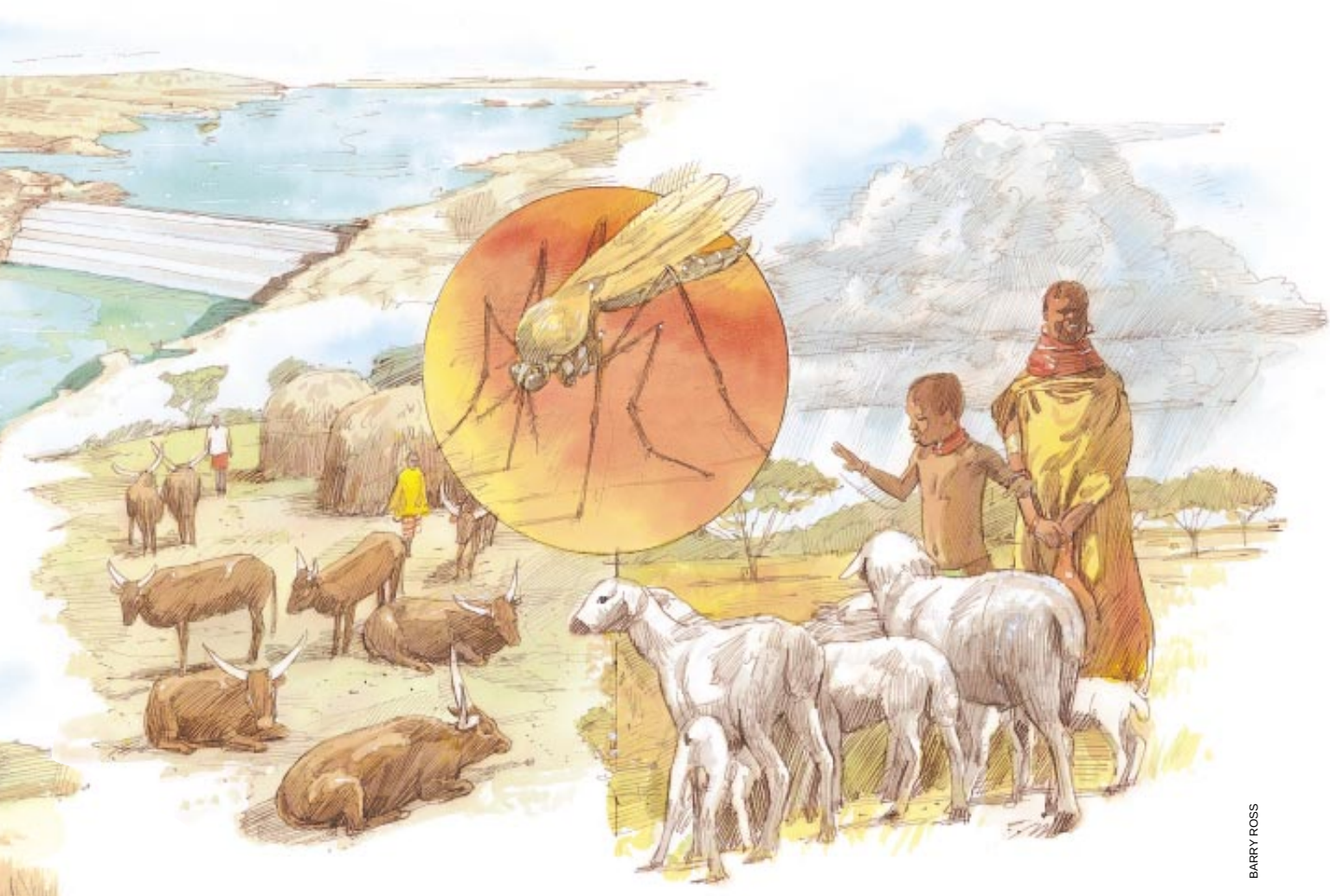
The Marburg and Ebola viruses are classified as filoviruses, so called because under the electron microscope they can be seen as filamentous structures as much as 1,500 nanometers in length (the spherical particle of an arenavirus, for comparison, is about 300 nanometers in diameter). These two representatives of the filovirus family are exceedingly dangerous. In 1989 specialists at the CDC were put in a panic when they learned that crab-eating macaques from the Philippines housed in an animal quarantine facility in Reston, Va., were dying from an infection caused by an Ebola-type filovirus. The virus was also isolated from other animal facilities that had received monkeys from the Philippines. No human illnesses were recorded in the wake of this epizootic, however, which demonstrates that even closely related viruses can vary widely in their effects.

In January of this year we isolated a previously unknown type of Ebola from a patient who had infected herself handling samples from wild chimpanzees that were being decimated by a strange epidemic. That the chimpanzees, from Ivory Coast, succumbed is further evidence that primates are not filoviruses' natural reservoir, which has not yet been identified. Although Marburg has infected few people, Ebola surfaced again to cause a human epidemic in Zaire this past May [*see box on pages 62 and 64*].

AGRICULTURAL WORKERS in some parts of the world are at risk of infection by arenaviruses, which are often carried by rodents. Machinery stirs up dried rodent urine containing the viruses and can create an aerosol of infective blood if the animals are accidentally crushed.

A Shifting, Hazy Target

The extreme variability and speed of evolution found among hemorrhagic fever viruses are rooted in the nature of their genetic material. Hemorrhagic fever viruses, like many other types, generally have genes consisting of ribonucleic acid, or RNA, rather than the DNA employed by most living things. The RNA of these viruses is "negative stranded"—before it can be used to make viral proteins in an infected cell, it must be converted into a positive



BARRY ROSS

RIFT VALLEY FEVER VIRUS, a bunyavirus, is transmitted by mosquitoes from cattle and sheep to humans. Dams allow multiplication of the insects by raising the water table and bring people and animals together in new locations, causing epidemics.

strand by an enzyme called RNA polymerase. RNA polymerases cause fairly frequent errors during this process. Because the errors are not corrected, an infected cell gives rise to a heterogeneous population of viruses resulting from the accumulating mutations. The existence of such "quasispecies" explains the rapid adaptation of these viruses to environmental changes. Some adapt to invertebrates and others to vertebrates, and they confound the immune systems of their hosts. Pathogenic variants can easily arise.

There is another source of heterogeneity, too. A characteristic common to arenaviruses and bunyaviruses is that they have segmented genomes. (The bunyaviruses have three segments of RNA, arenaviruses two.) When a cell is infected by two viruses of the same general class, they can then recombine so that segments from one become linked to segments from the other, giving rise to new viral types called reassortants.

Although we have a basic appreciation of the composition of these entities, we have only a poor understanding of how they cause disease. Far beyond the limited means of investigation in local tropical hospitals, many of these viruses are so hazardous they cannot be handled except in laboratories that conform to very strict safety requirements. There are only a few such facilities in the world, and not all of them have the required equipment. Although it is relatively straightforward to handle the agents safely in culture flasks, it is far more dangerous to handle infected monkeys: researchers risk infection from being scratched or bitten by sick animals. Yet the viruses cannot be studied in more common laboratory animals such as rats, because these creatures do not become ill when infected.

We do know that hemorrhagic fever viruses have characteristic effects on the body. They cause a diminution in the number of platelets, the principal cells of the blood-clotting system. But this diminution, called thrombocytopenia, is not sufficient to explain the hemorrhagic symptoms. Some hemorrhagic fever viruses destroy infected cells directly; others perturb the immune system and affect cells' functioning.

Among the first group, the cytolytic viruses, are the bunyaviruses that cause a disease called Crimean-Congo fever and Rift Valley fever; the filoviruses Marburg and Ebola; and the prototype of hemorrhagic fever viruses, the flavivirus Amaril. Their period of incubation is generally short, often less than a week. Serious cases are the result of an attack on several organs, notably the liver. When a large proportion of liver cells are destroyed, the body cannot produce enough coagulation factors, which partly explains the hemorrhagic symptoms. The viruses also modify the inner surfaces of blood vessels in such a way that platelets stick to them. This clotting inside vessels consumes additional coagulation factors. Moreover, the cells lining the vessels are forced apart, which can lead to the escape of plasma or to uncontrolled bleeding, causing edema, an accumulation of fluid in the tissue, or severely lowered blood pressure.

The arenaviruses fall into the noncytolytic group. Their period of incubation is longer, and although they invade most of the tissues in the body, they do not usually cause gross lesions. Rather the viruses inhibit the immune system, which delays the production of antibodies until perhaps a month after the first clinical signs of infection. Arenaviruses

Ebola's Unanswered Questions

by Laurie Garrett

Last spring in Kikwit, Zaire, Ebola proved once again that despite the agonizing and usually fatal illness it provokes, the microbe cannot in its present incarnation spread far—unless humans help it to do so. The virus is too swiftly lethal to propagate by itself. In the early waves of an epidemic, it kills more than 92 percent of those it infects, usually within a couple of weeks. Such rapidity affords the microbe little opportunity to spread unaided, given the severity of the illness that it causes.

In each of the four known Ebola epidemics during the past 19 years, people have helped launch the virus from its obscure rain forest or savanna host into human populations. In 1976 in Yambuku, an area of villages in Zaire's northern rain forest, the virus's appearance was multiplied dozens of times over by Belgian nuns at a missionary clinic who repeatedly used unsterilized syringes in some 300 patients every day. One day someone arrived suffering from the then unknown Ebola fever and was treated with injections for malaria. The syringes efficiently amplified the viral threat.

In both 1976 and 1979, humans helped the virus spread wildly in N'zara and Maridi, in the Sudan's remote southern grasslands. Improper hospital hygiene again played a key role, and local burial practices, which required the manual removal of viscera from cadavers, compounded the disaster.

Medical and funeral settings were likewise crucial in Kikwit earlier this year. Infections spread via bodily fluids among those who tended the dying and washed and dressed the cadavers. The major amplification event that seems to have started the epidemic, early in the new year, was an open casket funeral. The deceased, Gaspard Menga, probably acquired his infection gathering firewood in a nearby rain forest. The virus spread rapidly to 13 members of the Menga family who had cared for the ailing man or touched his body in farewell, a common practice in the region, or cared for those who got Ebola from Menga.

A second amplification event occurred in March inside Kikwit General Hospital. Overrun by cases of incurable bloody diarrhea, hospital officials thought they were facing a new strain of bacteria. The doctors ordered a laboratory technician to draw blood samples from patients and analyze them for drug resistance.

When he took ill, the hospital staff thought that his enormously distended stomach and high fever were the results of typhus infection and performed surgery to stave off damage. The first procedure was an appendectomy. The second was a horror. When the physicians and nurses opened the technician's abdomen again for what they expected to be repair work, they were immediately drenched in blood. Their colleague died on the operating table from uncontrolled bleeding. The contaminated surgical team became the second wave of the epidemic.

The virus's reliance on unintended help from humans forces attention to the common thread that runs through the known Ebola epidemics: poverty. All the outbreaks have been associated with abysmal medical facilities in which poorly paid (or, in the case of Kikwit, unpaid) medical personnel had to make do with a handful of syringes, minimal surgical equipment and intermittent or nonexistent running water and electricity.

It seems quite possible that Ebola (and other hemorrhagic fever viruses) might successfully exploit similar conditions occurring anywhere in the world. As air transportation be-

(continued on page 64)

suppress the number of platelets only slightly, but they do inactivate them. Neurological complications are common.

Hantaviruses are like arenaviruses in that they do not destroy cells directly and also have a long period of incubation, from 12 to 21 days. They target cells lining capillary walls. Hantaan and Puumala viruses invade the cells of the capillary walls in the kidney, which results in edema and an inflammatory reaction caused by the organ's failure to work properly. Sin Nombre, in contrast, invades pulmonary capillaries and causes death by a different means: it leads to acute edema of the lung.

Prospects for Control

Several research groups are trying to establish international surveillance networks that will track all emerging infectious agents. The World Health Organization has established a network for tracking hemorrhagic fever viruses and other insect-borne viruses that is particularly vigilant.

Once a virus is detected, technology holds some promise for combating it. An antiviral medication, ribavirin, proved effective during an epidemic of hantavirus in China. A huge effort is under way in Argentina to develop a vaccine to protect people against Junín.

KAREN KASMANSKI *Matrix*

PORTABLE ISOLATOR UNITS equipped with air filters have been maintained by the U.S. Army since 1980 for evacuating personnel carrying suspected dangerous pathogens. The equipment would be used to bring patients needing specialized care to an isolation facility at Fort Detrick, Md., but has never been called on for this mission.

(continued from page 62)

comes more readily available and affordable, viruses can be more easily moved around the planet. The rapid deterioration in public health and medical facilities in the former Soviet Union and other regions should therefore be cause for concern.

The exact nature of the risk, of course, depends on the Ebola virus's biology, much of which remains mysterious. Throughout the summer, researchers from the University of Kinshasa, the U.S. Centers for Disease Control and Prevention, the Pasteur Institute in Paris, the National Institute of Virology in Johannesburg and the World Health Organization combed Kikwit for answers to questions that have puzzled scientists since the first Yambuku epidemic: What are the precise constraints on Ebola's transmission? And where does it hide between epidemics?

The two Sudanese epidemics started among cotton factory workers. At the time scientists scoured the N'zara complex for infected insects or bats, but although the animals were plentiful, none carried the virus. In Yambuku, suspicions fell on a range of rain-forest animals, including monkeys. Again, however, no trapped animals tested positive for infection. Surveys conducted during the late 1970s in conjunction with a WHO effort to control monkeypox found no infected primates or large animals in central Africa.

The rain forest frequented by Gaspard Menga contained abundant rats, bats, mice and snakes. Trapping efforts in the region may eventually reveal Ebola's hideout. For the present, though, the virus's reservoir remains unknown. Also unknown is whether shared drinking water, foods and washing facilities can transmit infection.

Because all outbreaks to date have involved transmission by fluids, control has consisted of fairly straightforward, low-cost efforts. Patients were isolated, and the citizenry instructed to turn over their unwashed dead to authorities.

PATRICK ROBERT SYGMA

***MASKED AND GLOVED** health worker disinfects a bed used by a patient stricken by the Ebola virus in Kikwit, Zaire.*

Once residents appreciated the links between tending the sick, washing a cadaver and dying of Ebola, epidemics quickly ground to a halt.

One way that Ebola could escape such controls would be through a major mutational event that made it more easily transmissible. Were Ebola, or any hemorrhagic fever virus, to acquire genetic characteristics suitable for airborne transmission, an outbreak of disease anywhere would pose a threat to all humanity.

As far as is known, nobody has ever acquired the microbe from inhaled droplets coughed into the air (although it can certainly be passed in saliva during a kiss). There are usually many genetic differences between fluid-borne microbes and airborne ones, so it seems unlikely that the jump could be made easily. But the question has never been specifically studied in the case of Ebola, because research on microbes that are found primarily in developing countries has for many years been poorly funded.

LAURIE GARRETT is a reporter for Newsday *and the author of* The Coming Plague: Newly Emerging Diseases in a World Out of Balance *(Penguin USA, 1995).*

Indeed, vaccines against the Rift Valley fever in animals, and against yellow fever in humans, are already approved for use. Yet despite the existence of yellow fever vaccine, that disease is now raging in Africa, where few are vaccinated.

Other approaches are constrained because it is difficult or impossible to control animals that are natural reservoirs and vectors for the viruses or to predict ecological modifications that favor outbreaks of disease. There was an effective campaign against rodent vectors during the Lassa and Machupo arenavirus outbreaks, but it is not usually possible to sustain such programs in rural regions for long periods.

Precautions can be taken in laboratories and hospitals, which have ironically served as amplifiers in several epidemics. In the laboratory, viruses responsible for hemorrhagic fevers must be handled in maximum confinement conditions (known in the jargon as biosafety level 4). The laboratory must be kept at lowered pressure, so that no potentially infectious particle can escape; the viruses themselves should be confined in sealed systems at still lower pressure. In hospitals, the risk of infection from a patient is high for some viruses, so strict safety measures must be followed: hospital personnel must wear masks, gloves and protective clothing; wastes must be decontaminated. A room with lowered pressure is an additional precaution.

Since penicillin has been in widespread use, many people had started to believe that epidemics were no longer a threat. The global pandemic of HIV, the virus that causes AIDS, has shown that view to be complacent. Hemorrhagic fever viruses are indeed a cause for worry, and the avenues to reduce their toll are still limited.

The Author

BERNARD LE GUENNO leads the national reference center for hemorrhagic fever viruses at the Pasteur Institute in Paris. He graduated with a degree in pharmacology from Bordeaux University in 1972 and has been a virologist at Pasteur since 1983. This article was adapted from one by Le Guenno in the June issue of *Pour la Science,* the French edition of *Scientific American.*

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Companions to Young Stars

The surprising finding that even the youngest stars commonly exist in sets of two or three has revised thinking about the birth of star systems

by Alan P. Boss

A minor revolution in astronomy occurred on April 6, 1992. It did not take place at a mountaintop observatory but happened at an unlikely location—the Callaway Gardens Inn on Georgia's Pine Mountain (elevation: 820 feet). Astronomers had gathered there for an international meeting on the normally slow-paced research topic of double stars, a field where discoveries often require decades to allow for many of these systems to complete their orbits. While azaleas flowered outside in the spring rain, astronomers inside presented results pointing to the startling conclusion that even the youngest stars are frequently surrounded by stellar companions. This realization was the product of painstaking observations by many different people using a host of clever techniques and new devices. That morning in Georgia, the separate works of these numerous researchers appeared magically to dovetail.

The finding that binary systems are at least as common for young stars as for older ones might seem reasonable enough, but for astronomers it came as a shock. Most notions of double star formation had predicted that stellar companions are produced or captured well after a star has formed; hence, the youngest stars would be expected to exist singly in space. Such theories no longer bear weight. There remains, however, at least one idea for the formation of double stars that holds up to the recent observations. It may be the sole explanation for why binary star systems are so abundant in the universe.

The sun, a mature star, has no known stellar companions, even though most stars of its age are found in groups of two or more. In 1984 Richard A. Muller of Lawrence Berkeley Laboratory and his colleagues hypothesized that the sun is not truly a single star but that it has a distant companion orbiting it with a period of about 30 million years. He reasoned that gravitational forces from this unseen neighbor could disturb material circling in the outermost reaches of the solar system, sending a shower of comets toward the inner planets every time the star neared. Muller suggested that this effect might explain periodic mass extinctions: comets generated by the sun's companion would hit the earth every 30 million years or so and—as with the demise of the dinosaurs—would have wiped out much of life on earth. Because its approach would have sparked such widespread destruction, Muller called the unseen star "Nemesis."

Most scientists have not accepted Muller's interesting idea. For one, the closest known stars (the Alpha Centauri triple star system, at a distance of 4.2 light-years) are much too far away to be bound to the sun by gravity. In fact, there is no astronomical evidence that the sun is anything other than a single star whose largest companion (Jupiter) is 1,000 times less massive than the sun itself. But living on a planet in orbit around a solitary sun gives us a distorted view of the cosmos; we tend to think that single stars are the norm and that double stars must be somewhat odd. For stars like the sun, this turns out to be far from true.

Doubles, Anyone?

In 1990 the late Antoine Duquennoy and Michel Mayor of the Geneva Observatory completed an exhaustive, decade-long survey of nearby binary stars. They considered every star in the sun's "G-dwarf" class within 72 light-years, a sample containing 164 primary stars that are thought to be representative of the disk of our galaxy. Duquennoy and Mayor found that only about one third of these systems could be considered true single stars; two thirds had companions more massive than one hundredth the mass of the sun, or about 10 Jupiters.

Binary star systems have widely variable characteristics. Stars of some double G-dwarf systems may be nearly touching one another; others can be as far apart as a third of a light-year. Those in contact may circle each other in less than a day, whereas the most widely separated double stars may take tens of millions of years to complete a single orbit. Duquennoy and Mayor showed that triple and quadruple G-dwarf stars are considerably rarer than double stars. They counted 62 distinct doubles, seven triples and two quadruple groupings. They further determined that each of the triple and quadruple sets had a hierarchical structure, composed of a relatively close double orbited by either a more distant single star (forming a triple system) or another close double star (forming a quadruple system). The separation between distant pairs needs to be at least five times the gap of the close doubles for the group to survive for long. Arrangements with smaller separations are named Trapezium systems, after a young quadruple system in the Orion nebula. These arrangements are orbitally unstable—they will eventually fly apart. For instance, if the three stars of a triple system come close enough together, they will tend to eject the star of lowest mass, leaving behind a stable pair.

Double stars thus seem to be the rule rather than the exception. This conclusion does not, however, mean that planets must be rare. A planet could travel around a double star system provided that it circles either near one of the two stars or far away from both of them. Imagine living on such a world orbiting at a safe distance from a tightly bound binary, where the two stars complete an orbit every few days. The daytime sky would contain a pair of suns separated by a small distance. Sunrises and sunsets would be fascinating to watch as

DAVID MALIN *ROE/Anglo-Australian Observatory*

RHO OPHIUCHUS molecular cloud harbors colorful reflection nebulae and numerous stars in the process of formation. Because these stellar nurseries lie relatively close to the earth, observations of them can provide important insights into the birth of double stars.

WOLFGANG BRANDNER *University of Würzburg*

GLASS-1 proved to be a young double star when imaged by an infrared camera at a wavelength of 0.9 micron.

first one and then the other glowing orb crossed the horizon. Other strange celestial configurations might also occur. If, for example, the planet orbited in the same plane as did two stars of equal mass, the two suns periodically would appear to merge as they eclipsed each other, briefly halving the amount of combined sunlight reaching the planet.

Stellar Nurseries

The sun formed about 4.6 billion years ago and has about five billion years remaining of its so-called main-sequence lifetime. After it reaches the end of its main sequence, it will expand to become a red giant that will engulf the inner planets. This configuration will be somewhat akin to one that occurred early in the sun's history, when it extended far beyond its present radius. At that time, before it had contracted to its current size, the sun was similar to the T Tauri class of stars that can be seen in those regions of our galaxy where stars are now forming. During its T Tauri stage, the sun's radius was about four times greater than its present measurement of some 700,000 kilometers. Still earlier, the protosun must have extended out to about 1.5 billion kilometers, or 10 times the distance between the earth and the sun (that span, 150 million kilometers, is known as an astronomical unit, or AU).

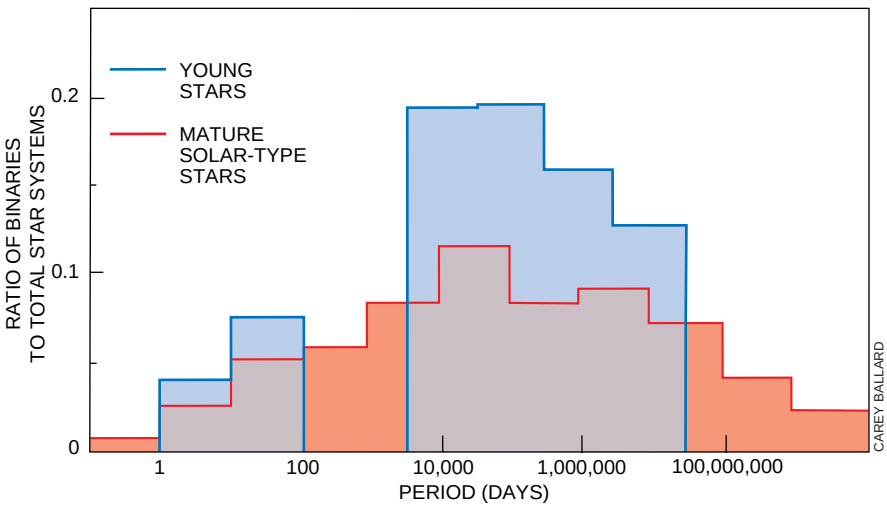
Present-day T Tauri stars offer astronomers an opportunity to learn what the sun was like early in its evolution. The nearest T Tauri stars are in two locations, known as the the Taurus molecular cloud and the Rho Ophiuchus molecular cloud, both about 460 light-years from the earth. The fact that young stars are always embedded in such dusty concentrations of gas gives convincing testimony to their origin—stars are born from the contraction and collapse of the dense cores of molecular hydrogen clouds.

Because young stars are typically enshrouded by dust, astronomers usually have difficulty viewing them in visible light, no matter how powerful the telescope. But these sites can be detected readily using infrared wavelengths that are characteristic of the emission from heated dust grains surrounding the nearby star. Progress in understanding the formation of stars has thus been dependent to a large extent on the development of detectors capable of sensing infrared radiation. At the 1992 meeting in Georgia, the first results were presented for several different infrared surveys specifically designed to detect companions to the T Tauri stars in Taurus and Ophiuchus.

Andrea M. Ghez, now at the University of California at Los Angeles, and her colleagues Gerry F. Neugebauer and Keith Matthews, both at the California Institute of Technology, used a new indium antimony array camera on the five-meter Hale telescope to photograph the regions around known T Tauri stars at the near-infrared wavelength of 2.2 microns. (Visible light has a wavelength between about 0.4 and 0.7 micron.) Using a so-called speckle imaging technique to minimize the noise introduced by fluctuations in the earth's atmosphere above the telescope, Ghez and her colleagues found that almost half of the 70 T Tauri stars in their sample showed stellar companions. For the limited range of separations considered, about 10 to 400 AU, this study indicated that for the youngest systems, binaries are twice as common as for main-sequence stars. Christoph Leinert of the Max Planck Institute for Astronomy in Heidelberg also presented results of a near-infrared speckle imaging survey. Leinert and his colleagues found that 43 of the 106 T Tauri stars they examined had nearby companions, again implying that binaries were much more common in these stars than in G-dwarf stars like our sun.

Hans Zinnecker and Wolfgang Brandner of the University of Würzburg in Germany and Bo Reipurth of the European Southern Observatory in Chile used a high-resolution digital camera in combination with the European New Technology Telescope to image 160 T Tauri stars at an infrared wavelength (one micron). They uncovered 28 companions lying from 100 to 1,500 AU from the T Tauri stars, about a third more than circle around older, solar-type stars in that distance range.

Michel J. Simon of the State University of New York at Stony Brook, along with Wen Ping Chen (now at National Central University in Taiwan) and their colleagues, reported a novel way to find young double stars. When the moon passes over, or occults, a distant star system, careful monitoring of the light received can reveal the presence of two or more sources, as first one and then another star slips behind the sharp edge of the lunar face. Simon and Chen's measurements detected companions much closer to T Tauri stars than was possible with infrared imaging. Their work again showed that a large fraction are binaries. Robert D. Mathieu of the University of Wisconsin employed a more traditional means for detecting close double stars, the same as that used by



CAREY BALLARD

YOUNG BINARIES are at least as ubiquitous as mature double stars. For all orbital periods yet determined, young doubles found in star-forming regions (*blue*) are even more common than solar-type binaries that have been surveyed in the sun's neighborhood (*red*).

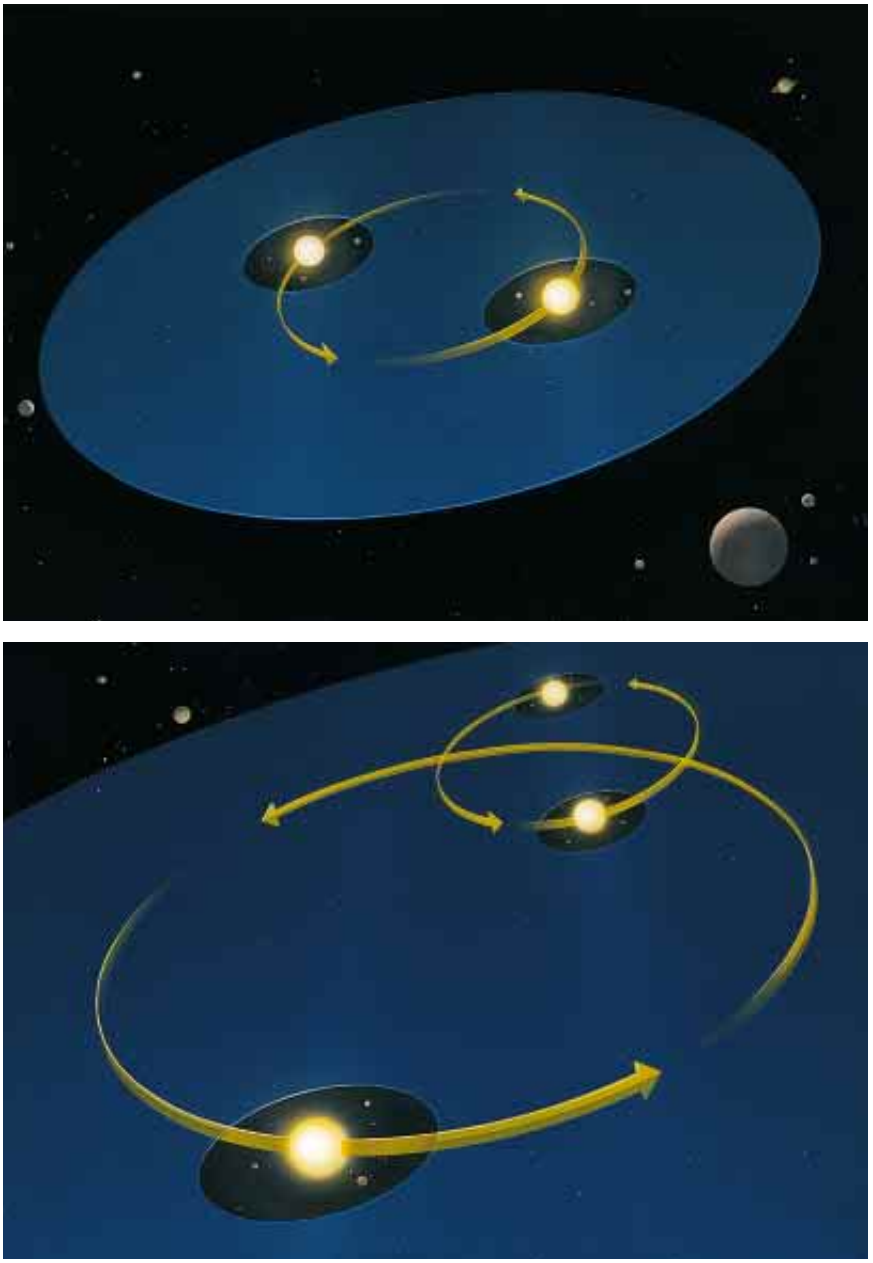
Duquennoy and Mayor. Mathieu used spectroscopic measurements of the periodic Doppler shift to show that some T Tauri stars have companions within 1 AU. Once more, closely spaced binaries proved more common in young T Tauri systems than for solar-type stars.

Search for a Theory

How did all these stellar companions come to be? Why did they form so abundantly and so early in their evolution? The wealth of observations of young stars presented in Georgia requires that binary stars must form well before even their pre-main-sequence (T Tauri) phase. Moreover, the finding that binaries are so common demands that the mechanism generating them—whatever it is—must be very efficient.

In principle, a double star system could arise from two stars that pass close enough together so that one forces the other into a stable orbit. The celestial mechanics of such an event, however, requires the intervention of a third object to remove the excess energy of motion between the two stars and leave them trapped in a gravitationally bound system. But such three-body encounters are too rare to account for very many binary stars. Cathy J. Clarke and James E. Pringle of the University of Cambridge studied a more likely way that companion stars might have paired up. They investigated the gravitational coupling between two young stars that still had flattened disks of dust and gas surrounding them. That geometry would be far more common than three-body encounters and could, in theory, remove enough energy from the stars' motions. But in their analysis they found that such interactions are much more likely to end up ripping apart the circumstellar disks than to result in one star's neatly orbiting with the other. So this embellishment seems to help little in explaining the existence of binary star systems.

Failure of the capture mechanism has forced most astronomers to think about processes that might form binary stars more directly. In fact, consideration of this notion goes back over a century. In 1883 Lord Kelvin proposed that double stars result from "rotational fission." Based on studies of the stability of bodies in rapid rotation, Kelvin suggested that as a star contracted, it would spin faster and faster until it broke up into a binary star. Astronomers now know that pre-main-sequence stars contract considerably as they approach the hydrogen-burning main sequence, but T Tauri stars do not rotate fast enough to become unstable. Furthermore, Kelvin's fissioning would act too late to explain the frequency of binaries among young stars. Richard H. Durisen of Indiana University and his colleagues showed that fission fails on theoretical grounds as well—a reasonable calculation of this instability shows that the ejected matter would end up as trailing spiral arms of gas rather than as a separate cohesive star.

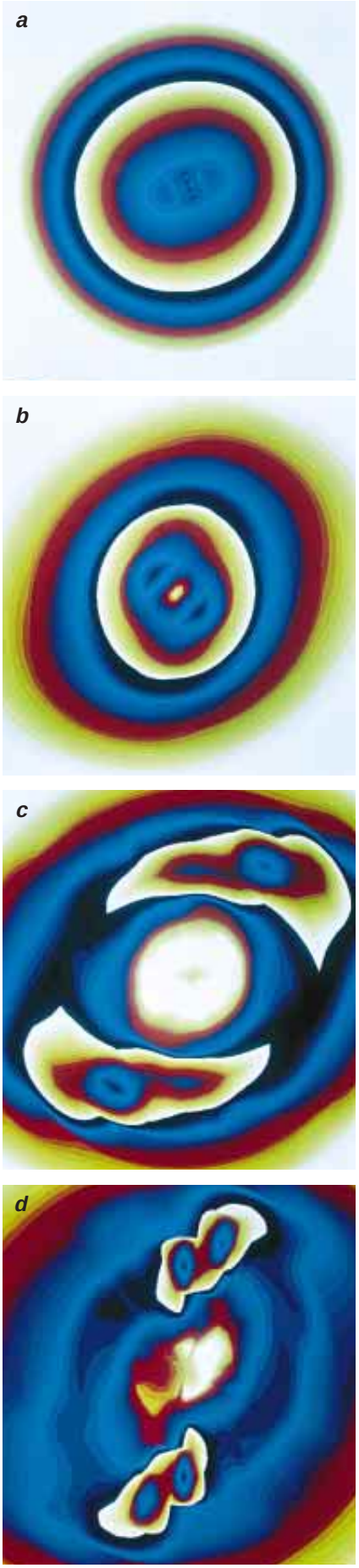


ALFRED T. KAMAJIAN

PLANETS in double or triple star systems would be excluded from special regions (*blue*) within which they could not orbit stably. Inside this zone, a planet would eventually be tossed out by gravitational interactions. For a double system (*top*), planets could reside either near each of the stars or far from them both. For a triple system (*bottom*), planets could orbit close to either of the paired stars, in a more extended region around the single member or far from all three.

In contrast to the century-old fission theory, there is an idea for creating binary stars that is only a decade old, called fragmentation. This concept supposes that binary stars are born during a phase when dense molecular clouds collapse under their own gravity and become protostars. The obscuring gas and dust then clear away, and a newly formed binary star (of the T Tauri class) emerges. In contrast to older theories of the birth of binary systems, fragmentation fully agrees with the latest observations of young stars.

The protostellar collapse that enables fragmentation occurs relatively suddenly in the scale of a several-billion-year stellar lifetime; the event takes place in



ALAN P. BOSS

HIERARCHICAL QUADRUPLE systems can form from the collapse of a molecular cloud. Computer simulations of the process show that an initially spherical cloud (*a*) first collapses to form a disk (*b*), which later fragments into a binary (*c*). Each member of the binary then breaks into two parts (*d*), giving rise to the final configuration, with four distinct regions of high density.

a few hundred thousand years. This violent transformation of a diffuse cloud into a compact star thus offers a special opportunity for a single object to break into several distinct members. Astrophysicists have identified two mechanisms that might operate. Very cold clouds can fragment directly into binaries, whereas warmer clouds with substantial rotation can first settle into thin disks that later break up as they gain more mass or become progressively flattened.

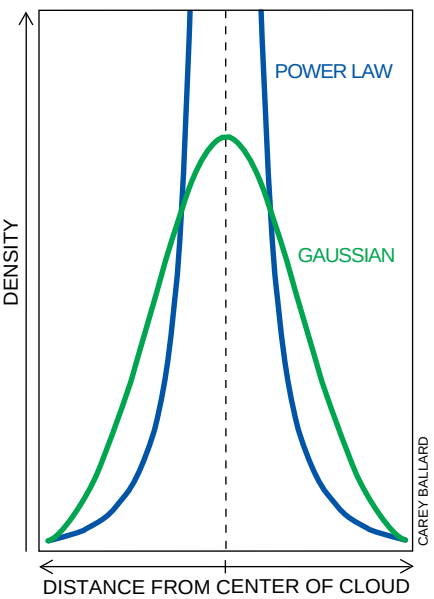
Cloudy Ideas

A key objection to the fragmentation theory involved the distribution of matter in protostellar clouds. It was previously thought that this material was distributed according to a so-called power law. That is, there would be an extremely high concentration of material near the center of the cloud and a rapid decrease in density with distance. This objection appears, however, to have been removed recently by high-resolution radio observations made using submillimeter wavelengths. Last year Derek Ward-Thompson of the Royal Observatory in Edinburgh and his colleagues determined the distribution of material inside several precollapse clouds. They found that the density follows a Gaussian (bell-shaped) distribution rather than a power law. Hence, matter would be less tightly concentrated toward a central point when the star system began to form. Elizabeth A. Myhill, then at the University of California at Los Angeles, and I had shown separately that the high density at the center of a cloud that follows a power law makes it almost impossible for a second or third star to coalesce. It proves much easier for fragmentation to occur with an initial Gaussian distribution.

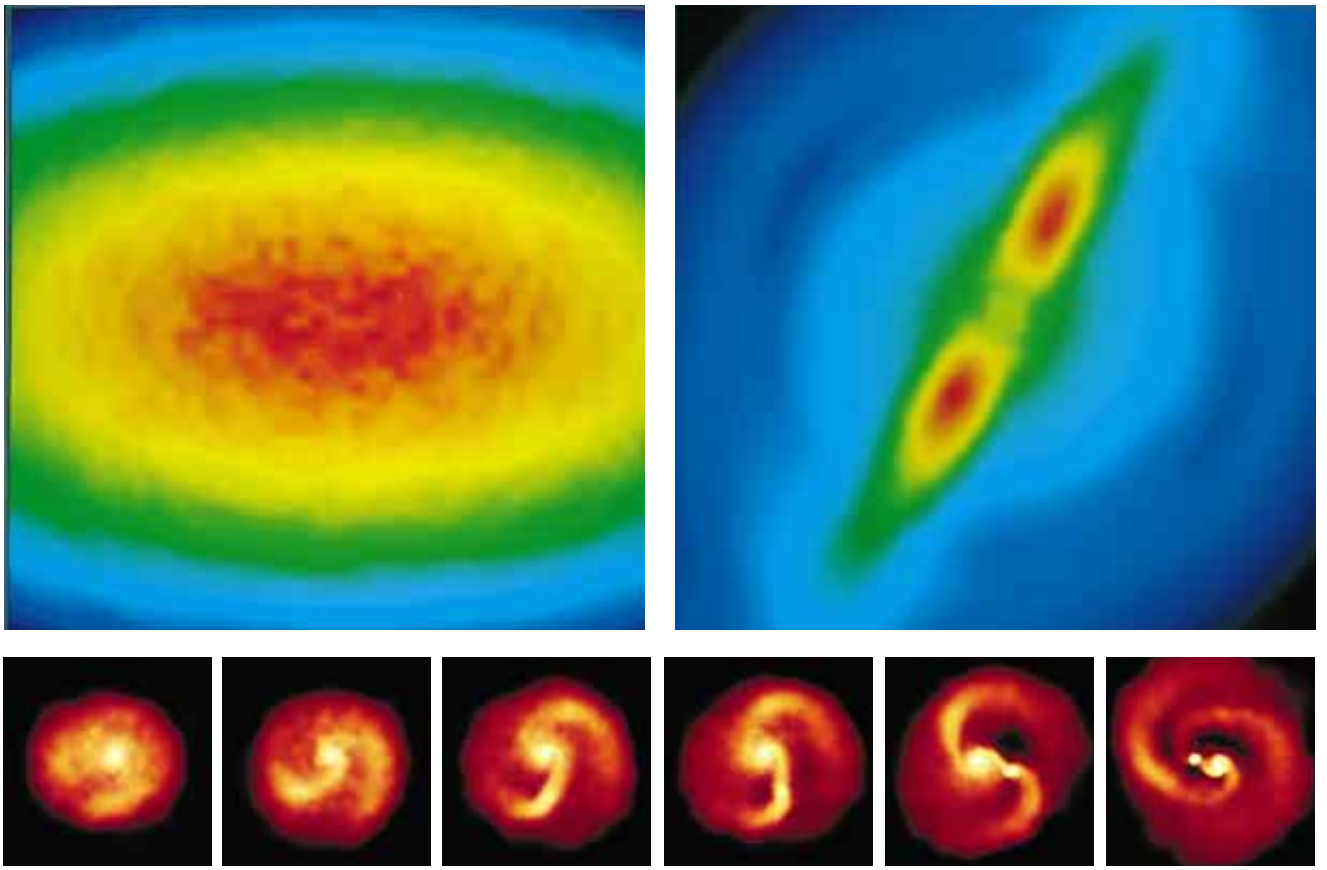
Astrophysicists can predict whether multiple fragments will ultimately form by solving the set of equations that govern the flow of gas, dust and radiation in a protostellar cloud. The calculations are sufficiently complex to require accurate software and a powerful computer for their solution. I began modeling the collapse of dense clouds with Gaussian density profiles in 1986 and found that fragmentation could readily occur provided certain conditions were met. As long as a Gaussian cloud has sufficient rotation to give the binary system the angular momentum it requires and the precollapse material is cold enough (less than 10 kelvins) to make its thermal energy less than about half its gravitational energy, the cloud will fragment during its gravitational contraction. The conditions appear to be nothing out of the ordinary for the clouds found in stellar nurseries.

Whether a binary, triple or quadruple system eventually forms depends on many details, including the three-dimensional shape of the original cloud, how lumpy it is and the precise amount of thermal and rotational energy available. In general, prolate, or football-shaped, clouds tend to form bars that fragment into binary systems, whereas more oblate, or pancake-shaped, clouds flatten to disks that later fragment into several members.

The collapse is thought to occur in two separate steps. The first phase generates protostars with a radius on the order of 10 AU. Thus, the first phase of fragmentation can produce only binary systems with separations of about 10 AU or larger. These bodies then undergo a second collapse to form the final protostars of stellar dimensions. Ian A. Bonnell and Matthew R. Bate of the University of Cambridge have shown that fragmentation can happen during the second collapse phase as well, and this process can lead to the formation of protostellar cores separated by distanc-



DENSITY in star-forming clouds was thought to follow a power law that concentrates mass tightly, but new findings suggest it matches a bell-shaped Gaussian curve that allows binaries to form.



ALAN P. BOSS (*top*); IAN A. BONNELL AND MATTHEW R. BATE (*bottom*)

BINARY SYSTEMS can form directly when a slightly elongated molecular cloud (*top left*) collapses and fragments into a bar-shaped protostellar system (*top right*). High-density regions in the upper computer simulation are shown in red.

Numerical modeling of the second phase of collapse of a protostellar cloud demonstrates how a more closely spaced binary can evolve (*bottom, left to right*). The double stars are separated by only 0.02 astronomical unit.

es comparable with those of the closest main-sequence stars. Fragmentation appears to be capable of generating the entire range of separations observed in young binary stars, from the closest to the widest systems.

Brown Dwarfs and Giant Planets

What about finding companions of even lower mass? Duquennoy and Mayor produced evidence that as many as 10 percent of solar-type stars are bound to brown dwarfs—that is, they have stellar companions with masses from 0.01 to 0.08 times the mass of the sun. Brown dwarfs are too small to ignite hydrogen the way the sun does but could be massive enough to burn deuterium soon after formation. After that, their radiation would cease, and they would become cool and extremely difficult to detect. Although the evidence offered by Duquennoy and Mayor is intriguing, there is as yet no confirmed example of a brown dwarf star, in spite of the many efforts to detect one.

The search is also on for planetary companions, although again astronomers have yet found no convincing candidates. But in the next decade, experimental techniques should improve to the point that planets the size of Jupiter could be detected (or else demonstrated not to exist) around a number of nearby stars. Whether it is reasonable to examine binaries or restrict the search to single stars like the sun is an open question; astronomers will probably target some of both in their ongoing effort to uncover a planetary system comfortingly similar to our own.

The Author

ALAN P. BOSS began modeling the formation of stellar and planetary systems as a physics graduate student at the University of California, Santa Barbara, where he received a doctorate in 1979. After two years at the National Aeronautics and Space Administration Ames Research Center, he joined the Department of Terrestrial Magnetism at the Carnegie Institution of Washington (where, despite its name, terrestrial magnetism has not been studied for decades). Boss chairs a committee that advises NASA about searches for planets outside the solar system.

Further Reading

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Quantum-Mechanical Computers

Quantum-mechanical computers, if they can be constructed, will do things no ordinary computer can

by Seth Lloyd

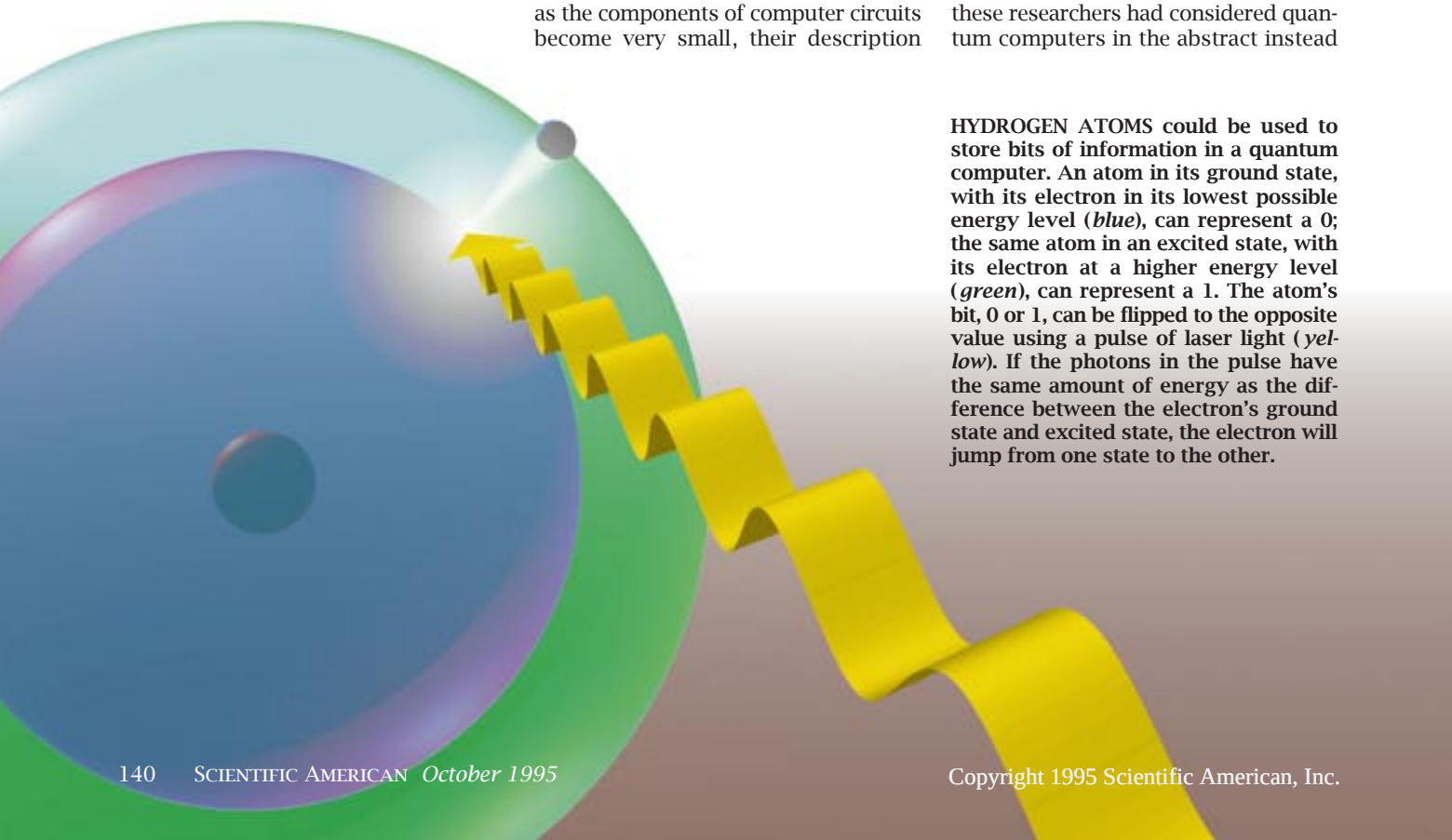
Every two years for the past 50, computers have become twice as fast while their components have become twice as small. Circuits now contain wires and transistors that measure only one hundredth of a human hair in width. Because of this explosive progress, today's machines are millions of times more powerful than their crude ancestors. But explosions do eventually dissipate, and integrated-circuit technology is running up against its limits.

Advanced lithographic techniques can yield parts 100 times smaller than what is currently available. But at this scale—where bulk matter reveals itself as a crowd of individual atoms, integrated circuits barely function. Ten times smaller again, the individuals assert their identity, and a single defect can wreak havoc. So if computers are to become much smaller in the future, new technology must replace or supplement what we now have.

Several decades ago pioneers such as Rolf Landauer and Charles H. Bennett, both at the IBM Thomas J. Watson Research Center, began investigating the physics of information-processing circuits, asking questions about where miniaturization might lead: How small can the components of circuits be made? How much energy must be used up in the course of computation? Because computers are physical devices, their basic operation is described by physics. One physical fact of life is that as the components of computer circuits become very small, their description must be given by quantum mechanics.

In the early 1980s Paul Benioff of Argonne National Laboratory built on Landauer and Bennett's earlier results to show that a computer could in principle function in a purely quantum-mechanical fashion. Soon after, David Deutsch of the Mathematical Institute at the University of Oxford and other scientists in the U.S. and Israel began to model quantum-mechanical computers to find out how they might differ from classical ones. In particular, they wondered whether quantum-mechanical effects might be exploited to speed computations or to perform calculations in novel ways.

By the middle of the decade, the field languished for several reasons. First, all these researchers had considered quantum computers in the abstract instead



HYDROGEN ATOMS could be used to store bits of information in a quantum computer. An atom in its ground state, with its electron in its lowest possible energy level (*blue*), can represent a 0; the same atom in an excited state, with its electron at a higher energy level (*green*), can represent a 1. The atom's bit, 0 or 1, can be flipped to the opposite value using a pulse of laser light (*yellow*). If the photons in the pulse have the same amount of energy as the difference between the electron's ground state and excited state, the electron will jump from one state to the other.

of studying actual physical systems—an approach that Landauer faulted on many counts. It also became evident that a quantum-mechanical computer might be prone to errors and have trouble correcting them. And apart from one suggestion, made by the late Richard P. Feynman of the California Institute of Technology, that quantum computers might be useful for simulating other quantum systems (such as new or unobserved forms of matter), it was unclear that they could solve mathematical problems any faster than their classical cousins.

In the past three years, the picture has changed. In 1993 I described a large class of familiar physical systems that might act as quantum computers in ways that avoid some of Landauer's objections. Peter W. Shor of AT&T Bell Laboratories has demonstrated that a quantum computer could be used to factor large numbers—a task that can foil the most powerful of conventional machines. And in the past year, workshops at the Institute for Scientific Interchange in Turin, Italy, have spawned many designs for constructing quantum circuitry. Most recently, H. Jeff Kimble's group at Caltech and David J. Wineland's team at the National Institute of Standards and Technology have built some of these prototype parts. This article explains how quantum computers might be assembled and describes some of the astounding things they could do that digital computers cannot.

Quantum Mechanics

Let's face it, quantum mechanics is weird. Niels Bohr, the Danish physicist who helped to invent the field, said, "Anyone who can contemplate quantum mechanics without getting dizzy hasn't properly understood it." For better or worse, quantum mechanics predicts a number of counterintuitive effects that have been verified experimentally again and again. To appreciate the weirdness of which quantum computers are capable, we need accept only a single strange fact called wave-particle duality.

Wave-particle duality means that things that we normally think of as solid particles, such as basketballs and atoms, behave under some circumstances like waves and that things we normally describe as waves, such as sound and light, occasionally behave like particles. In essence, quantum-mechanical theory sets forth what kind of waves are associated with what kind of particles and vice versa.

The first strange implication of wave-particle duality is that small systems such as atoms can exist only in discrete energy states. So when an atom moves from one energy state to another, it absorbs and emits energy in exact amounts, or "chunks," called photons, which might be considered the particles that make up light waves.

A second consequence is that quantum-mechanical waves, like water waves, can be superposed, or added together. Taken individually, these waves offer a rough description of a given particle's position. When two or more such waves are combined, though, the particle's position becomes unclear. In some weird quantum sense, then, an electron can sometimes be both here and there at the same time. Such an electron's location will remain unknown until some interaction (such as a photon bouncing off the electron) reveals it to be either here or there but not both.

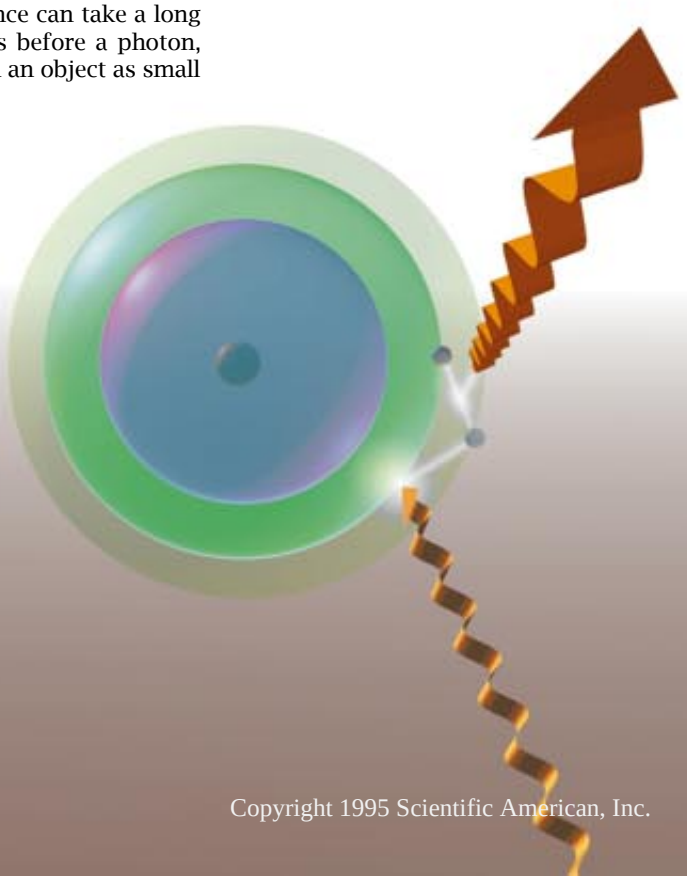
When two superposed quantum waves behave like one wave, they are said to be coherent; the process by which two coherent waves regain their individual identities is called decoherence. For an electron in a superposition of two different energy states (or, roughly, two different positions within an atom), decoherence can take a long time. Days can pass before a photon, say, will collide with an object as small as an electron, exposing its true position. In principle, basketballs could be both here and there at once as well (even in the absence of Michael Jordan). In practice, however, the time it takes for a photon to bounce off a ball is too brief for the eye or any instrument to detect. The ball is simply too big for its exact location to go undetected for any perceivable amount of time. Consequently, as a rule only small, subtle things exhibit quantum weirdness.

Quantum Information

Information comes in discrete chunks, as do atomic energy levels in quantum mechanics. The quantum of information is the bit. A bit of information is a simple distinction between two alternatives—no or yes, 0 or 1, false or true. In digital computers, the voltage between the plates in a capacitor represents a bit of information: a charged capacitor registers a 1 and an uncharged capacitor, a 0. A quantum computer functions by matching the familiar discrete character of digital information processing to the strange discrete character of quantum mechanics.

Indeed, a string of hydrogen atoms can hold bits as well as a string of capacitors. An atom in its electronic ground state could encode a 0 and in an excited state, a 1. For any such quantum system to work as a computer, though, it must be capable of more than storing bits. An operator must be able to load information onto the sys-

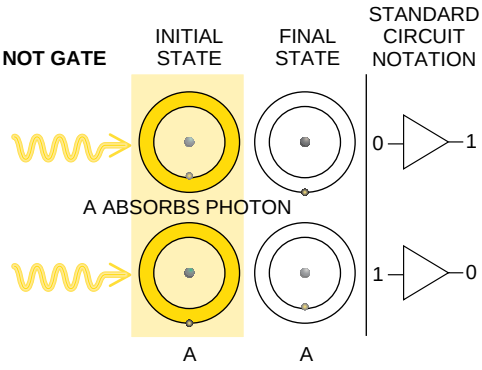
BORIS STAROSTA



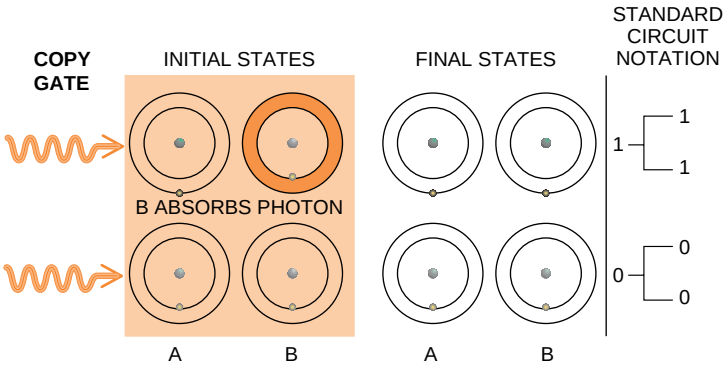
READING the bit an atom stores is done using a laser pulse having the same amount of energy as the difference between the atom's excited state, call it E_1, and an even higher, less stable state, E_2. If the atom is in its ground state, representing a 0, this pulse has no effect. But if it is in E_1, representing a 1, the pulse pushes it to E_2. The atom will then return to E_1, emitting a telltale photon.

Quantum Logic Gates

Logic gates are devices that perform elementary operations on bits of information. The Irish logician George Boole showed in the 19th century that any complex logical or arithmetic task could be accomplished using combinations of three simple operations: NOT, COPY and AND. In fact, atoms, or any other quantum system, can perform these operations.



NOT involves nothing more than bit flipping, as the notation at the right shows: if *A* is 0, make it a 1, and vice versa. With atoms, this can be done by applying a pulse whose energy equals the difference between *A*'s ground state (its electron is in its lowest energy level, shown as the inner ring) and its excited state (shown as the outer ring). Unlike conventional NOT gates, quantum ones can also flip bits only halfway.



COPY, in the quantum world, relies on the interaction between two different atoms. Imagine one atom, *A*, storing either a 0 or 1, sitting next to another atom, *B*, in its ground state. The difference in energy between the states of *B* will be a certain value if *A* is 0, and another value if *A* is 1. Now apply a pulse of light whose photons have an energy equal to the latter amount. If the pulse is of the right intensity and duration and if *A* is 1, *B* will absorb a photon and flip (*top row*); if *A* is 0, *B* cannot absorb a photon from the pulse and stays unchanged (*bottom row*). So, as in the diagram at the right, if *A* is 1, *B* becomes 1; if *A* is 0, *B* remains 0.

MICHAEL GOODMAN

tem, to process that information by way of simple logical manipulations and to unload it. That is, quantum systems must be capable of reading, writing and arithmetic.

Isidor Isaac Rabi, who was awarded the Nobel Prize for Physics in 1944, first showed how to write information on a quantum system. Applied to hydrogen atoms, his method works as follows. Imagine a hydrogen atom in its ground state, having an amount of energy equal to E_0. To write a 0 bit on this atom, do nothing. To write a 1, excite the atom to a higher energy level, E_1. We can do so by bathing it in laser light made up of photons having an amount of energy equal to the difference between E_1 and E_0. If the laser beam has the proper intensity and is applied for the right length of time, the atom will gradually move from the ground state to the excited state, as its electron absorbs a photon. If the atom is already in the excited state, the same pulse will cause it to emit a photon and go to the ground state. In terms of information storage, the pulse tells the atom to flip its bit.

What is meant here by gradually? An oscillating electric field such as laser light drives an electron in an atom from a lower energy state to a higher one in the same way that an adult pushes a child on a swing higher and higher. Each time the oscillating wave comes around, it gives the electron a little push. When the photons in the field have the same energy as the difference between E_0 and E_1, these pushes coincide with the electron's "swinging" motion and gradually convert the wave corresponding to the electron into a superposition of waves having different energies. The amplitude of the wave associated with the electron's ground state will continuously diminish as the amplitude of the wave associated with the excited state builds. In the process, the bit registered by the atom "flips" from the ground state to the excited state. When the photons have the wrong frequency, their pushes are out of sync with the electron, and nothing happens.

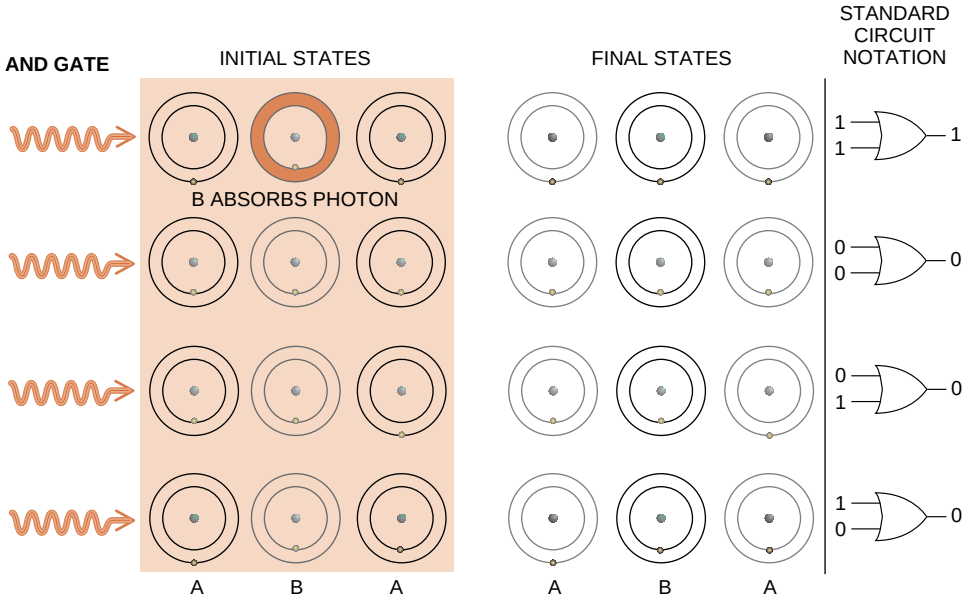
If the right light is applied for half the time it takes to flip the atom from 0 to 1, the atom is in a state equal to a superposition of the wave corresponding to 0 and the wave corresponding to 1, each having the same amplitudes. Such a quantum bit, or qubit, is then flipped only halfway. In contrast, a classical bit will always read either 0 or 1. A half-charged capacitor in a conventional computer causes errors, but a half-flipped qubit opens the way to new kinds of computation.

Reading bits from a quantum system is similar to flipping them. Push the atom to an even higher, less stable energy state, call it E_2. Do so by subjecting the atom to light having an energy equal to the difference between E_1 and E_2: if the atom is in E_1, it will be excited to E_2 but decay rapidly back to E_1, emitting a photon. If the atom is already in the ground state, nothing happens. If it is in the "half-flipped" state, it has an equal chance of emitting a photon and revealing itself to be a 1, or of not emitting a photon, indicating that it is a 0. From writing and reading information in a quantum system, it is only a short step to computing.

Quantum Computation

Electronic circuits are made from linear elements (such as wires, resistors and capacitors) and nonlinear elements (such as diodes and transistors) that manipulate bits in different ways. Linear devices alter input signals individually. Nonlinear devices, on the other hand, make the input signals passing through them interact. If your stereo did not contain nonlinear transistors, for example, you could not change the bass in the music it plays. To do so requires some coordination of the information coming from your CD and the information coming from the adjustment knob on the stereo.

Circuits perform computations by way of repeating a few simple linear and nonlinear tasks over and over at



AND also depends on atomic interactions. Imagine three atoms, *A*, *B* and *A*, sitting next to one another. The difference in energy between the ground and excited states of *B* is a function of the states of the two *A*'s. Suppose *B* is in its ground state. Now apply a pulse whose energy equals the difference between the two states of *B* only when the atom's neighboring *A*'s are both 1. If, in fact, both *A*'s are 1, this pulse will flip *B* (*top row*); otherwise it will leave *B* unchanged (*all other rows*).

great speed. One such task is flipping a bit, which is equivalent to the logical operation called NOT: true becomes false, and false becomes true. Another is COPY, which makes the value of a second bit the same as the first. Both those operations are linear, because in both the output reflects the value of a single input. Taking the AND of two bits—another useful task—is a nonlinear operation: if two input bits are both 1, make a third bit equal to 1 as well; otherwise make the third bit a 0. Here the output depends on some interaction between the inputs.

The devices that execute these operations are called logic gates. If a digital computer has linear logic gates, such as NOT and COPY gates, and nonlinear ones as well, such as AND gates, it can complete any logical or arithmetic task. The same requirements hold for quantum computers. Artur Ekert, working with Deutsch and Adriano Barenco at Oxford, and I independently have shown that almost any nonlinear interaction between quantum bits will do. Indeed, provided a quantum computer can flip bits, any nonlinear quantum interaction enables it to perform any computation. Hence, a variety of physical phenomena might be exploited to construct a quantum computer.

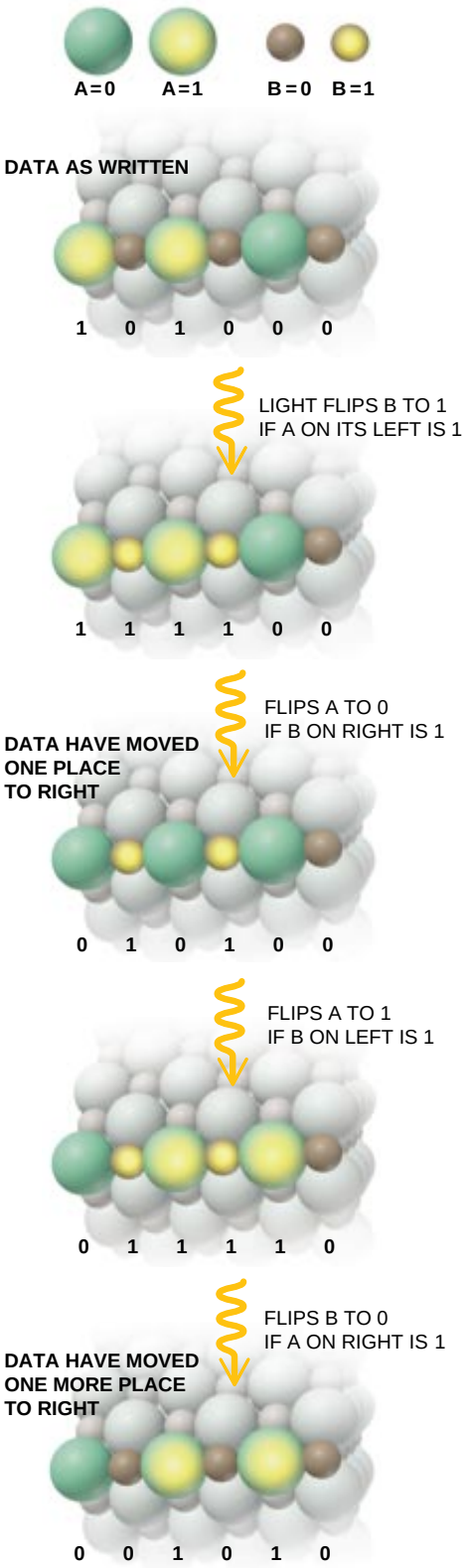
In fact, all-purpose quantum logic gates have been around almost as long as the transistor! In the late 1950s, researchers managed to perform simple two-bit quantum logic operations using particle spins. These spins—which are simply the orientation of a particle's rotation with respect to some magnetic field—are, like energy levels, quantized. So a spin in one direction can represent a 1 and in the other, a 0. The researchers took advantage of the interaction between the spin of the electron and the spin of the proton in a hydrogen atom; they set up a system in which they flipped the proton's spin only if the electron's spin represented a 1. Because these workers were not thinking about quantum logic, they called the effect double resonance. And yet they used double resonance to carry out linear NOT and COPY operations.

Since then, Barenco, David DiVincenzo of IBM, Tycho Sleator of New York University and Harald Weinfurter of the University of Innsbruck have shown how, by flipping proton and electron spins only part way, double resonance can be used to create an AND gate as well. Such quantum logic gates, wired together, could make a quantum computer. Needless to say, quantum "wires" are hard to build. In a conventional computer, the wires need only be strips of metal, which readily transmit voltage signals from one logic gate to another. Wiring together double resonance gates, on the other hand, is an outrageously difficult task: the wire must be able to disassemble atoms in order to move electrons and protons about at will and then reassemble atoms, all without disturbing the particles' spins.

Researchers have recently devised less daunting means for linking quantum logic gates. For example, single photons passing through optical fibers or through the air can ferry bits of information from one gate to another. A particularly promising development has come from Caltech: by concentrating photons together with a single atom in a minute volume, Kimble's group has enhanced the usually tiny nonlinear interaction between photons. The result is a quantum logic gate: one photon bit can be flipped partway when another photon reads 1. A computer built entirely from quantum optical gates of this kind would be fast and relatively immune to perturbations from the environment that would destroy coherence, but it would still face a number of the hurdles Landauer predicted. Notably, the length of all optical paths in the system would have to be accurate to within a tiny fraction of a wavelength of the light used.

There are other solutions to the wiring problem. J. Ignacio Cirac of the University of Castilla–La Mancha in Spain and Peter Zoller of the University of Innsbruck have proposed a design that would isolate qubits in an ion trap, effectively insulating them from any unwanted external influences. Before a bit were processed, it would be transferred to a common register, or "bus." Specifically, the information it contained would be represented by a rocking motion involving all the ions in the trap. Wineland's group at NIST has taken the first step in realizing such a quantum computer, performing both linear and nonlinear operations on bits encoded by ions and by the rocking motion. The prospects are good for building ion-trap computers having a few tens or hundreds of bits: two-bit operations have been done, and the number of bits in the computer can be increased simply by adding more ions to the trap.

As it stands, scientists can control quantum logic operations on a few bits, and in the near future, they might well do quantum computations using a few tens or hundreds of bits. How can this

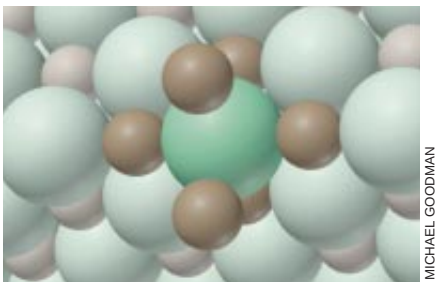


possibly represent an improvement over classical computers that routinely handle billions of bits? In fact, even with one bit, a quantum computer can do things no classical computer can. Consider the following. Take an atom in a superposition of 0 and 1. Now find out whether the bit is a 1 or a 0 by making it fluoresce. Half of the time, the atom emits a photon, and the bit is a 1. The other half of the time, no photon is emitted, and the bit is a 0. That is, the bit is a random bit—something a classical computer cannot create. The random-number programs in digital computers actually generate pseudorandom numbers, using a function whose output is so irregular that it seems to produce bits by chance.

Multiparticle Quantum States

Imagine what a quantum computer can do with two bits. Copying works by putting together two bits, one with a value to be copied and one with an original value of 0; an applied pulse flips the second bit to 1 only if the first bit is also 1. But if the value of the first bit is a superposition of 0 and 1, then the applied pulse creates a superposition involving both bits, such that both are 1 or both are 0. Notice that the final value of the first bit is no longer the same as it was originally—the superposition has changed.

In each component of this superposition, the second bit is the same as the first, but neither is the same as the original bit. Albert Einstein noted that such states would violate all classical intuition about causality. In such a superposition, neither bit is in a definite state, yet if you measure one bit, thereby putting it in a definite state, the other bit also enters into a definite state. The change in the first bit does not *cause* the change in the second. But by virtue of destroying the coherence between the two, measuring the first bit also robs the second of its ambiguity. Even stranger entangled states can be established between three qubits.



MICHAEL GOODMAN

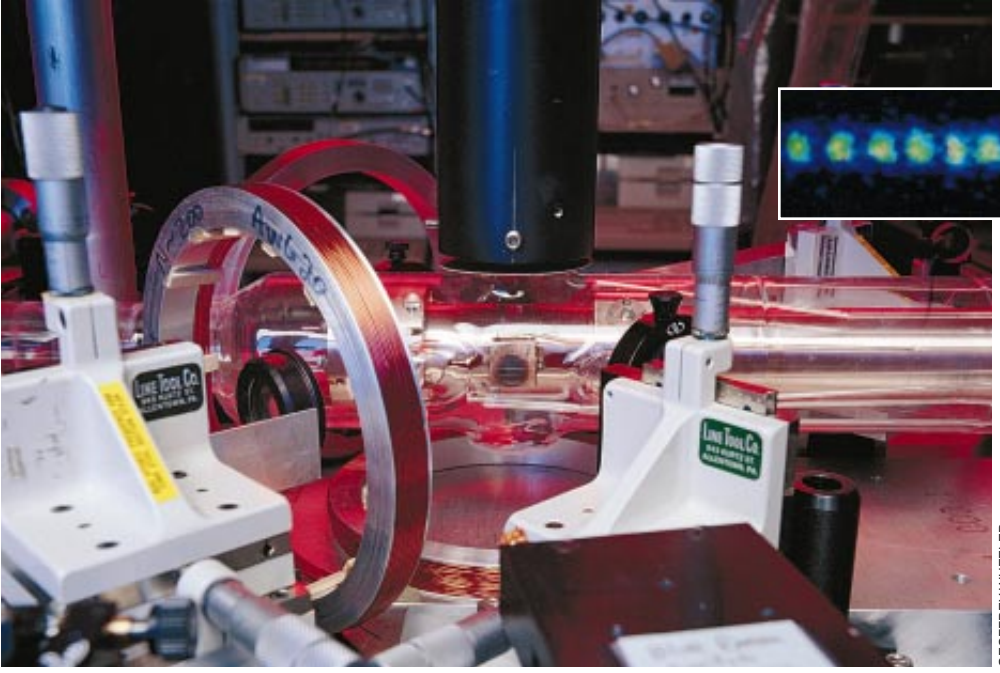
SALT CRYSTAL could be made to compute by acting on pairs of neighboring ions. Flip the bit held by each *B* if the *A* on its left stores a 1; then flip each *A* if the *B* on its right is 1. This moves the information from each *A* to the *B* on its right. Now, using the same tactics, move the information from each *B* to the *A* on its right. The process allows a line of atoms to act as a quantum "wire." Because a crystal can carry out these "double resonance" operations simultaneously in all directions with every neighboring ion (*bottom, right*), the crystal can mimic the dynamics of any system and so serves as a general-purpose quantum analog computer.

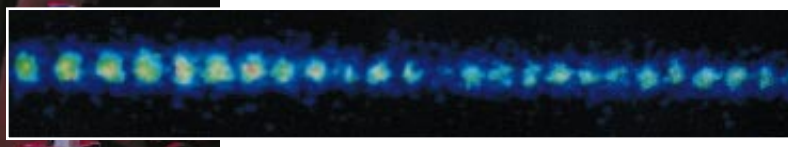
Indeed, given just two or three qubits, and one or two quantum logic gates, it is possible to create fascinating quantum states. I have shown that with more bits, a quantum computer could be used to simulate the behavior of any quantum system. When properly programmed, the computer's dynamics would become exactly the same as the dynamics of some postulated system, including that system's interaction with its environment. And the number of steps the computer would need to chart the evolution of this system over time would be directly proportional to the size of the system.

Even more remarkable, if a quantum computer had a parallel architecture, which could be realized through the double resonance between neighboring pairs of spins in the atoms of a crystal, it could mimic any quantum system in real time, regardless of its size. This kind of parallel quantum computation, if possible, would give a huge speed-up over conventional methods. As Feynman noted, to simulate a quantum system on a classical computer generally requires a number of steps that rises exponentially both with the size of the system and with the amount of time over which the system's behavior is tracked. In fact, a 40-bit quantum computer could re-create in little more than, say, 100 steps, a quantum system that would take a classical computer, having a trillion bits, years to simulate.

What can a quantum computer do with many logical operations on many qubits? Start by putting all the input bits in an equal superposition of 0 and 1, each having the same magnitude. The computer then is in an equal superposition of all possible inputs. Run this input through a logic circuit that carries out a particular computation. The result is a superposition of all the possible outputs of that computation. In some weird quantum sense, the computer performs all possible computations at once. Deutsch has called this effect "quantum parallelism."

Quantum parallelism may seem odd, but consider how waves work in general. If quantum-mechanical waves were sound waves, those corresponding to 0 and 1—each oscillating at a single frequency—would be pure tones. A wave corresponding to a superposition of 0 and 1 would then be a chord. Just as a musical chord sounds qualitatively different from the individual tones it in-





GEOFFREY WHEELER

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

READOUT from a quantum computer might look like the image above. Each colored spot is the fluorescent light coming from a single mercury ion in an ion trap (*left*). The light indicates that each ion is in the same state, so the entire string reads as a series of 1's.

cludes, a superposition of 0 and 1 differs from 0 and 1 taken alone: in both cases, the combined waves interfere with each other.

A quantum computer carrying out an ordinary computation, in which no bits are superposed, generates a sequence of waves analogous to the sound of "change ringing" from an English church tower, in which the bells are never struck simultaneously and the sequence of sounds follows strict mathematical rules. A computation done in quantum parallel mode is like a symphony: its "sound" is that of many waves interfering with one another.

Shor of Bell Labs has recently shown that the symphonic effect of quantum parallelism might be used to factor large numbers very quickly—something classical computers and even supercomputers cannot always accomplish. Shor demonstrated that a quantum parallel computation can be orchestrated so that potential factors will stand out in the superposition the same way that a melody played on violas, cellos and violins an octave apart will stand out over the sound of the surrounding instruments in a symphony. Indeed, his algorithm would make factoring an easy task for a quantum computer, if one could be built. Because most public-key encryption systems—such as those protecting electronic bank accounts—rely on the fact that classical computers cannot find factors having more than, say, 100 digits, quantum-computer hackers would give many people reason to worry.

Whether or not quantum computers (and quantum hackers) will come about is a hotly debated question. Recall that the quantum nature of a superposition prevails only so long as the environment refrains from somehow revealing the state of the system. Because quantum computers might still consist of thousands or millions of atoms, only one of which need be disturbed to damage quantum coherence, it is not clear how long interacting quantum systems can last in a true quantum superposition. Experimental evidence suggests that some systems can maintain quantum superpositions for several hours. Shor and his collaborators have shown that his algorithm still functions in the face of modest levels of decoherence.

Another problem quantum computers face is error correction. The various systems that might be used to register and process information are susceptible to noise, which can flip bits at random. Classical methods for error correction involve measuring bits to see if they are wrong, which in a quantum computer would result in decoherence. Ekert's and Deutsch's groups have shown that quantum error correction is possible in principle but unwieldy in practice. So even if quantum computers can be built, they may not be able to perform computations involving many bits over long periods.

To surpass the factoring ability of current supercomputers, quantum computers using Shor's algorithm might need to follow hundreds of bits over thousands of steps, maintaining quantum coherence all the while. Because of the technical problems mentioned by Landauer, including decoherence, uncontrollable variations in laser pulses and the lack of effective error correction, building a computer to perform such a computation will very likely prove difficult. To surpass classical simulations of quantum systems, however, would require only tens of bits followed for tens of steps, a goal that is more attainable. And to use quantum logic to create strange, multiparticle quantum states and to explore their properties is a goal that lies in our current grasp.

The Author

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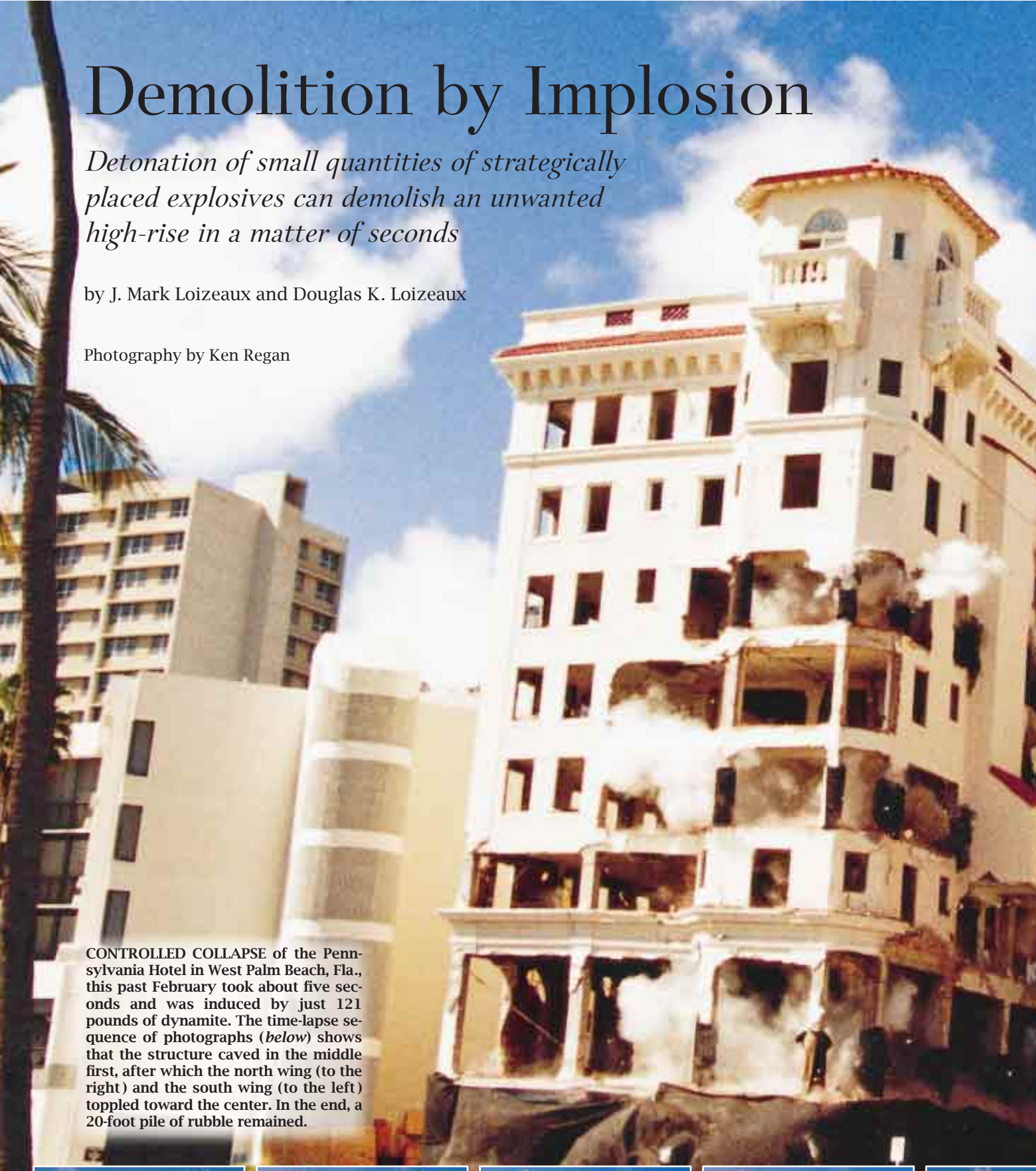
Demolition by Implosion

Detonation of small quantities of strategically placed explosives can demolish an unwanted high-rise in a matter of seconds

by J. Mark Loizeaux and Douglas K. Loizeaux

Photography by Ken Regan



CONTROLLED COLLAPSE of the Pennsylvania Hotel in West Palm Beach, Fla., this past February took about five seconds and was induced by just 121 pounds of dynamite. The time-lapse sequence of photographs (*below*) shows that the structure caved in the middle first, after which the north wing (to the right) and the south wing (to the left) toppled toward the center. In the end, a 20-foot pile of rubble remained.

PHOTOGRAPHS BY KEN REGAN *Camera 5*





PREPARING THE HOTEL for implosion included slicing the building in two (*above, showing a back view*). This maneuver later helped to cause the north and south wings to collapse toward the center. In addition, steel cables were connected from one column to another (*top left*) to help draw the south wing of the building away from a narrow alley separating the hotel from a nursing home. A test blast done several days before the implosion assessed the structural integrity of the columns (*bottom left*) and showed their concrete to be rather weak.

The Pennsylvania Hotel, a cream-colored Mediterranean revival structure facing the Intracoastal Waterway in West Palm Beach, Fla., stood for 69 years. In its first life, it welcomed visitors for nearly four decades. It even counted the occasional luminary—including Elvis Presley and Hoagy Carmichael—among its guests. In 1964 the eight-story building assumed a new role, when a religious order, the Carmelite Sisters, converted it into a retirement hotel for the elderly. Eventually, though, the sisters decided the structure needed to be replaced with a building offering more modern amenities.

So on Saturday, February 18, 1995, the Pennsylvania Hotel retired from its long service—in an interval of but five seconds. At 11:14 A.M., the staccato report of dynamite charges reverberated down city streets and across the water. In a blink, the center section of the roof dropped earthward. Its fall began to pull the rest of the structure toward the ground as well.

In another blink, a brownish cloud of dust reached 100 feet into the air—once the height of the hotel itself. When the dust cleared within a minute, a 20-foot-high pile of debris was all that remained of the venerable residence. A building only 14 feet from where the hotel's south wall had stood was blanketed with dust but otherwise unscathed.

The razing of the Pennsylvania Hotel is an example of a type of demolition called implosion, a name first applied to the technique by our company, Controlled Demolition Incorporated (CDI), based in Phoenix, Md. The term, borrowed from physics, means a violent bursting inward. An implosion has nothing to do with "blowing up" a building, a notion associated with the thousands of pounds of explosives that have been employed in terrorist bombings. In bringing down a building, only enough dynamite is used to eliminate critical structural supports—often just 200 pounds is needed for a 10-story building. The weight of the edifice then produces its own collapse.

The quantity of explosives is less important than are the placement of the charges and the timing of their detonation. The charges must detonate where a structure would fail naturally, if it were ever overloaded or thrust into what we call its natural failure mode. By carefully calculating where to place the charges—and the sequence in which they are detonated—we can determine where the concrete and steel debris will fall to the ground: a wall touching another building can be pulled away before it drops, with no damage to the adjoining structure. These events, moreover, occur in seconds, in contrast to the weeks or months of noise and dust that are produced by demolishing a structure with a wrecking ball or by dismantling it through manual labor.

The techniques for razing a building by implosion have never made their way into any engineering school. Indeed, they have been perfected mostly by members of our family. Our family's experience, amassed over five decades, comes from razing more than 7,000 structures, including 1,700 high-rise buildings. Because our knowledge of how to collapse a structure with explosives was gained through years of experimentation, our approach cannot be replicated consistently by most other demolition contractors.

Until the late 1950s, explosives had occasionally been employed to fell unneeded chimneys or industrial structures in open areas. Our father, Jack Loizeaux, extended and refined those early techniques. Having gained experience in using explosives to remove stumps that remained after cutting down trees blighted by Dutch Elm disease, Jack, who is now 80, began to apply his skills some 50 years ago to razing chimneys, bridges and, eventually, multistory structures. In 1957 he became the first person to take down buildings in heavily populated urban areas. The two of us became involved in placing and detonating explosives while still youths and took over the

LOADING OF COLUMNS with dynamite required holes to be drilled by a vehicle outfitted with a rotary drill (*top left*). Later, sticks of dynamite were broken, and blasting caps were inserted (*bottom left*). The primed dynamite was packed, cushioned by small sandbags, into the holes with a wooden dowel (*wielded by Doug at top right*).

business when Jack retired in the 1980s.

Each building has its own personality, manifested not only in its design but also in the 60-year-old sardine cans and scraps of prewar newspaper that turn up once we start knocking out walls and drilling holes in the support columns to insert the dynamite. A building's distinctive character is also revealed in the diverse technical challenges presented because of structural anomalies or proximity to other facilities that must remain intact. The Pennsylvania Hotel was neither the largest nor the most difficult structure we have demolished. But its destruction with explosives illustrates many of the strategies we apply and the kinds of problems we face routinely.

A Challenge in Florida

The hotel initially seemed as if it would present only minor difficulties. Our biggest challenge would be ensuring that the implosion did not damage the Lourdes-Noreen McKeen Nursing Home—the facility, also owned by the Carmelite Sisters, that sat 14 feet from the south wall of the hotel across an adjoining alleyway.

Ideally, we would have obtained blueprints of the hotel to aid us in preparing for the implosion, but none existed for a building of this age. We did receive, however, the standard plan of the interior that shows the location of fire exits and building columns, although some of the column placements indicated in the plan turned out to be incorrect. From this information, and an initial trip Doug made to Florida to inspect the strength of the concrete and the type of steel reinforcing in the columns, we deduced the implosion would require placing an average of half a pound or so of explosives in each of a total of 400 holes drilled in columns on three floors. We then instructed the local contractor that had hired us on where to drill the various holes.

Our relationship with this contractor, Cobra, Inc., was typical of the arrangement in many of our projects. We often serve as a consultant to the property owner—in this case, the Carmelite Sisters—and as a specialty subcontractor to the main demolition firm. We provide planning expertise and, after the building is prepared, take responsibility for staging the implosion.

Before we arrived, Cobra had to strip the hotel of everything except the 11,000 tons of support columns, beams, floor slabs and exterior walls that held the building upright. By the day of the implosion, the company had already carted away 4,500 tons of debris, including the remains of an elevator, a low-rise parking garage and a swimming pool.

Our first hint that the job would be more difficult than expected came about two weeks before the scheduled implosion, during a telephone conversation with the president of Cobra. He reported that the drilling of the 400 holes was proceeding quickly—to our minds, a little too quickly. The speed at which the crew progressed, completing 100 or more holes a day, was a sign that the concrete was weaker than our initial inspection had suggested and that the reinforcing steel bars in the columns had deteriorated substantially over the hotel's long lifetime. A subsequent test blast—the detonation of a small amount of dynamite in a few selected columns—confirmed the debility of the material.

Concrete is a mixture of cement, water and a coarser material, often gravel, called aggregate. The bonding of the cement with aggregate is what gives concrete the compressive strength needed to sustain the heavy loads placed on the columns that support the building. In Florida the builders of many older structures had used beach sand in the cement without washing out the salt and had also used an aggregate known as cocina limestone, which is essentially calcified coral. Besides being easily eroded, this concrete does not adhere well to the steel reinforcing bars that supply tensile strength (the ability to withstand pulling mo-

COLUMNS WERE WRAPPED with chain-link fencing and then heavy fabric (*left*) to prevent debris from flying everywhere. Once the columns were loaded with dynamite, wires from the blasting caps in each column were connected to one another. Finally, wires from the upper floors were dropped through an elevator shaft (*right*), drawn outside and connected to a blasting machine that set off the implosion.

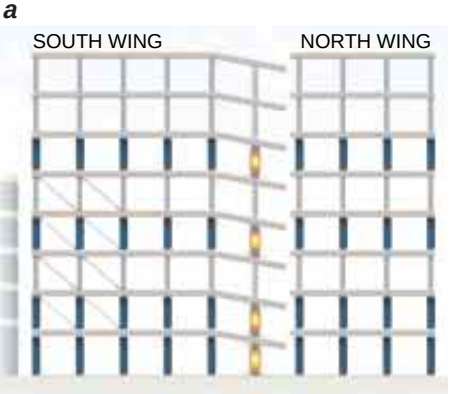
tions). The salt in the sand starts a slow oxidation of the reinforcing bars, which further reduces their attachment to the concrete and weakens the structure.

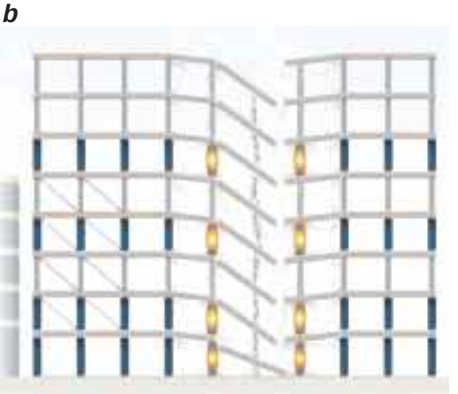
Weak concrete can severely hinder our control over the rate of a building's collapse and over where debris falls after the dynamite detonates. Demolition by implosion resembles the art of a judo expert who downs an opponent by first kicking out the opponent's leg and then twisting the adversary's off-balance upper body to the mat. The martial-arts master takes advantage of the natural balance and intrinsic resistance of a partner's body—the rigidity of the rib cage and other bone structures. Similarly, we must make sure that the columns and beams of the collapsing building retain enough lingering stiffness so that they can be guided where we want them. Otherwise, igniting the explosives resembles setting off a firecracker in a ball of dirt: the pieces fly every which way.

Reconstruction for Destruction

For these reasons, a fragile building such as the Pennsylvania Hotel had to be partly rebuilt before it could be torn down. In other jobs, we occasionally have had to pour new concrete and install braces to shore up a structure before imploding it. Although we did not add supplementary concrete in West Palm Beach, a number of precautionary steps were taken before loading the dynamite to ensure that the building would fall safely away from the nursing home across the alley.

We needed the concrete beams that supported each floor to collapse in a manner that would pull the building away from the alley. Because of the softness of the concrete, we had to add to the natural "pull" of the beams. We did so by attaching three-quarter-inch steel cables between adjacent columns in the south wing—which stood on the left side of the roughly horseshoe-shaped facility. The cables were attached to the top of a series of columns, affixed to the bottom of the nearest columns to the north and tensioned. On detonation of the charges, the cables' oblique tug would help drag the south wing away from the alley and the nursing home. We also had to make a cavity in which the rubble could collect safely. So we asked Cobra to excavate dirt below the ground floor of the south wing, creating a basement where none was before.





Although we had to strengthen the building in some places, we had to promote its collapse in others. To further ensure that the cross beams in the old hotel would pull the south wall away from the alley, we had Cobra make a structural change in the west wing as well—that is, in the connecting loop of the horseshoe. The workers essentially severed the building into two independent parts, making a cut that spanned from front to back and from ground to roof [*see illustration at top right on page 148*]. Only a few of the steel reinforcing bars in the beams that had connected the two parts were intentionally left intact. Those bars provided enough support to prevent premature failure of the floor slabs during the week the building was to remain standing.

We intended to detonate the charges in a sequence that would induce the columns closest to the cut to fail first, followed in series by the next row of columns on either side of the cut, then the next and so on. Moreover, the columns in the north wing would fall just before those of the south wing, which would tumble onto the northern rubble. We knew from having worked on similar structures that unless we divided the building in two, the first columns in which the explosives were detonated would not drop to the ground on cue. The horizontal beams would shakily support the vertical columns for a fraction of a second too long, causing the columns throughout the structure to fall in unpredictable directions. In fact, the southern columns might tilt the wrong way momentarily before collapsing, causing rubble to slide across the worrisome alleyway.

Severing the structure, in contrast, would ensure that the columns would fail precisely in the timed sequence we had programmed. Beams previously braced by a column would become unstable cantilevers. So when the first row of columns on either side of the cut fell, the beams previously supported by the pillars would rotate earthward. As they leaned (into the cut), they would exert a downward diagonal pull on adjacent beams and columns. That motion would mark the start of a controlled and progressive collapse that, fueled by the timed detonation of other explosive charges, would force the entire building to incline in the desired direction.

Final Preparations

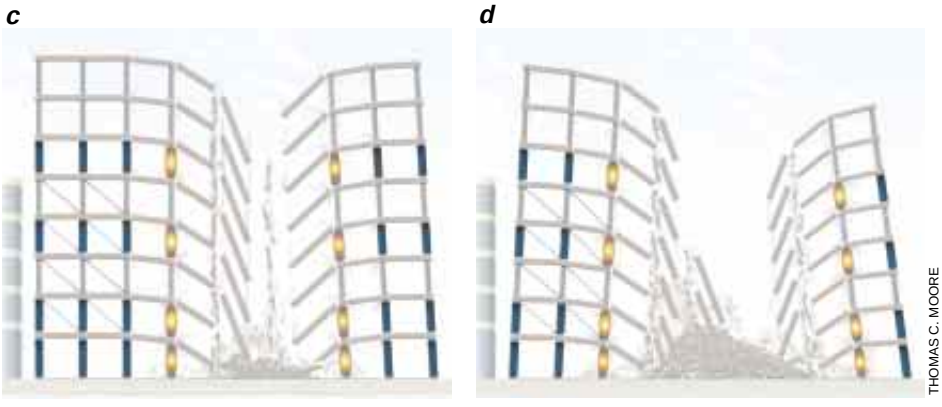
Beginning on Thursday, February 16, we started the laborious task of loading the dynamite into the drilled holes and wiring the charges together, in preparation for the Saturday implosion. The crumbling concrete meant less dynamite would be needed to trigger the fall of the columns and beams—approximately a quarter pound per hole instead of the half pound of dynamite originally planned. At the same time, we decided to spread the explosives in more places. For instance, we put dynamite in an additional upper floor to make the columns fail more quickly. In the end, we used a total of 121 pounds, far less than we initially expected. The softness of the concrete also meant the building had to be brought down very fast, or we might lose control of where the debris would fall. We therefore accelerated the timing of the detonations, intending to demolish the building in about five seconds—half the time required for some other buildings that retain more structural integrity and about two seconds faster than our original plan.

Some 520 holes, not the original 400 planned, were loaded with dynamite on the first, second, fourth and sixth floors. One, two or three holes were drilled in a column depending on how quickly we wanted that particular column to collapse. To place the charges in the holes, we cut half-pound sticks of dynamite into as many as three pieces. The dynamite—a commercial mixture—was a moderately high velocity explosive. It detonates at a rate of around 18,000 feet per second, about one third slower than the highest-velocity explosives.

Into one end of the dynamite went an electric blasting cap, which sets off the detonation. Caps can set off the explosive instantaneously or follow a predetermined delay; in this case, the delays ranged up to 2.25 seconds (for the columns farthest away from the cleft dividing the hotel). Small bags of sand, called stemming bags, were positioned in the holes, one on each side of the dynamite, in part to confine the explosive energy within the column.

Both sand and dynamite were packed firmly into the holes using a wooden dowel, an action that resembles the wadding of a cannon. Still protruding from the holes were red and green wires that would deliver the electric current to the blasting caps. On Friday, the day before the explosion, we attached the free end of the wires from each hole to wires from other holes and then to wires from nearby columns on the same floor. Finally, the wires from the upper floors were dropped to the ground floor, picking up wiring connections from lower floors along the way. These circuits, eight of them in all, got connected to a blasting machine that would provide the current needed to initiate the implosion.

Any time explosives are set off, the fragmentation of the concrete in the columns can create projectiles, some as big as a softball, that can injure people and damage property. To check their flight, we wrapped each column with a chain-link fence, which would allow the column to expand and gases to escape but would form a barrier against large airborne fragments. The columns were further covered with heavy polypropylene fabric, which safeguarded against the escape of smaller pieces of debris. The same material was draped as a skirt around the length of the ground floor. In the south wing of the building, moreover, doors that had been removed from entryways and closets were affixed to each column; the doors served as secondary shields to prevent ballistic de-



THOMAS C. MOORE

ON IMPLOSION DAY, the blasting machine (*photograph*) detonated explosives on the first, second, fourth and sixth floors—as can be seen in the diagrams, depicting a south-to-north slice through the hotel. The first columns affected were those to the immediate left of the cut (*a*), followed about half a second later by the next closest columns on both sides of the incision (*b*). As the explosions progressed from row to row, cantilevered beams leaned into the cut. Then the north (*c*) and south (*d*) wings fell toward each other, creating a growing mound of rubble.

Buildings and Beyond

Among the thousands of structures the authors have demolished are the former Orlando City Hall (*far left*), for the movie *Lethal Weapon 3.* As they commonly do for movies, they enhanced the visual effects by setting off fireworks and by igniting aviation fuel seconds before the dynamite needed to fell the structure was detonated. The authors were also responsible for the razing of blast furnaces at U.S. Steel's Youngstown Works in Ohio (*center*), of the old Dunbarton Bridge over San Francisco Bay (*top right*) and of a reinforced concrete pier belonging to the Sunshine Skyway Bridge in St. Petersburg, Fla. (*sequence at bottom right*). Some demolition projects not shown include 26 buildings damaged after the devastating 1985 earthquake in Mexico City, the Travelers Insurance building in Boston, dozens of burning offshore oil rigs, and the Traymore Hotel, which was featured in a scene of the 1981 film *Atlantic City.*

bris from tearing through the windows in the nearby nursing home.

Implosion Day

The Saturday morning of the event began as a brilliant Florida winter day, a stroke of luck because the electrical activity of a thunderstorm or high winds would have forced us to delay the implosion. Perhaps the most stressful part of our work comes in these few hours leading up to the actual demolition. By this point, many of the innumerable details that need to be handled remain largely out of our direct control.

In the morning, roughly 120 residents of the nursing home had to be evacuated or moved to the side of the building away from the explosion. Some of them went to a chapel inside the home to watch the collapse on television.

Although we often schedule an implosion on a weekend or during early-morning hours to minimize disruptions, the event usually generates intense interest. Inevitably, crowds form. But it is not just people we have to worry about. At times we have had to delay a detonation so that someone could rescue a stray dog, a kitten or, once, a peregrine falcon that had inadvertently wandered into the blast area.

As eleven o'clock neared, some 5,000 bystanders had already gathered behind a police line a few hundred feet away on Flagler Drive, which runs next to the waterway and is separated from the Pennsylvania Hotel by a small park. On the water itself, dozens of boats had moored to view the spectacle.

Up until 30 seconds before the dynamite is detonated, we monitor the circuits that wire together the blasting caps to ensure that they remain intact. The blasting machine was set down 300 feet to the southeast of the building, on Flagler Drive. At 11:13 A.M., a last radio check was made among the various police posts and to the nursing home. A minute later the countdown began. The crowd picked up the cadence: 10, 9, 8, 7.... At zero, Cliff Geyer, Cobra's owner, pushed the button.

The implosion proceeded as programmed: the charges went off at precisely timed intervals, starting from the middle columns and moving toward those at the north and south ends of the building. Spectators could hear a series of loud cracks as the explosives were triggered. The building teetered for less than a second. A notch opened in the roof of the west wing as the columns shot straight toward the ground, pulling the adjacent beams after them. A moment later, visible for only a second before the entire scene was engulfed with dust, the north and south wings inclined toward the middle, and the south wing crumpled on top of the north. The sound of rolling thunder followed as tons of debris toppled into a pile.

Seconds later, as the dust dispersed, a pyramidal mound marked the remains of the hotel. Eyes went first to the alleyway, where huge shards of concrete reached as far as the base of the nursing home, and to a few bricks piled against plywood sheets that had been placed against the building's wall for added protection. The walls themselves—and a gas main less than a foot below the alleyway surface—were left untouched.

As with every implosion, we filmed the event with video and still cameras placed on tripods near the building. The images serve as an archival record, the best means to study and refine our techniques. In addition, a seismographic firm was hired to take readings—in

PHOTOGRAPHS BY CONTROLLED DEMOLITION INCORPORATED

case we receive any later complaints of property damage from vibration. Minutes after the detonation, Cobra pulled up trucks and bulldozers and began the weeks-long labor of removing the rubble, still a shorter and cleaner task than demolishing a structure with a wrecking ball or by hand.

The months following the demise of the Pennsylvania Hotel were busy ones for us. Mark flew to Latvia to raze a 21-story radar installation that had been built by the former Soviet Union for detecting incoming ballistic missiles. On a trip to Hungary he demolished a number of Scud missile launchers. In late April we received a call from the U.S. General Services Administration. The agency requested that we bring down the Alfred P. Murrah Federal Building in Oklahoma City, whose facade had been blasted away by several thousand pounds of nitrogen fertilizers blended with fuel oil.

That building was a technically difficult challenge. What remained of the front could have collapsed with little notice. At the same time, the rear sections remained relatively intact. Like the Pennsylvania Hotel, this one required extensive structural bolstering because of the weakening induced by the blast. On May 23 the nine-story office building disappeared in a towering cloud of dust, a sad close to one of the worst acts of terrorism in U.S. history.

The use of implosions has expanded as both the public and private sectors have come to accept the exploitation of this technique for razing a building. Demolition, once the sole domain of the wrecking ball, has now become a craft that requires a careful understanding of how to weaken a structure just enough to allow gravity to take its course.

The Authors

J. MARK LOIZEAUX (*right*) and DOUGLAS K. LOIZEAUX (*left*) learned about using explosives to implode buildings from their father, Jack (*center*), while still youths. Their company, Controlled Demolition Incorporated (CDI), based in Phoenix, Md., has conducted implosions of more than half of the 2,500 high-rise buildings demolished commercially in this manner. Mark received a bachelor's degree in business administration from the University of Tennessee, where he also studied architectural engineering; Doug holds a bachelor's of science degree in communications from Towson State University in Baltimore.

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The Molecular Logic of Smell

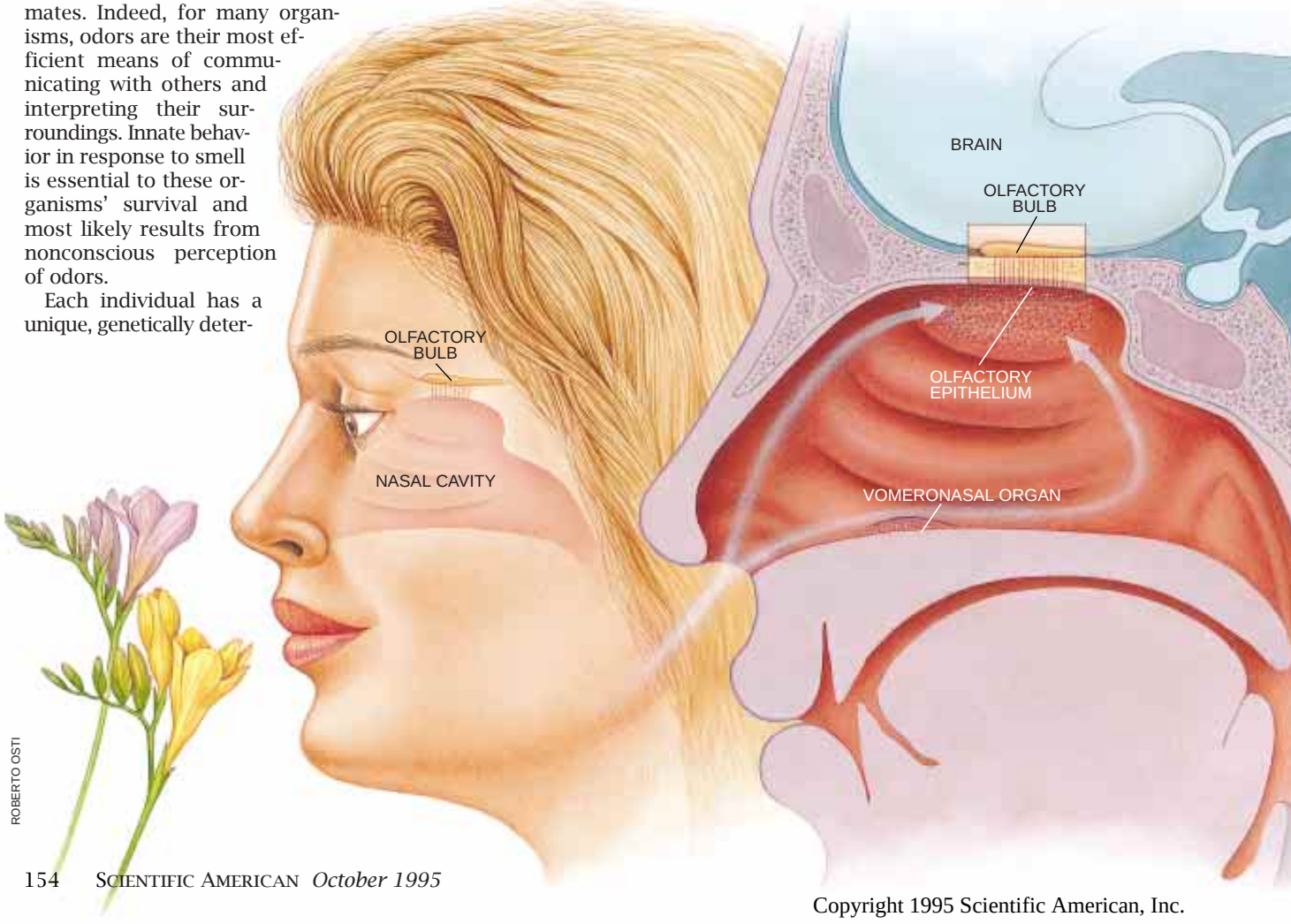
Mammals can recognize thousands of odors, some of which prompt powerful responses. Recent experiments illuminate how the nose and brain may perceive scents

by Richard Axel

Smell is perhaps our most evocative sense. In Marcel Proust's novel *Remembrance of Things Past,* the nostalgic flavor and fragrance of a madeleine, a delicate pastry, evokes a description of taste and smell, the senses that "alone, more fragile but more enduring, more unsubstantial, more persistent… bear unflinchingly, in the tiny and almost impalpable drop of their essence, the vast structure of recollection." Humans often view smell as an aesthetic sense, yet for most animals smell is the primal sense, one they rely on to identify food, predators and mates. Indeed, for many organisms, odors are their most efficient means of communicating with others and interpreting their surroundings. Innate behavior in response to smell is essential to these organisms' survival and most likely results from nonconscious perception of odors.

Each individual has a unique, genetically determined scent. This olfactory identity is coupled with a remarkable ability to distinguish a diversity of odors. Humans, for instance, can recognize approximately 10,000 scents, ranging from the pleasurable scent of freshly cut flowers to the aversive smell of an angry skunk. Many animals have an even greater sensitivity to odors than humans do: bloodhounds, for example, are legendary for their extraordinary ability to discriminate scents.

The wide spectrum of odors that humans consciously detect prompt varied emotional and cognitive responses. But do humans recognize other smells without a conscious awareness of this perception, and do such odors elicit innate behavioral responses? How does the perception of specific odors lead to appropriate thoughts, memories and behaviors? Whether smell is primal or aesthetic to a species, all organisms must have developed in the course of evolution mechanisms to recognize various odors and transmit this olfactory information from the nose to the brain, where it is decoded to provide an inter-



ROBERTO OSTI

nal representation of the external world.

As molecular biologists studying perception, my colleagues and I have reduced these questions to the level of genes and proteins. We have used these molecules to examine how animals recognize such a diverse array of scents and how the recognition of odors in the nose is translated into a map of odor quality in the brain.

The basic anatomy of the nose and olfactory system has been understood for some time. In mammals, for example, the initial detection of odors takes place at the posterior of the nose, in the small region known as the olfactory epithelium. A scanning electron micrograph of the area reveals two interesting types of cells. In this region, millions of neurons, the signaling cells of sensory systems, provide a direct physical connection between the external world and the brain. From one end of each neuron, hairlike sensors called cilia extend outward and are in direct contact with the air. At the other end of the cell, a fiber known as an axon runs into the brain. In addition, the olfactory epithelium contains neuronal stem cells, which generate olfactory neurons throughout the life of the organism. Unlike most neurons, which die and are never replaced, the olfactory sensory neurons are continually regenerated.

When an animal inhales odorous molecules, these structures bind to specialized proteins, known as receptor proteins, that extend from the cilia. The binding of odors to these receptors initiates an electrical signal that travels along the axons to the olfactory bulb, which is located in the front of the brain, right behind the nose itself. The olfactory bulb serves as the first relay station for processing olfactory information in the brain; the bulb connects the nose with the olfactory cortex, which then projects to higher sensory centers in the cerebral cortex, the area of the brain that controls thoughts and behaviors.

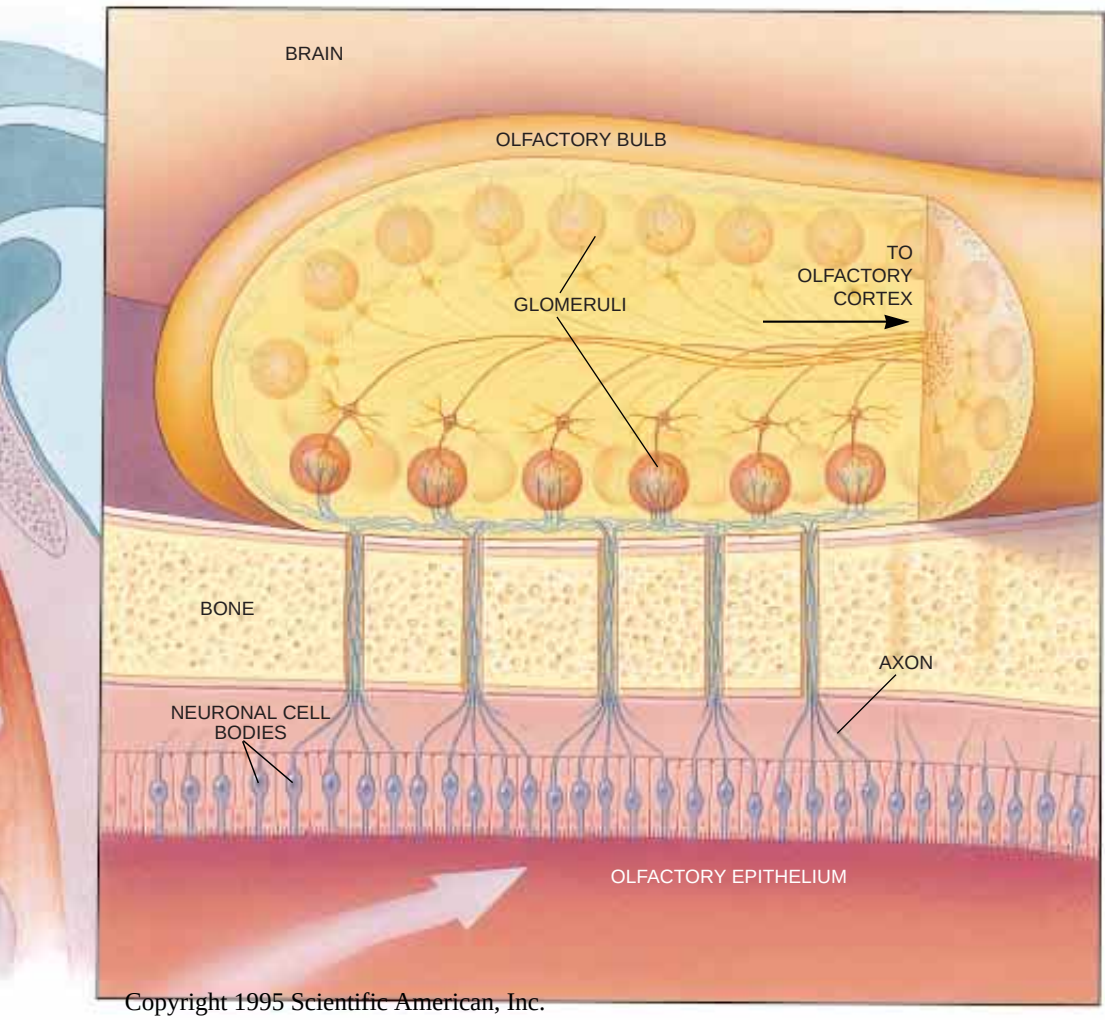
A Family of Receptors

Somewhere in this arrangement lies an intricate logic that the brain uses to identify the odor detected in the nose, distinguish it from others and trigger an emotional or behavioral response. To probe the organization of the brain, my co-workers and I began where an odor is first physically perceived—at the odor receptor proteins.

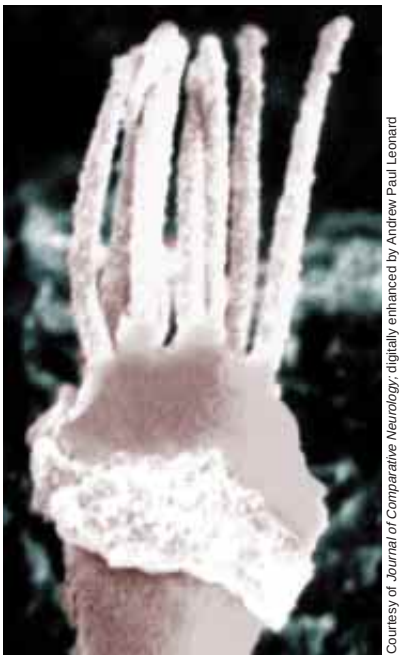
Instead of examining odor receptors directly, Linda Buck, then a postdoctoral fellow in my laboratory and now a professor at Harvard University, and I set out to find the genes encoding odor receptors. Genes provide the template for proteins, the molecules that carry out the functions of cells. Once we isolate the genes that encode a protein, we can use them as tools to study the structure and function of the odor receptors themselves.

Furthermore, using genes to investigate proteins is much simpler and faster than studying the receptors directly. By artificially manipulating genes, we can easily alter odor receptors in ways that help us understand how the molecules enable the nose and brain to perceive smell. After we understand how the receptors work, we can then study how olfactory information is transmitted to the brain and processed to permit the discrimination of smells.

Using the technique of gene cloning, we were able to isolate the genes encoding the odor receptors. This family of receptor genes exhibited several properties that suited it to its role in odor recognition. First, the genes encoded proteins that



SCENT OF A FLOWER is translated from a sniff to a smile by the olfactory sensory system. An odor is first detected in the upper region of the nose, at the olfactory epithelium. Within this area, odor molecules bind to receptors on hairlike projections, or cilia. The receptors are part of neurons that can extend three to four centimeters from the inside of the nose to the brain. Structures known as axons run from the neuronal cell body to the olfactory bulb in the brain. In the bulb, axons converge at sites called glomeruli; from there signals are relayed to other regions of the brain, including the olfactory cortex. The vomeronasal organ is part of a separate sensory system that governs innate responses in some mammals. Its role in human behavior is not well known.



Courtesy of *Journal of Comparative Neurology*; digitally enhanced by Andrew Paul Leonard

SENSORY NEURON in the human olfactory epithelium (*left*) is surrounded by support cells and sits over a layer of neuronal stem cells, which generate new olfactory neurons during an organism's life. Hairlike cilia protrude from the tip of an individual neuron (*above*), shown magnified 17,500 times; receptors located on cilia bind to odor molecules. These images were taken by R. M. Costanzo and E. E. Morrison of Virginia Commonwealth University.

fall squarely within a previously described group of receptors that pass through the cell membrane of the neuron seven times; these receptors activate signaling proteins known as G proteins. Early studies by Doron Lancet of the Weizmann Institute of Science and Randall R. Reed of the Johns Hopkins School of Medicine have established that odor receptors, too, use G proteins to initiate the cascade of events resulting in the transmission of an electrical impulse along the olfactory sensory axon.

Second, the genes encoding the odor receptor proteins are active only in olfactory neurons. Although nearly every cell of the body carries a copy of every gene, many genes are expressed only in specialized cells.

Finally, a broad range of odor receptor genes appears to mirror the striking range of odors. The technique known as molecular hybridization allowed us to determine the number of these genes in the chromosome. This procedure works because genes consist of two strands of DNA that come together to create a double helix. We can label one strand so that when it finds its complementary strand in the chromosome we can locate a gene and determine both the number and position of a gene or gene family.

Specifically, by examining DNA from a variety of mammals, including humans, we determined that around 1,000 genes encode 1,000 different odor receptors. (Each type of receptor is expressed in thousands of neurons.) Given that mammalian DNA probably contains around 100,000 genes, this finding indicates that 1 percent of all our genes are devoted to the detection of odors, making this the largest gene family thus far identified in mammals. The enormous amount of genetic information devoted to smell perhaps reflects the significance of this sensory system for the survival and reproduction of most mammalian species.

The large family of odor receptors contrasts sharply with the far more restricted repertoire of receptors in the eye. Humans, for example, can discriminate among several hundred hues using only three kinds of receptors on the retina. These photoreceptors detect light in different but overlapping regions of the visible spectrum, so the brain can compare input from all three types of detectors to identify a color. Our data suggest that a small number of odor receptors would not be able to recognize and discriminate the full array of scents that can be perceived by mammals.

Mammals can detect at least 10,000 odors; consequently, each of the 1,000 different receptors must respond to several odor molecules, and each odor must bind to several receptors. Scientists believe that various receptors respond to discrete parts of an odor's structure and that an odor consists of several chemical groups that each activate a characteristic receptor. For example, the molecules responsible for the scents of jasmine and freshly baked bread are made up of different structural groups, and each group activates a distinct set of receptors; to distinguish the smell, the brain must then determine the precise combination of receptors activated by a particular odor.

How does the brain identify which of the 1,000 types of receptors have been turned on? Several scenarios are possible. If every neuron carries all 1,000 types, every neuron would send a signal to the brain every time an odor was sensed. All the engaged receptors would then need to contribute some distinctive component to the neuron's signal; the brain could then compare these signals to decipher the identity of the smell. Alternatively, if each neuron features only one type of receptor, the problem of distinguishing which receptor was activated by a particular odor reduces to the problem of identifying which neurons fired. Such a model would greatly simplify the task of the brain in sorting out which of the numerous receptors have been activated.

One Neuron, One Receptor

To investigate which of these two schemes occurs in the detection of smells, we again looked at gene expression in the olfactory neurons. Using the

procedure of molecular hybridization, Andrew Chess, John Ngai and Robert Vassar, then all at Columbia University, and I observed that in mammals, each of the 1,000 receptors is expressed in about 0.1 percent of the neurons. In fish, which have 100 odor receptors, each receptor can be found in about 1 percent of the neurons. These results suggest that, in both cases, each neuron may express only one receptor gene. Furthermore, in recent experiments, Catherine Dulac, also at Columbia, and I have used the polymerase chain reaction, which amplifies small parts of DNA, to clone the odor receptor genes that are expressed in individual olfactory neurons. When such receptor genes are isolated from a single neuron, they all appear to be identical. When the same procedure is applied to a collection of neurons, however, hundreds of different receptor genes are obtained. Taken together, these observations indicate that each sensory neuron expresses only one receptor and is therefore functionally distinct.

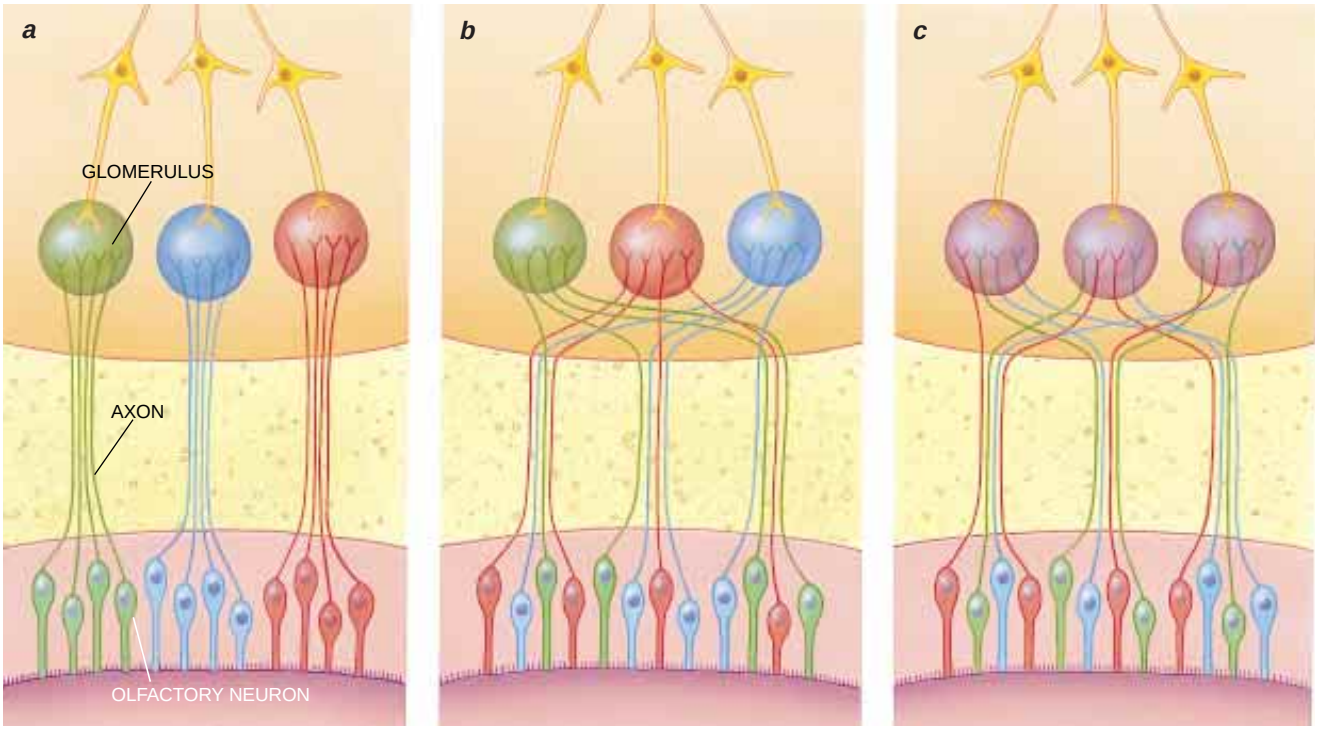
This simple correlation between receptors and neurons does not explain the much more complex processing that the brain must employ to discriminate an odor. For example, how does the brain determine which olfactory neurons have fired? In all other sensory systems, the brain relies on defined spatial patterns of neurons as well as the position of the neurons' ultimate targets to define the quality of a sensation. Perhaps the brain applies a similar logic to the sense of smell.

There are a number of potential scenarios for arranging neurons and axons in the nose and brain [*see illustration below*]. In one model, neurons that bear a given type of receptor would be localized in the olfactory epithelium. Activation of neurons at specific sites would then define the quality of an odor. Alternatively, neurons carrying one type of receptor could be randomly positioned in the epithelium, but their axons would converge on discrete areas in the brain. In this case, exposure to a particular odor would result in defined patterns of activity in the brain. In a third model, both the neurons and their projections to the brain could be arranged randomly. To interpret the scent, the brain would have to use a sophisticated algorithm to decode the random signals.

Some neurons in the nose are spatially segregated according to the scents they detect. Most mammals, including humans, possess a "sexual nose," or vomeronasal organ, that is physically separate from the main olfactory epithelium. The vomeronasal organ detects the pheromones that govern reproductive and social behaviors. Sexual activity in male rodents, for example, is an innate response, prompted by the detection at the vomeronasal organ of pheromones secreted by females. If the neurons in the vomeronasal system in virgin mice are destroyed, the mice can still smell with their main olfactory system, but the damage to their vomeronasal organ prevents them from ever mating.

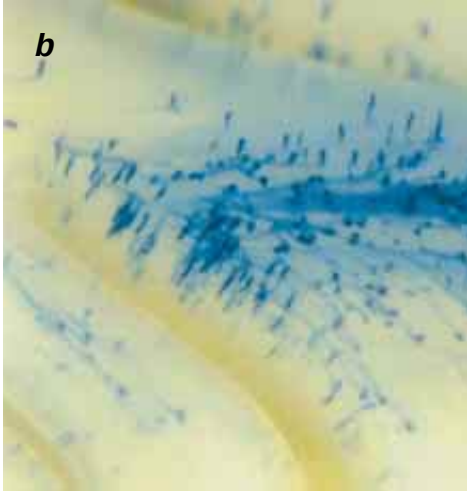
Additionally, as Dulac and I have shown by studying the genes encoding pheromone receptors, the sequence of amino acids (the building blocks of proteins) in the receptors of the vomeronasal organ is completely different from that in the receptors of the main olfactory epithelium. These differences suggest that the two systems may have evolved independently of each other.

Finally, neurons in the main olfactory epithelium project their axons to an area of the brain that is distinct from the region where neurons in the vomeronasal organ send nerve impulses. Consequently, signals from these two



ROBERTO OSTI

PATTERNS OF NEURONS can help the brain interpret a smell. Several arrangements are possible. In one scenario (*a*), neurons that contain a particular type of receptor (*indicated here by color*) would be localized in the olfactory epithelium; in this way, the brain could identify an odor by determining what area of the olfactory epithelium was activated by the smell. Alternatively (*b*), neurons may be arranged randomly throughout the epithelium, but their axons may converge on localized regions of the olfactory bulb known as glomeruli. An odor would therefore be identified by a characteristic pattern of activity in the glomeruli. Finally (*c*), both the neurons and their axons may be arranged randomly.



PETER MOMBAERTS

BLUE NEURONS reveal the pathway of sensory information from the olfactory epithelium in the nose to the olfactory bulb in the brain (*a*). By genetically modifying the odor receptor genes in mice, the author and his colleagues dyed

regions of the nose produce very different behavioral responses. The neurons of the vomeronasal organ bypass the cognitive centers of the brain and send signals directly to those areas that control innate behavioral and emotional responses. In contrast, the main epithelium sends signals to higher centers in the olfactory cortex that elicit more measured responses.

Organized Axons

The anatomic segregation of these two functionally distinct olfactory systems immediately prompted us to examine whether neurons within the main olfactory system itself also exploit spatial segregation to define the quality of an odor. Some of this spatial organization is well known: each neuron projects a single, unbranched axon toward the brain. As the collection of axons emerges from the olfactory epithelium, about 10 million axons come together to form the olfactory nerve, which then enters the brain. Once inside the brain, groups of 10,000 axons converge at sites called glomeruli in the olfactory bulb. In the glomeruli the axons communicate with neurons that project to higher centers in the brain.

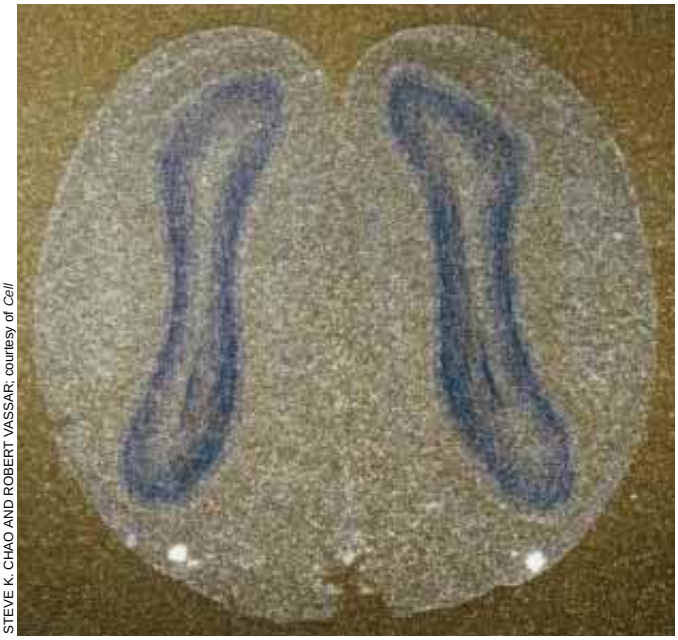
Experiments done by Vassar in my laboratory at Columbia, as well as independent research carried out by Buck, showed that the olfactory epithelium is divided into four broad regions according to the types of receptors found in each zone. Despite this coarse organization, the most important feature of this arrangement is the random distribution of receptors within each region. Because we were unable to detect a more precise spatial pattern of neurons in the epithelium, we searched for a pattern in the projections of axons into the brain.

If such a pattern is indeed employed, neurons expressing a given receptor, though randomly distributed throughout a region of the epithelium, must project their axons to a small number of glomeruli. Several pieces of evidence support this model.

First, the number of glomeruli is roughly the same as the number of types of receptors; because each neuron expresses only one receptor, each type of neuron may connect to a characteristic glomerulus. Second, physiological experiments have revealed that different odors elicit distinct patterns of activity in the brain. For example, Gordon M. Shepherd and his colleagues at Yale University established that exposure of newborn rodents to their mother's milk led to activity in restricted regions of the olfactory bulb. Similarly, John S. Kauer of Tufts University used voltage-sensitive dyes to show that the pattern of activity in the olfactory bulb is distinct for various odors. Furthermore, electrophysiological studies by Kensaku Mori of the Osaka Bioscience Institute directly demonstrated that distinct glomeruli are activated by different odors.

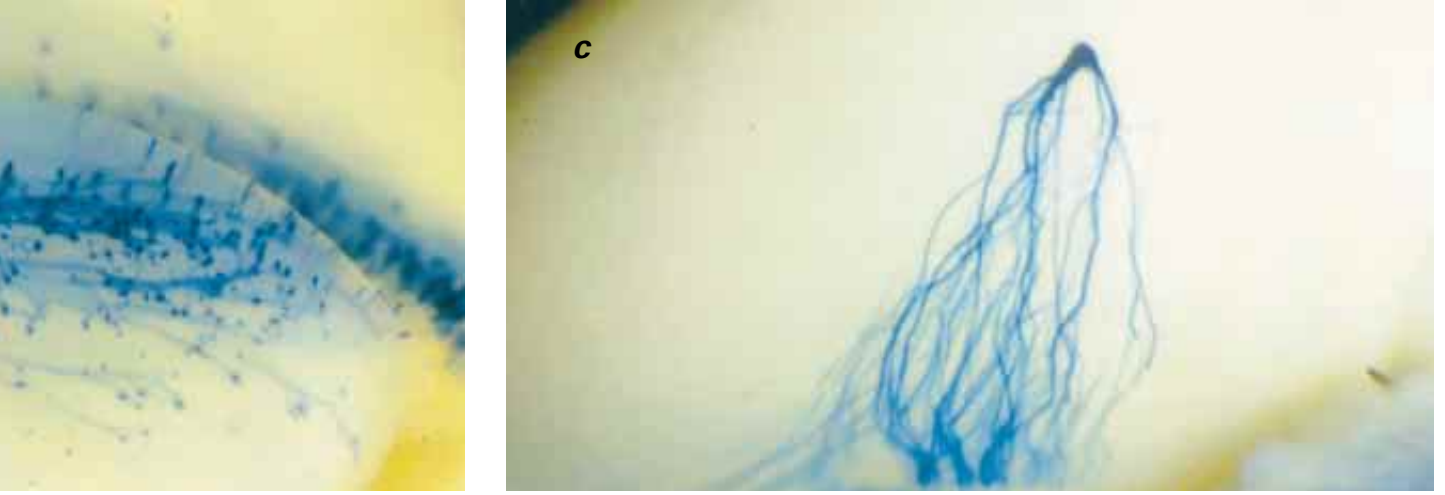
My colleagues and I have devised two molecular approaches to study the spatial segregation of neurons and axons. First, Vassar, Steve K. Chao and Leslie B. Vosshall, working in my laboratory, modified the technique of molecular hybridization used in previous work so that we could examine receptor RNA in the tips of the axons, where they converge in the olfactory bulb. These experiments, as well as independent work by Buck, indicated that neurons expressing a given receptor project to one or, at most, a few glomeruli among the thousands within the olfactory bulb. Moreover, the positions of the glomeruli are fixed, assuring that a given odor will elicit the same pattern of activity in the brains of all animals in a species.

In another approach, Pe-



STEVE K. CHAO AND ROBERT VASSAR; courtesy of *Cell*

OLFACTORY BULB of a rat is seen in cross section in this micrograph. The two white spots indicate where axons that bear a specific receptor gene converge. Because each axon projects to a characteristic location in the olfactory bulb, the bulb provides a two-dimensional map of odor quality, which the olfactory cortex employs to decipher an odor.



deep blue the neurons that bear a particular type of receptor—and are therefore sensitive to a limited number of odors. Randomly positioned neurons on the olfactory epithelium (*b*) converge at one location in the olfactory bulb (*c*).

ter Mombaerts and Fan Wang, also at Columbia, and I have genetically altered mice, breeding experimental animals in which neurons that activate a specific receptor were dyed blue. Our procedure involves isolating a gene for one of the odor receptors and then attaching to it a second, marker gene. This marker gene, which will become active whenever the odor receptor gene is expressed, triggers a chemical reaction that turns the neuron and its axon blue. The modified gene is inserted into cells that are then introduced into a mouse embryo. In the resulting mice that develop, neurons that make this particular receptor appear blue, allowing us to see where the cells are located.

We examined the olfactory epithelia and brains of the mice and observed that about one in 1,000 neurons were blue. Most important, individual axons stretching from the neurons could be identified and followed into the brain. The blue axons projected to only two of the 2,000 glomeruli in the olfactory bulb. These experiments provide convincing visual evidence that neurons that activate one type of receptor—and therefore respond to a limited number of odors—project their axons to a small number of glomeruli in the brain. Because the glomeruli in the olfactory bulb are differentially sensitive to specific odors, and the positions of the individual glomeruli are topologically defined, the olfactory bulb provides a two-dimensional map that identifies which of the numerous receptors have been activated in the nose. We believe a given odor will activate a characteristic combination of glomeruli in the olfactory bulb; signals from the glomeruli are then transmitted to the olfactory cortex, where they must be processed to allow odor discrimination.

Decoding the Signal

According to this model of smell, mammals should, in theory, be able to detect an extraordinarily large number of odors. Because odors interact with multiple receptors rather than with individual ones, the possible combinations exceed by several orders of magnitude the number of odors animals can actually detect. Consequently, just as with other senses, the olfactory system offers a meager representation of the environment. Presumably, animals discriminate only those odors that are biologically important to their survival and reproduction.

This view of olfactory perception shares several basic features with perception in other sensory systems. For example, in vision the brain analyzes an image by interpreting the individual components: form, location, movement, color. The unity of an image is accomplished by reconstructing the signals in the visual centers of the higher cortex. In comparison, the brain analyzes an odor by dissecting the structural features of the scent. The odor is then reconstructed by the olfactory cortex.

But how does the olfactory cortex, which receives signals from the olfactory bulb, decode the map provided by the olfactory bulb? This question is one of the central and most elusive problems in neurobiology. It seems likely that some form of spatial segregation, similar to that seen in the olfactory bulb but undoubtedly far more complex, will be maintained as the signals project into the cortex. This arrangement, however, merely places the problem of interpreting spatial information one level beyond the olfactory bulb, in the cortex. How does the cortex prompt the range of emotional or behavioral responses that smells often provoke? To what extent is the recognition of odors in humans conscious or nonconscious, and how much of behavior or mood is governed by the perception of odors in our environment? We have only begun to explore the logic of smell and how it can evoke the "vast structure of recollection."

The Author

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The Laboratory Notebooks of Thomas Edison

The raw visual and textual evidence of his imagination, Edison's notebooks were the unrevealed talismans of the inventor's career

by Neil Baldwin

While still in his early twenties, Thomas Alva Edison (1847–1931) pledged resolutely to "keep a full record" of his career. And he was true to his word, as is borne witness by a staggering array of more than 3,500 notebooks housed in the archives of the great inventor's laboratory and machine shop at the Edison National Historic Site in West Orange, N.J.

These fascinating documents of discovery reveal far more than the genesis of the 1,000 patents granted to Edison and his colleagues for such familiar constituents of our material culture as the lightbulb, the phonograph and the motion picture camera. Indeed, the great majority of his formative ideas never saw the light of day. Rather Edison reveled in his notebook drawings as sheer process, the life of his mind in full gear. He wrote literally to find out what he was thinking.

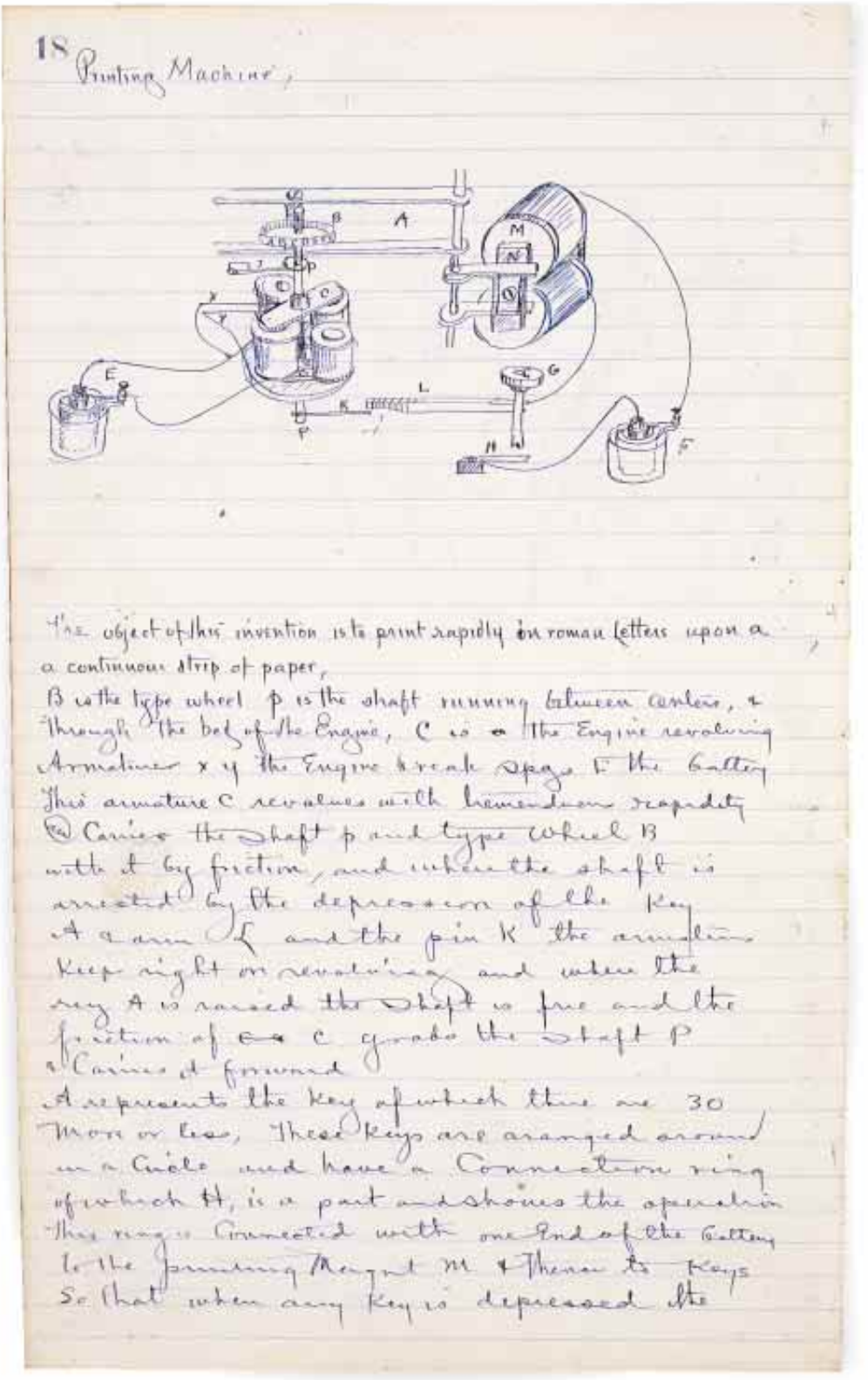
In the 19th century, invention was referred to as an art. Edison's own road from sketch to concrete object was marked by imagination of the highest order. Compensating for progressive hearing loss since childhood, Edison was—as these selections illustrate—a consummately visual thinker and a fine draftsman. Concepts came swiftly, surely and unrelentingly. His notebooks indicate a multifaceted sensibility sharply at odds with the cherished myth of Edison as a rustic, inarticulate hayseed. We are surprised to observe the practical manufacturer stating his intentions; the complex mind capable of realizing a machine fully formed at the outset; the wild dreams of a visionary; the consumer-driven capitalist; and most triumphantly in old age, the octogenarian pressing on with new technological possibilities, even as he could hardly lift his head from the sickbed pillow.

Viewed in their encyclopedic, rough-hewn magnitude, Thomas Edison's laboratory notebooks remind us of the formative roots of modern research and development—in the brain of one resolute man.

The inventor at work in his private room on the second floor of the main laboratory building in West Orange, N.J., at the turn of the century.

Edison was renowned for his ability to catch a few minutes of sleep wherever necessary—in this case, on a worktable at the laboratory.

NOTEBOOK PAGES AND PHOTOGRAPHS COURTESY OF THE EDISON NATIONAL HISTORIC SITE; PAGES PHOTOGRAPHED BY BETH PHILLIPS



18 Printing Machine,

The object of this invention is to print rapidly in roman letters upon a a continuous strip of paper,

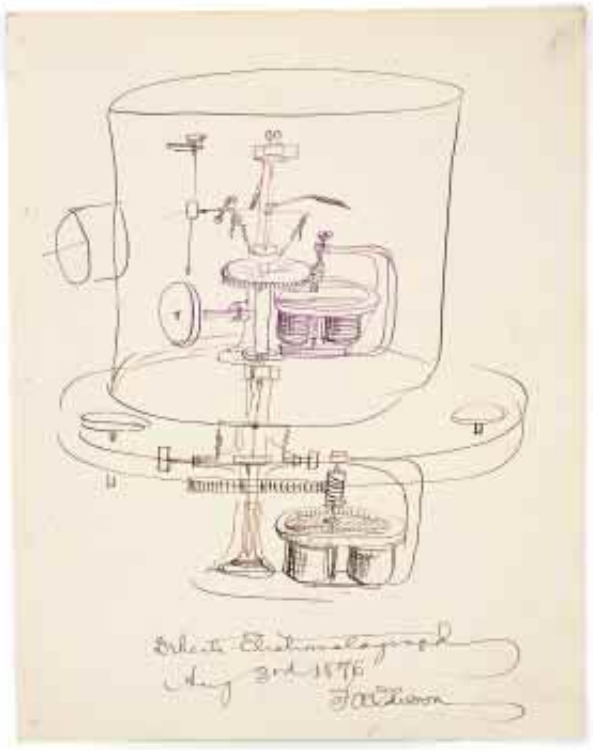
B is the type wheel P is the shaft running between centers, & through the bed of the Engine, C is a the Engine revolving Armatures x y the Engine break Spaces E the Battery This armature C revolves with tremendous rapidity & Carries the shaft P and type Wheel B with it by friction, and when the shaft is arrested by the depression of the Key A a arm L and the pin K the armatures Keep right on revolving and when the key A is raised the shaft is free and the friction of C C grabs the shaft P & Carries it forward

A represents the key of which there are 30 More or less, These Keys are arranged around in a Circle and have a Connecting ring of which H, is a part and shows the operation This ring is Connected with one End of the Battery & the printing Magnet M & Thence to Keys So that when any Key is depressed the

Printing machine, **January 27, 1872**

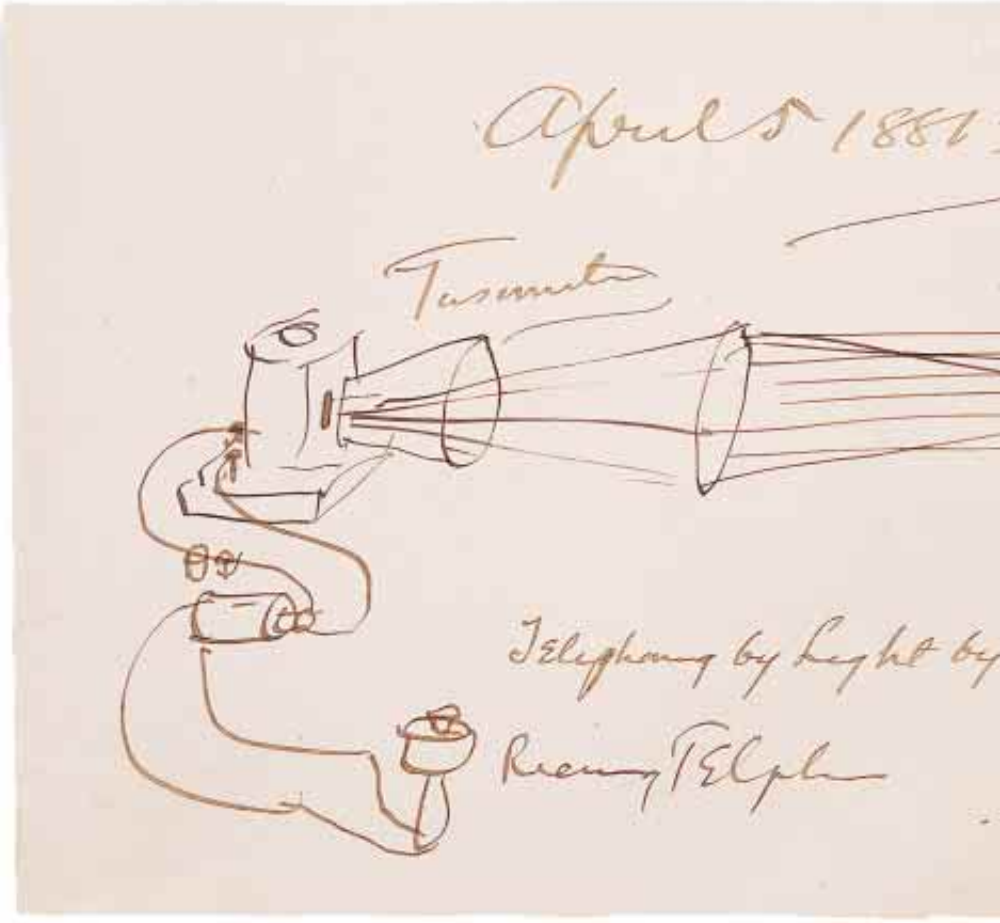
From his adolescent years as an itinerant telegrapher working the night shift in small-town train depots throughout his native Midwest, Edison was obsessed with enhancing communications technology. As with so many of his inventions, components of one machine generated elements of the next, with the telegraph the important starting point for many of his ideas. The prototypical typewriter shown here developed naturally from the inventor's previous work in printing telegraphy and is a fine example of Edison's precise methodology: to state the "object of the invention" in the first line, thereby staking his territory before moving on to identify the succession of inner mechanics in exhaustive, alphabetical detail, aiming to make the patent application a seamless document impervious to imitation.

Delicate electromotograph,
August 3, 1876



Again with the goal of transcending conventional telegraphic practice, this machine did away with the punching of "dot and dash" holes in a long tape. Instead it used chemically prepared paper to receive and record electrical impulses with a stylus. The stylus hangs in the middle of the large cylindrical container, on top of a tape spool connected to a horizontally placed gear. At the invitation of his friend George Frederick Barker, professor of physics at the University of Pennsylvania and editor of the *Journal of the Franklin Institute,* Edison had demonstrated an earlier version of the electromotograph at a meeting of the National Academy of Sciences in Washington, D.C. His findings were first published in *Scientific American,* in the September 5, 1874, issue.

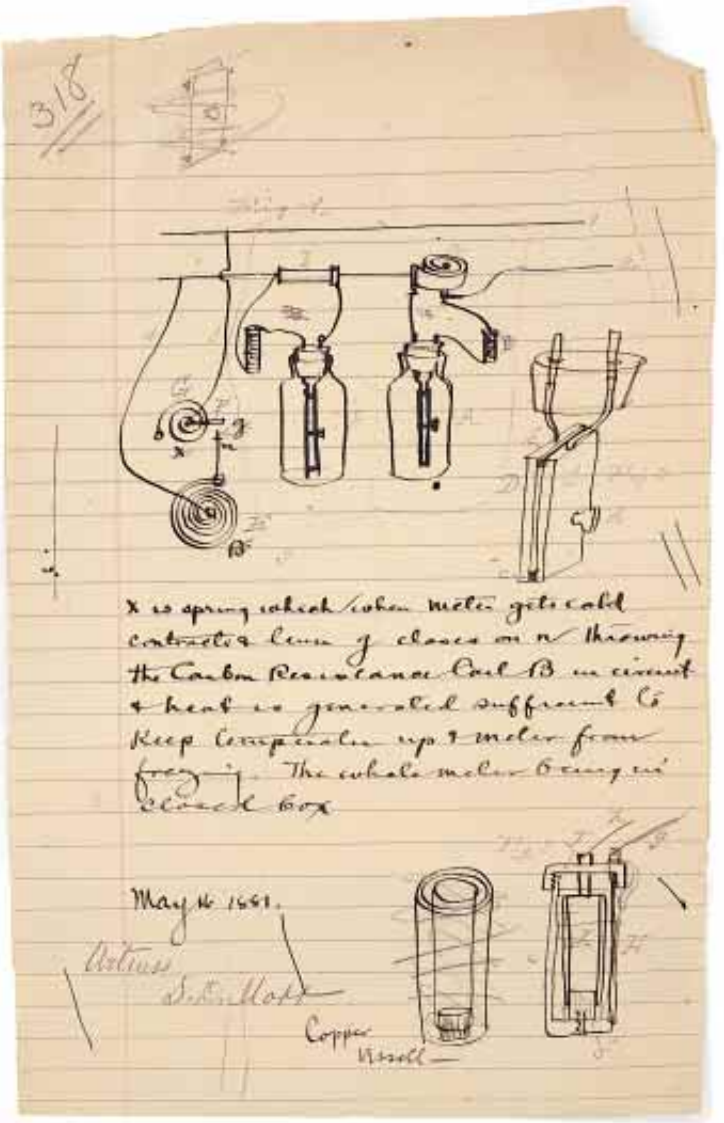
Telephony by light by use of tasimeter,
April 5, 1881

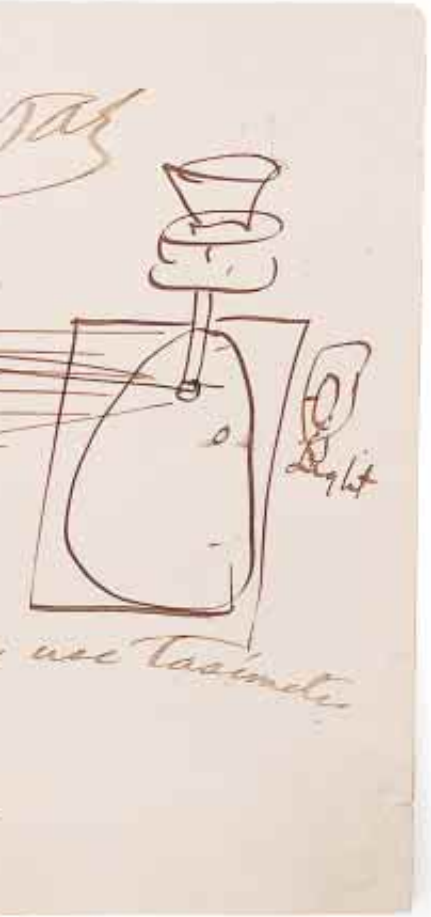


As this bizarre drawing (for a construction that never became a reality) demonstrates, Edison was equally capable of disregarding evolution from one invention to the next. The tasimeter was a thermometer-based instrument that Edison created to quantify the heat given off by the sun's corona during a total eclipse on July 29, 1878. The most important component of the tasimeter was a compressed carbon "button" that expanded and contracted in response to minute variants in temperature. Edison employed this same carbon button in his telephonic transmitter (an improvement on Alexander Graham Bell's invention) because of its comparable sensitivity to the pressure of spoken-voice sound waves. He fancifully imagined "marrying" the two inventions, although he had no idea how to transmit telephone signals by light.

Electricity metering system,
May 16, 1881

Before launching his Napoleonic campaign against antiquated gaslight, fighting to illuminate homes and offices in lower Manhattan with his new incandescent bulb, Edison worked on a reliable way to measure the use of electricity. One year after this drawing was made, success was achieved. The design even included Edison's stipulation that "the whole meter [be] in a closed box" to avoid freezing. The electrolytic meter held parallel zinc plates, as shown here, immersed in zinc sulfate solution. Through a silver wire, a small amount of the current entering each residence or place of business was diverted through the jar-shaped meter, so that zinc from the solution would be deposited on the plates and then collected monthly. The amount of current consumed was determined according to the increased weight of the plates. Such meters were used for about a decade, at which time they were superseded by modern meters, which relied on the electromagnetically induced movement of a rotor.

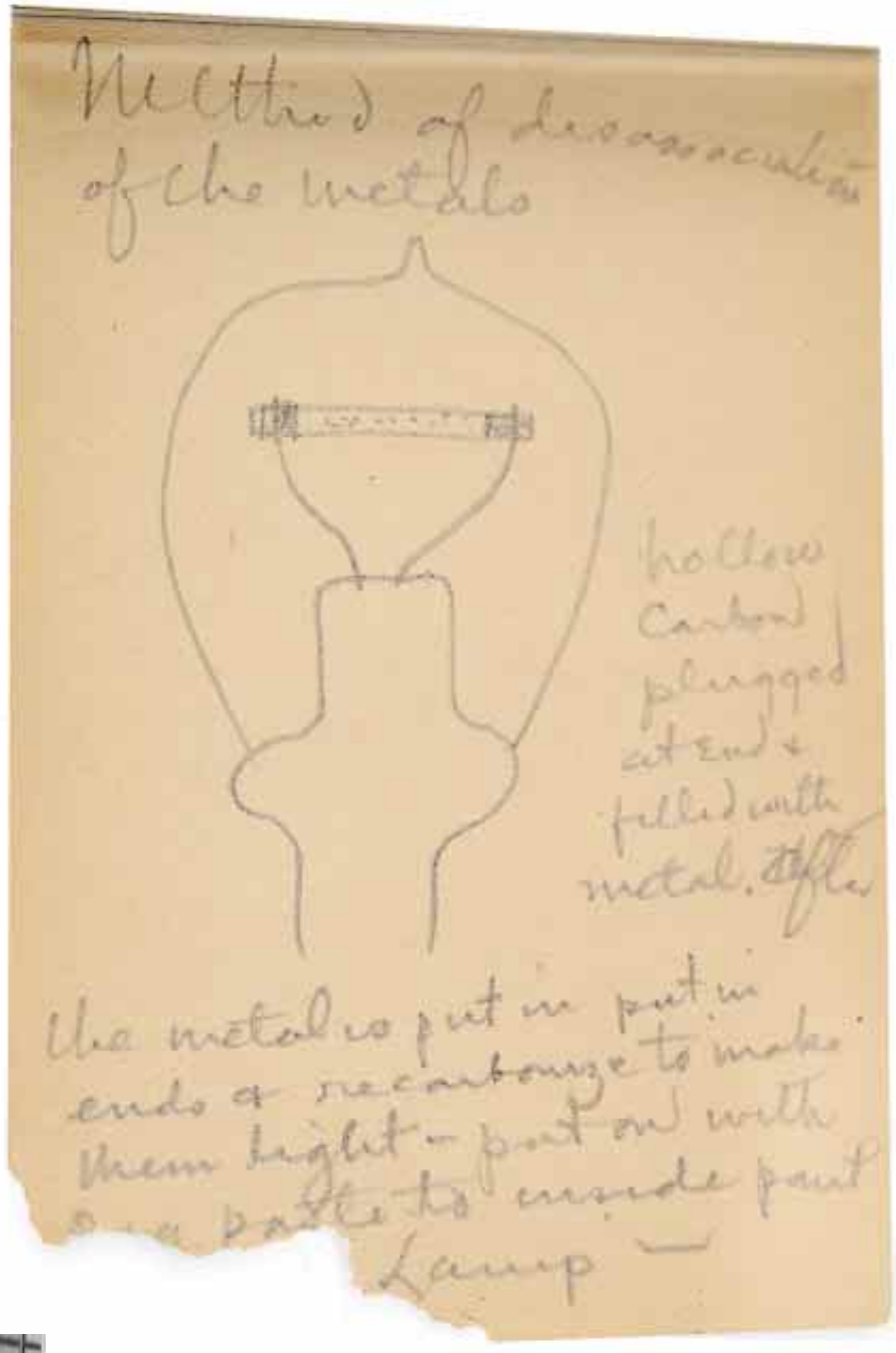




With his "insomnia squad" of laboratory assistants, Edison takes a rare break. He ate sparingly, believing that occasional snacks in small amounts were better for the digestive system.

***Quick sketch for the electric lightbulb,* August 16, 1888**

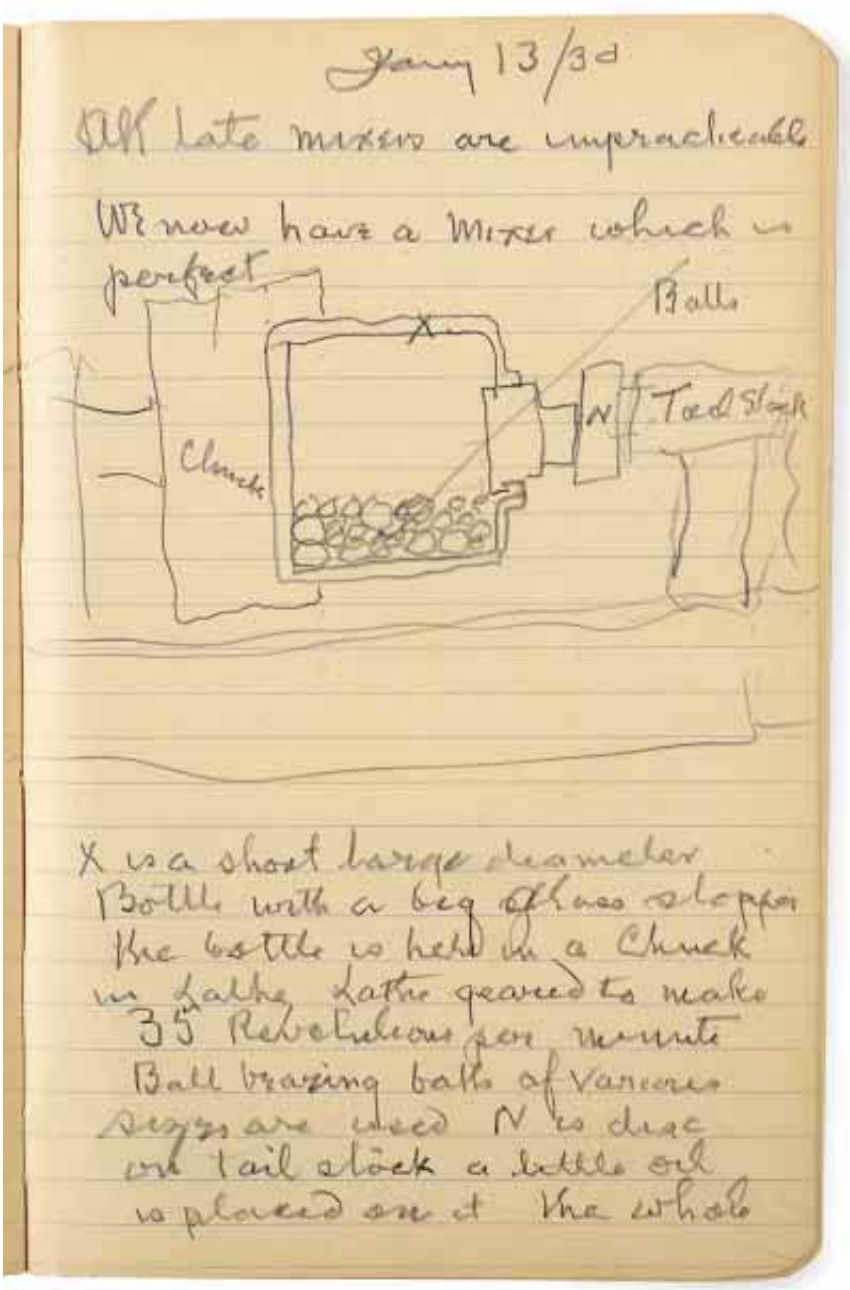
With the success of electric lighting in New York City came the proliferation of entire Edison systems, marketed throughout the country and in Europe, and the concomitant establishment of the Edison Electric Lamp Company in New Jersey, first at Menlo Park and then in Harrison, for mass production of the bulb. Francis R. Upton was assigned to manage this corporate initiative and to promote the bulb, to take it beyond unique laboratory phenomenon to widespread consumer item. He had been trained at Bowdoin College and Princeton University and had completed a postgraduate apprenticeship at the University of Berlin with the great mathematician and physicist Hermann von Helmholtz. Edison constantly passed intuitive sketches and suggestions along to Upton and his co-workers at the lamp company for improvements in the composition of the essential incandescent filament of the lamp, as in this hasty draft from the inventor's ever present pocket notebook.



In his Fort Myers, Fla., laboratory in the late 1920s, Edison persists with organic rubber experiments, transferring data into his laboratory journal from a small pocket notebook used in the field.

***Method of rubber refining; raw goldenrod "tar" [sap] tumbled through steel ball bearings within a large glass bottle rotated on a lathe,* January 13, 1930**

This excerpt is taken from the last laboratory notebook in the West Orange archives that was written entirely in Edison's hand, 20 months before the inventor's death (later notebooks were scribed by his assistants). The sketch and text here were cast by one of his custom-made stubby pencils, which Edison preferred because they survived the hard pressure he exerted when writing. In old age, his penmanship became tremulous, but the deliberate alphabetic configuration of machine parts and the determined intention to make a prototype and see how it would work take us back to the lettered components of the early telegraphic inventions of the 1870s, revealing how pervasive Edison's methodology remained. In the final decade of his life, Edison devoted himself utterly to finding a source for rubber in nature and toward that end installed a vast goldenrod plantation on his winter estate in Fort Myers, Fla. From the refined milky sap, his friend Harvey Firestone fabricated a set of tires for Edison's Model-T Ford.



The Author

NEIL BALDWIN received his Ph.D. in modern American poetry in 1973 from the State University of New York at Buffalo. He is currently executive director of the National Book Foundation in New York City, which sponsors the National Book Awards and literary outreach efforts across the country. He is the author of three biographies: *To All Gentleness: William Carlos Williams, The Doctor-Poet* (Atheneum, 1984); *Man Ray, American Artist* (Clarkson N. Potter, 1988); and *Edison: Inventing the Century* (Hyperion, 1995). He acknowledges the kind assistance of Douglas Tarr, archives technician, and George Tselos, archivist, at the Edison National Historic Site in West Orange, N.J.

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Can Environmental Estrogens Cause Breast Cancer?

The authors of a provocative hypothesis spell out their reasons for suspecting that hormone-mimicking chemicals in the environment contribute to many unexplained cases of breast cancer

by Devra Lee Davis and H. Leon Bradlow

Physicians have no idea why breast cancer arises in two out of three women with the disease. The long-awaited "breast cancer gene"—BRCA1—turns out to account for perhaps 5 percent of cases. Genetic inheritance and all other characteristics, or risk factors, known to increase susceptibility explain only about a third of all cases. We cannot claim to have solved the mystery fully, but a hypothesis we and our colleagues put forward in 1993 may clear up part of the uncertainty.

Our proposal, based on our own research and that of others, suggests substances we named xenoestrogens (foreign estrogens) might account for some fraction of the unexplained cases. Xenoestrogens, which are introduced into the body from the environment, mimic the action of estrogen produced in cells or alter the hormone's activity. Some xenoestrogens can reduce estrogen's effects; these varieties, which are rapidly degraded in the body, usually occur in plant foods such as soy products, cauliflower and broccoli. Other, typically synthetic, forms can amplify the effects and are long-lived. Since World War II the amplifying varieties—found in certain pesticides, drugs, fuels and plastics—have become increasingly prevalent in modern societies; they are the ones eliciting concern.

The possibility that some xenoestrogens promote breast cancer remains speculative, but evidence in its favor is accruing steadily. If the suggestion proves correct, the discovery could lead to new ways to prevent a disorder that this year will strike roughly 182,000 women in the U.S. and kill some 46,000, typically robbing 20 years of life from those who die. New preventive strategies are badly needed. No fundamental new treatments have been introduced in the past two decades, and survival rates have improved only minimally.

Xenoestrogens are not the only hormone-mimicking compounds that may contribute to breast cancer. There are indications that other endocrine-disrupting materials may also promote development of the disease. What is more,

within the past 12 months, analyses issued by the German, British and Danish governments have combined with earlier studies to suggest that xenoestrogens and other endocrine-disrupting materials are also harming men and wildlife [*see box on page 172*]. Indeed, it appears that such compounds may contribute to abnormal development in animals and to a range of reproductive disorders that have reportedly become increasingly common in men worldwide—notably testicular cancer, undescended testes, urinary tract defects and lowered sperm counts.

Early Thinking

Breast cancer, like other malignancies, arises when a cell escapes the usual restraints on replication and multiplies out of control. This escape is now believed to require the accumulation of mutations in genes that regulate cell division and ensure the accurate replication of DNA. Hormones and other substances around the cell can also prompt abnormal cell growth.

We and our co-workers began to consider a role for xenoestrogens when we were puzzling over why so many women who acquire breast cancer lack most known risk factors. Among the established risks are early onset of menstruation, late entry into menopause and never having had or breast-fed a child. A well-recognized feature common to these and other factors is that they promote breast cancer by elevating total lifetime exposure to biologically active estrogen—principally the form known as estradiol. (Estradiol is produced in quantity during each menstrual cycle; some is kept in an inactive state, but the rest is able to influence physiological functioning.) Ironically, then, the estrogen women require for sexual development and reproduction can harm them, by facilitating the development of breast cancer.

Similarly, women older than 50 are more likely to acquire breast cancer than are younger women, probably because they have sustained longer exposure to bioactive estradiol. Diets high in animal fat or alcohol also seem to increase risk, probably because fat tissue can make estrogen and because alcohol can increase production of the hormone. Beyond estrogen exposure and inheritance of a susceptibility gene (often signaled by having blood relatives with premenopausal breast cancer), another major risk factor is past irradiation of the chest with high doses of x-rays.

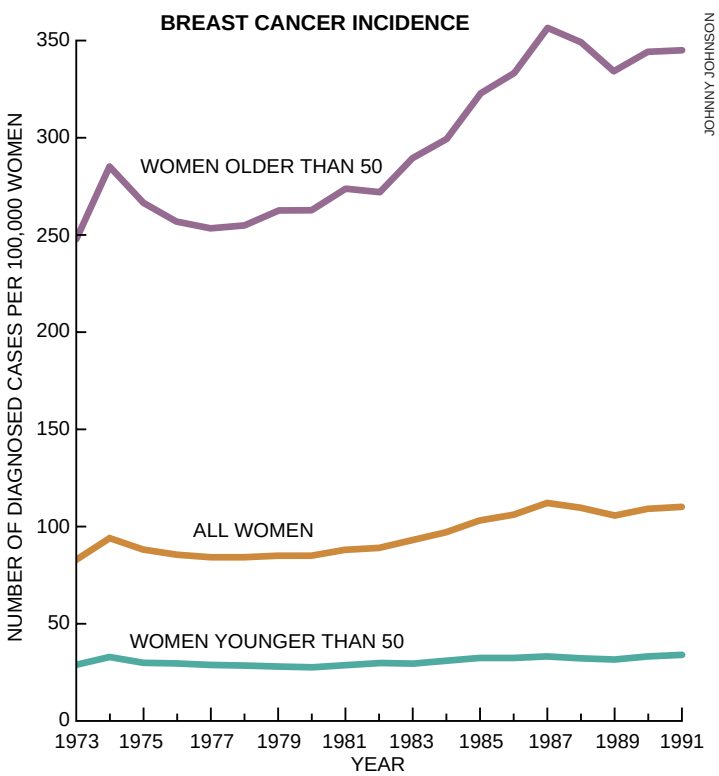
If too much natural estrogen can be dangerous, we reasoned, prolonged exposure to xenoestrogens could probably be harmful also and might account for some fraction of cases that had no obvious cause. The possibility that xenoestrogens could be culprits intrigued us for another reason. We thought it could partly explain why the reported incidence of breast cancer worldwide (often represented by the number of cases in 100,000 women) has risen steadily since 1940. The rate is highest in the industrial nations but is rising most rapidly in some developing ones. Part of the rise since the 1980s stems from better detection, at least in women younger than 65; older women have been less likely to have breast exams and mammograms, although they can benefit greatly from screening. Changes in risk factors—such as a trend toward earlier menarche (as a result of modern diets) and fewer pregnancies—influence the pattern, too. But the basis for the rest of the rise has eluded researchers.

Some investigators, such as Stephen H. Safe of Texas A&M University, doubt xenoestrogens have a role in breast cancer. They assert that people are exposed to minute quantities of individual chemicals, that the compounds are far less potent than estradiol and that plant xenoestrogens able to dampen estrogen's effects cancel out the activity of the damaging kinds. Yet these arguments are unconvincing. Although any given synthetic xenoestrogen may enter the body in small amounts, as a group the substances are ubiquitous. In the body, they also tend to persist for decades and can accumulate to high levels. In contrast, plant estrogens are degraded rapidly, and so it is unlikely that those consumed in most people's diets can negate the activity of the persistent synthetic compounds.

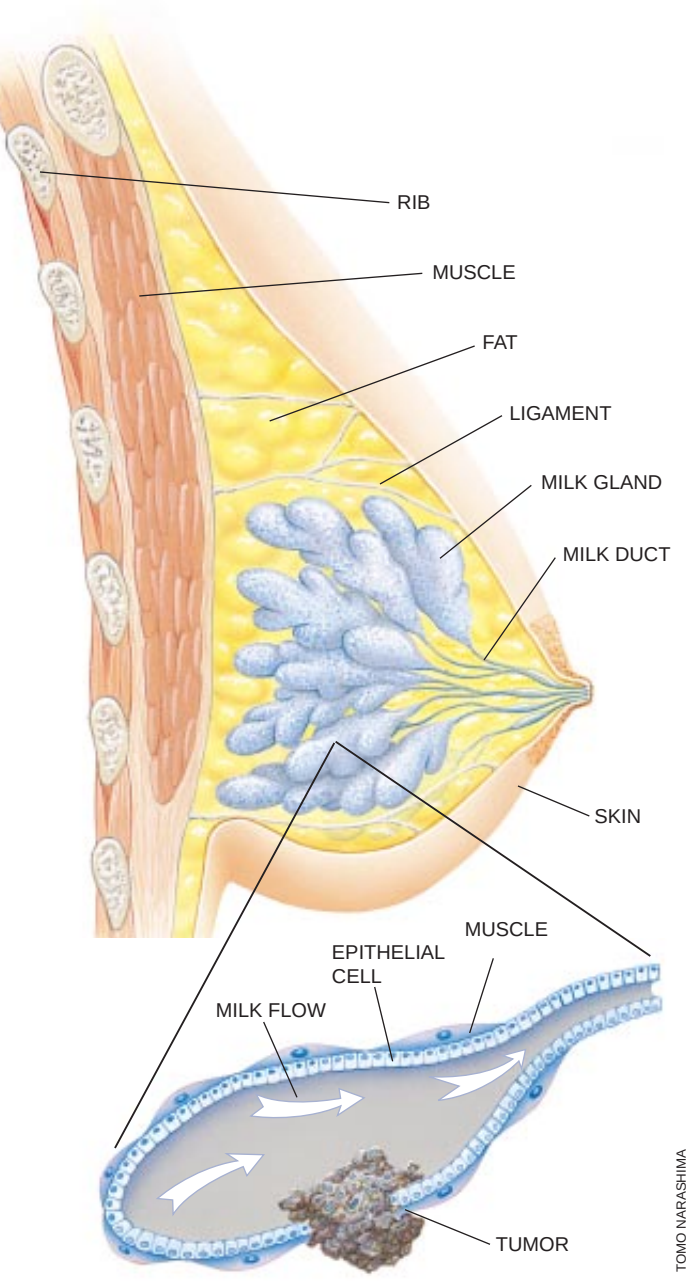
To understand how xenoestrogens might lead to cancer, one needs a sense

PESTICIDES SPRAYED ON CROPS are a major source of foreign estrogens, or xenoestrogens, in the environment. The authors propose that increased exposure to xenoestrogens may explain part of the rise in the incidence of breast cancer over the past several decades in many nations. The plots at the right show that most of the recent rise in the U.S. has occurred in women older than 50. The data are from the National Cancer Institute's Surveillance, Epidemiology and End Results (SEER) Program, which adjusted the rates to eliminate the confounding influence of changes in the age distribution of the population over time.

WESLEY HITT *Gamma Liaison*



JOHNNY JOHNSON



BREAST contains various tissues. Tumors are most likely to arise in the epithelial cells (*cutaway*) that line the milk glands and ducts.

of how natural, or endogenous, estradiol itself participates in the process. The steps are not entirely clear, but estradiol's ability to induce epithelial cells in mammary tissue to multiply is undoubtedly involved. These cells line the milk glands and the ducts through which milk is carried to nursing infants. The hormone influences cell growth by binding to an intracellular protein known as the estrogen receptor. Complexes of hormone and receptor can bind to DNA in the nucleus and activate genes that direct cell division. Such activation speeds the rate of DNA replication and so increases the likelihood that a mutation, possibly carcinogenic, will arise and go unrepaired.

As noted earlier, estradiol is one of several forms of estrogen manufactured by the body. Conversion, or metabolism, of estradiol to other varieties of estrogen may further influence the development of cancer. At some point after estradiol is formed, enzymes alter the placement of an OH group—the hydroxyl radical—in a large fraction of such molecules. At times, the enzymes yield a product, or metabolite, that is known as 16-alpha-hydroxyestrone; at other times, they may produce 2-hydroxyestrone [*see diagram on page 170*]. The two products, whose activities differ markedly, cannot be produced at the same time; hence, whenever cells make one metabolite, the ratio of the 16-alpha type to 2-hydroxyestrone changes.

We suspect that processes favoring metabolism of estradiol to the 16-alpha form help to give rise to breast cancer, although this view is not accepted universally. For one thing, 2-hydroxyestrone activates the estrogen receptor only weakly; in analogy with "good" cholesterol, it might be called the "good" estrogen. Yet the 16-alpha variety—the putative "bad" estrogen—strongly increases the interaction of the receptor with growth-promoting genes, enhances breast-cell proliferation and perhaps damages DNA. Moreover, studies in animals and recent human trials have linked elevated levels of 16-alpha-hydroxyestrone to breast cancer.

In one of the animal projects, mouse strains that naturally acquire spontaneous breast tumors were found to have four times more of the bad metabolite in their breast tissue than did strains normally resistant to breast cancer. More recently, Michael P. Osborne, Nitin T. Telang and others at the Strang-Cornell Cancer Research Laboratory in New York City showed in a small study that breast tissue from women with breast cancer contained nearly five times as much of the 16-alpha compound as did comparable tissue from women without cancer. In the past few months Joachim G. Liehr of the University of Texas at Galveston and Ercole L. Cavalieri of the Eppley Institute for Research in Cancer in Omaha have also reported that 4-hydroxyestrone appears to be elevated in some cases of breast cancer.

The extent to which estrogens encourage the development of breast cancer may depend not only on the amount of exposure but also on the timing. Various investigations suggest that unusually high exposure to estrogen during prenatal development, adolescence or the decade or so before menopause primes breast cells to become malignant. At those times, the estrogen presumably programs the cells to respond strongly to stimulation later in life. Timing of a different sort may also explain why women who have children young seem to gain some protection from breast cancer. It is now thought that full-term pregnancy at a young age causes breast tissue to develop in ways that help epithelial cells to resist estrogen's growth-promoting signals.

How Xenoestrogens Work

Certain xenoestrogens may promote cancer by enhancing the production of "bad" estrogens. Other xenoestrogens may act by binding to the estrogen receptor and inducing it to issue unneeded proliferative signals. Chemicals with these properties may encourage the development of cancer in added ways as well. For example, there are indications that some xenoestrogens help cells to generate the new blood vessels needed for tumor growth and spread; others seem to damage DNA. Exposure at critical times may also heighten the carcinogenic effects of xenoestrogens.

How might xenoestrogens get into the body to act on breast cells? One of the most common pathways is probably through animal fat, because synthetic xenoestrogens tend to accumulate in fatty tissue. Foods from animals at the top of the food chain are likely to deliver larger doses than are foods from organisms at lower levels; hence, meat derived from animals that eat smaller animals or contaminated grass, grain or water would probably yield more exposure than would a plate of vegetables carrying residues of estrogenic pesticides. Corn oil and related polyunsaturated fats appear to have estrogenic effects and can also be a source of exposure. People who live in areas where the air or water is highly polluted by industry or by the dumping or burning of wastes might take in estrogenic chemicals simply by breathing the air or drinking contaminated water. Occupational exposures can occur also.

The first hints that synthetic chemicals could exert harmful estrogenic effects on living organisms emerged more than 50 years ago, when a number of

researchers reported that chemicals in the environment seemed to affect reproduction profoundly in many species, including mink and sheep. Experimental work subsequently confirmed that DDT (dichlorodiphenyltrichloroethane) and certain other chlorinated organic pesticides—among them methoxychlor and Kepone (also known as chlordecone)—could indeed disrupt the endocrine system.

DDT was once used liberally (in fact it was sometimes sprayed directly on people), but it was banned in the U.S. in 1972. Since then, levels in the environment have declined. Nevertheless, because the chemical persists in the environment for more than 50 years, it remains ubiquitous. It is also widely used in many developing nations, especially in places where malaria is prevalent, and residues may be present in some imported foods. Methoxychlor is an insecticide used on trees and vegetables, and Kepone was a constituent of ant and roach traps until it was discontinued in 1977.

During the past 15 years, experiments have shown several compounds to be estrogenic and to cause mammary tumors in animals. They include certain aromatic hydrocarbons in fuels and some PCBs (polychlorinated biphenyls). PCBs are long-lived chlorinated organic compounds that were once used as electrical insulators. They are no longer manufactured in the U.S. but can still be found in old transformers and have been detected in soil, water, animals and, at times, human tissue. Further, injections of DDT have been found to accelerate the growth of existing mammary tumors in male mice. Growth of such tumors in males is a sign that a chemical is unusually carcinogenic, because male rodents are generally resistant to breast cancer. Similarly, injection into male rats of atrazine, a popular weed killer often found in groundwater, increases the incidence of breast tumors.

Many experiments delivered larger doses than animals would typically encounter in nature. But data collected by Ana M. Soto and Carlos M. Sonnenschein of Tufts New England Medical Center hint that small amounts may be harmful when exposures are combined. The workers incubated breast cancer cells with a mixture of commonly used organochlorine pesticides, each at low levels. They saw greater proliferation than occurred when the compounds were added to the cells individually.

More recently, examinations of various pesticides have bolstered the proposition that certain xenoestrogens may promote breast cancer by shifting the balance of estradiol's by-products toward the bad, 16-alpha variety. In particular, we and our colleagues at Strang-Cornell found that DDT, DDE (a by-product of DDT), atrazine and Kepone greatly increase the amount of the 16-alpha metabolite in cultured breast cancer cells. In contrast, a natural plant xenoestrogen produces the opposite effect. The compound, indole-3-carbinol (which occurs in broccoli, brussels sprouts, cabbage and cauliflower), favors production of the 2-hydroxy metabolite. Separate work indicates that soy products behave in much the same way.

Laboratory evidence that plastics, too, can be estrogenic has emerged only in the past five years, although subtle clues vexed scientists long before that. In the late 1970s David Feldman and Aruna V. Krishnan of Stanford University found to their surprise that a form of yeast apparently produced estrogen. They then spent more than a decade trying to figure out just how this simple, single-cell organism, which had no obvious use for the hormone, managed that feat. Finally, in 1990, they found their answer: the yeast did not synthesize estrogen after all. The "estrogen" was really a chemical that had leached out of the plastic flasks in which the yeast were growing. That chemical, bisphenol A, is a breakdown product of polycarbonate, which is used abundantly in many plastics. Polycarbonate may sometimes be found in the lining of food cans and in packaging for juices. Bisphenol A escapes from plastics when polycarbonate is subjected to high temperature.

The ability of bisphenol A to produce estrogenic effects in humans is evident from the fact that some men in the plastics industry have developed

Some Proved Xenoestrogens

The compounds listed below are among the better known ones that have been shown in laboratory tests to be xenoestrogens. Of these, DDT and certain PCBs have now been implicated in human studies as a cause of breast cancer. The substances that have been banned in the U.S. persist in the environment for many years and are available in some other countries. They may appear in foods imported from abroad and may occasionally travel as air pollution.

COMPOUND	USE	COMMENT
Chlorinated organic compounds		
Atrazine	Weed killer	Widely used today
Chlordane	Termite killer	Widely used before it was banned in 1988
DDT	Insecticide	Widely used before it was banned in 1972; still present in virtually everyone's body
Endosulfan	Insecticide	Widely used today
Kepone	Bait in ant and roach traps	Banned in 1977
Methoxychlor	Insecticide	A close relative of DDT
Some PCBs	Component of electrical insulation	No longer made in the U.S. but still found in old transformers
Plastics		
Bisphenol A	Breakdown product of polycarbonate	Leaches out into fluids when hot
Nonylphenol	Softener for plastics	Leaches out into fluids readily at room temperature
Pharmaceuticals		
Synthetic estrogens	Constituent of birth-control pills and estrogen-replacement therapies	One drug, diethylstilbestrol (DES), was given to several million women during pregnancy before it was essentially banned for that use in 1971
Cimetidine	Ulcer treatment	———
Fuel constituents		
Aromatic hydrocarbons	Components of petroleum	Can be inhaled readily from gasoline and from car exhaust

breasts after chronically inhaling the chemical in dust. But no one has yet learned whether it seeps into foods that are unheated or are heated to normal cooking temperatures, whether it remains active when ingested or whether it can participate in transforming normal breast cells into malignant ones.

In 1992 another plastic-related puzzle was unraveled by Soto and Sonnenschein of Tufts. In research unconnected to the effects of estrogen or xenoestrogens, they found that cultures of breast cancer cells sometimes multiplied more rapidly than was expected. Further probing revealed that a chemical used to make plastic flexible—nonylphenol—was the culprit. As was true of bisphenol A, it had escaped from the laboratory's plastic ware and, mimicking estrogen, induced growth. Related substances can be found in polystyrene containers, intravenous tubing and some detergents and household cleaners. The effects in the body have yet to be determined.

Human Findings

Like the laboratory analyses that have been performed, human studies—mainly examining organochlorine pesticides and PCBs—implicate xenoestrogens in breast cancer. Many of the earliest investigations found no association between cancer and xenoestrogens, but those projects relied on small pools of subjects and often failed to compare patients with like characteristics. Several newer discoveries imply those earlier conclusions were premature.

In one of the more recent investigations, Mary S. Wolff of Mount Sinai Medical Center in New York City and her colleagues at New York University had access to stored blood from 14,000 women. The team measured the levels of DDE in the serum of the 58 women who were eventually diagnosed with breast cancer and in the serum of 171 women well matched for age and risk factors. The samples from cancer patients had higher levels of DDE. In addition, women whose blood harbored the most DDE had four times the cancer risk of women who carried the least DDE. In another well-controlled study, a Canadian research team lead by Éric Dewailly of Laval University looked at tissue from 41 women who had a breast mass removed for biopsy. Patients who turned out to have estrogen-responsive breast cancer had higher concentrations of DDE and PCBs.

Meanwhile, however, one large trial looking at DDE and PCBs has yielded what its authors have described as inconclusive results. In 1994 Nancy K. Krieger and her co-workers at the Kaiser Foundation Research Institute in Oakland, Calif., compared levels of these contaminants in stored blood from 150 women with breast cancer and 150 controls. When they combined the study's three ethnic groups—African-Americans, whites and Asian-Americans—they saw no difference between the breast cancer patients and the controls.

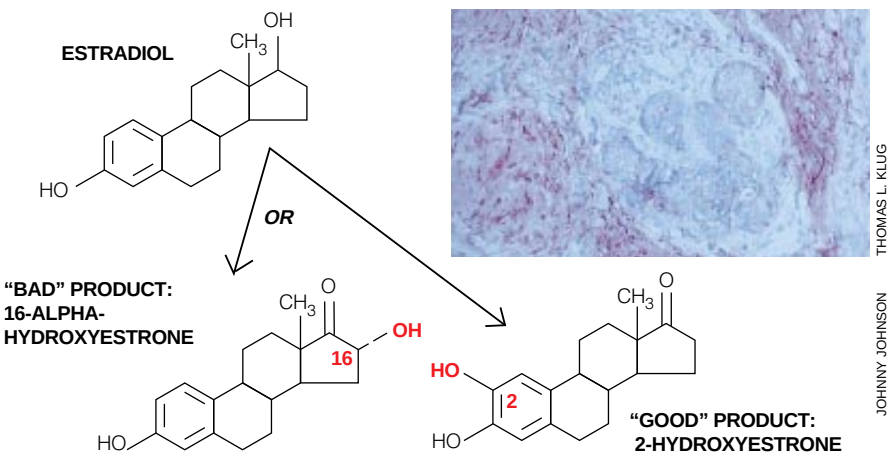
On its surface, this report casts doubt on our hypothesis. Yet David Savitz of the University of North Carolina argues that combining Asian women with other American women masks a troubling trend. When he reviewed the published data on each group separately, he discovered that whites and African-Americans with the highest levels of exposure to the chemicals were two to three times more likely to acquire breast cancer than were those with lower levels. Aggregating the data from the groups washed out these sharp differences because the Asian subjects with high levels of chlorinated organic compounds in their blood did not have excess cancer. This outcome in the Asians is consonant with reports that Asian women in their native lands have five times less breast cancer than do Americans, Europeans and African-Americans.

What might explain the lack of cancer in the Asian subjects? Even when living in the U.S., many Asians eat diets rich in soy products, cabbage, broccoli and other vegetables. According to at least one study, they also generally have higher levels of 2-hydroxyestrone and lower levels of 16-alpha-hydroxyestrone than do their non-Asian counterparts. It is tempting to speculate that the Asian women are protected in part by diets that favor formation of the good hydroxyestrone and minimize production of the bad, although genetic differences and other environmental factors could also be important.

What To Do?

The research that thus far ties xenoestrogens to breast cancer certainly underscores the need for further bench and clinical investigation. Some important clinical trials are already planned. Thanks largely to the organizing skills of activists, the U.S. now has a national action plan for exploring potentially avoidable causes of breast cancer, including xenoestrogens. The plan, which calls for an extensive survey of environmental influences on breast cancer on Long Island in New York State, was developed by Donna Shalala, secretary of the U.S. Department of Health and Human Services. A European project looking at the relation between diet and breast cancer is considering whether plant xenoestrogens can help prevent the disease.

But should more research be the end of it? Should government and industry wait until scientists can make a still stronger case for a link between xenoestrogens and breast cancer? We think not. Where large populations are subject to uncertain but possibly widespread risk, waiting for more and more proof of danger gambles with human health. Certainly, delays in declaring cigarettes a major health hazard contributed to



THOMAS L. KLUG

JOHNNY JOHNSON

ESTRADIOL CAN BE CONVERTED to two products that differ structurally only in the placement of one OH group (*red in diagram*). Many findings suggest that the form carrying the OH at position 16—16-alpha-hydroxyestrone—promotes breast cancer, and the form known as 2-hydroxyestrone is protective. For instance, Thomas L. Klug of Immuna Care Corporation in Bethlehem, Pa., finds that cancerous breast tissue from women (*micrograph*) harbors much more 16-alpha-hydroxyestrone (*stain*) than does normal breast tissue. Some xenoestrogens may contribute to breast cancer by elevating levels of 16-alpha-hydroxyestrone in breast tissue.

A Message from Wildlife?

Reproductive anomalies have been found in animals born into ecosystems polluted by xenoestrogens and other compounds that disrupt the endocrine system, especially those that persist in the environment. Such anomalies include:

Top: J. G. SIKARSKIE *Michigan State University; Middle:* WORLD WILDLIFE FUND; *Bottom:* CHIP CLARK *Smithsonian Institution; shells courtesy of Phillip Gibbon*

- Production of vitellogin, a female protein, by male fish living near outlets from municipal sewer systems.

- Death of embryos, deformities and abnormal nesting behavior in fish-eating birds living in Great Lakes regions contaminated by chlorinated organic compounds. For example, eagles (*top photograph*) and other birds have been born with crossed beaks; also female herring gulls have been found to share nests with other females and, together, to produce supranormal clutches (*middle photograph*). Nest sharing is a sign that the male population has dwindled.

- Abnormally small penises and altered hormone levels in alligators hatched in Lake Apopka, Fla., following a massive spill in 1980 of Kelthane—a pesticide that at the time (and until the late 1980s) contained DDT as an "inert" ingredient.

- Incompletely descended testes in panthers living in regions of south central Florida in which soil or water contained high concentrations of heavy metals and persistent chlorinated organic substances.

- Deformation of shells in oysters harvested from Kepone-contaminated waters (*middle and right specimens in bottom photograph*).

- Twice the rate of testicular cancer and reproductive defects in military dogs that served in Vietnam, compared with dogs that served elsewhere during the same period.

The causes of such disturbances are difficult to nail down conclusively. Nevertheless, some of the defects have been reproduced in experimental animals deliberately exposed to selected pollutants. The combined field and laboratory studies suggest that endocrine-disrupting compounds in the environment may well contribute not only to breast cancer in women but also to reproductive disturbances in men and to developmental abnormalities in animals.

millions of avoidable deaths from smoking-associated lung cancer, other lung diseases and heart disease.

Prudence dictates that several steps be implemented now. First, potential estrogenicity should be assessed for materials that play critical roles in our society, such as fuels, drugs and plastics—and for any proposed substitute agents. Second, the possible effects of estrogenic compounds on the human body should be assessed. Such tests should look at the consequences of long-term exposure and of interactions among widely used chemicals. Third, use of known inessential xenoestrogens should be curtailed.

Cancer is a complicated disease, resulting from many interacting factors that may differ from one person to the next. We realize that xenoestrogens cannot account for all breast cancer. But in contrast to many established risk factors (such as early onset of menarche and late menopause), they represent preventable causes. If reducing avoidable exposures to xenoestrogens made it possible to avert only 20 percent of breast cancers every year (four times more than are caused by inheritance of flawed genes), at least 36,000 women—and those who care about them—would be spared this difficult disease, and the public would be spared the burgeoning expenses of treatment and care. Such prospects are too tantalizing to ignore.

The Authors

DEVRA LEE DAVIS and H. LEON BRADLOW have collaborated since the late 1980s. Davis has been newly appointed senior fellow and program director of World Resources Institute, a research center based in Washington, D.C. She is also visiting scientist at the Strang-Cornell Cancer Research Laboratory in New York City and was formerly senior adviser to the assistant secretary for health in the U.S. Department of Health and Human Services. She holds a 1972 Ph.D. in science studies from the University of Chicago and a 1982 master's degree in public health from Johns Hopkins University. Bradlow, who earned his Ph.D. in chemistry in 1949 from the University of Kansas, is director of the Laboratory of Biochemical Endocrinology at Strang-Cornell and professor of biochemistry in surgery at the Cornell University School of Medicine. His work has confirmed insightful research his eldest daughter undertook in her student days, before she died at age 30.

Further Reading

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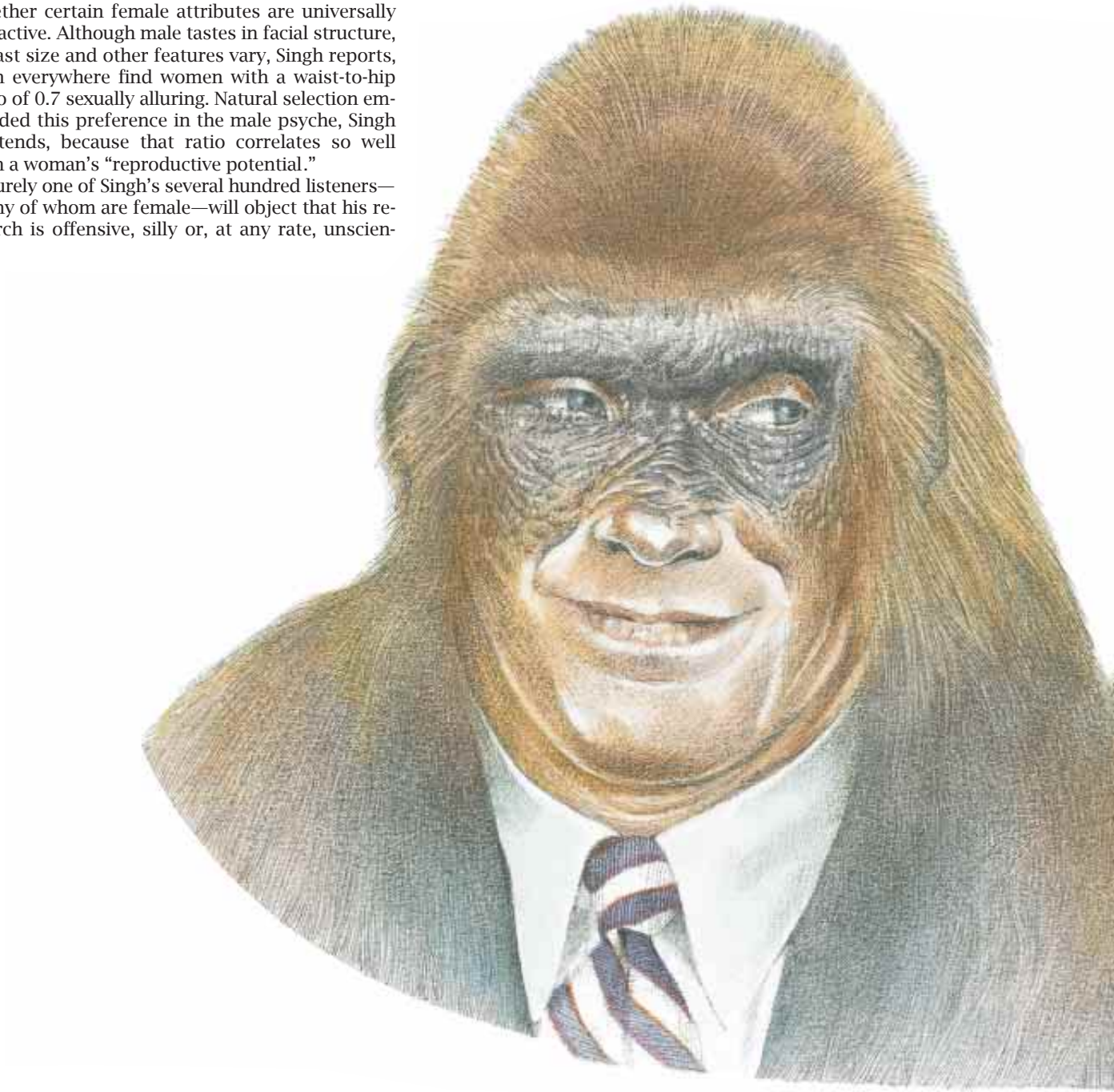
The New Social Darwinists

by John Horgan, *senior writer*

The headless woman in black leather panties has got to be the last straw. Devendra Singh, a psychologist at the University of Texas at Austin, flashes the photograph of the curvaceous torso on a giant screen during his talk on "men's preference for romantic relationships." For years Singh has been circling the globe, showing "sexy" pictures like this to men in an effort to determine whether certain female attributes are universally attractive. Although male tastes in facial structure, breast size and other features vary, Singh reports, men everywhere find women with a waist-to-hip ratio of 0.7 sexually alluring. Natural selection embedded this preference in the male psyche, Singh contends, because that ratio correlates so well with a woman's "reproductive potential."

Surely one of Singh's several hundred listeners—many of whom are female—will object that his research is offensive, silly or, at any rate, unscientific. Men's tastes are obviously dictated by culture, someone will argue, rather than by "instinct." But this is no ordinary social science meeting. It is the annual conference of the Human Behavior and Evolution Society. Attendees are trying to fulfill Charles Darwin's prophecy (reprinted on the cover of the meeting's program, along with a photograph of a bare-



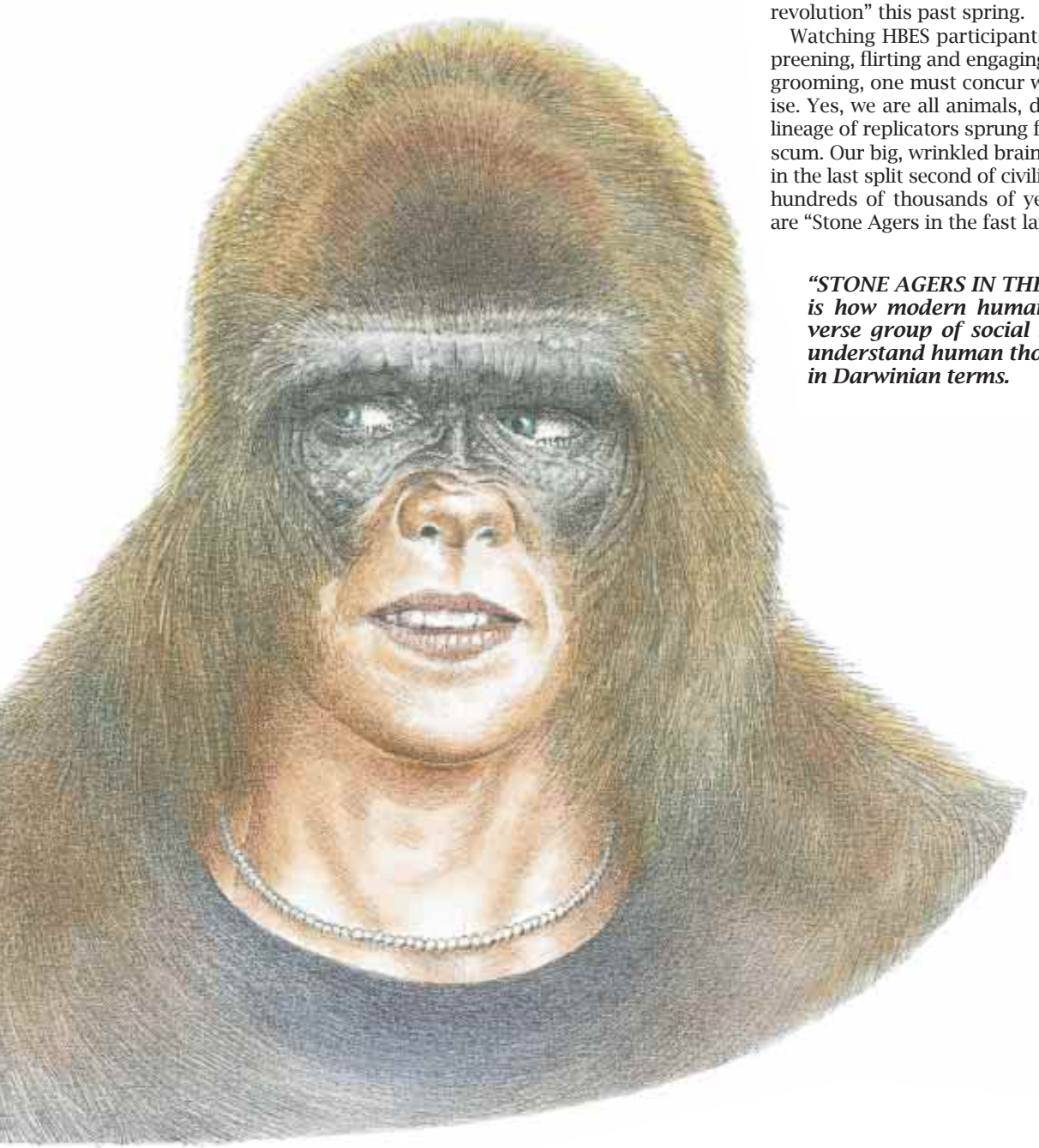
Psychologists and others try to sidestep old pitfalls—both political and scientific—as they apply evolutionary theory to the clothed ape

breasted Amazonian maiden) that "in the distant future… [p]sychology will be based on a new foundation"—that is, Darwin's own theory of evolution by natural selection.

Darwin, as usual, was right—about Darwinian psychology being in the distant future, that is. But over the past decade evolutionary theory has been racing, like a mutant virus, through the social sciences. In the seven years since the HBES was founded, it has attracted a growing number of psychologists, anthropologists, economists, historians and others seeking to understand human affairs (in all senses of the word). Publishers have released a swarm of books by scientists and journalists propounding the "new" paradigm. A highly regarded PBS series, *The Human Quest,* highlighted what it dubbed the "second Darwinian revolution" this past spring.

Watching HBES participants bonding, bickering, preening, flirting and engaging in mutual rhetorical grooming, one must concur with their basic premise. Yes, we are all animals, descendants of a vast lineage of replicators sprung from primordial pond scum. Our big, wrinkled brains were fashioned not in the last split second of civilization but during the hundreds of thousands of years preceding it. We are "Stone Agers in the fast lane," as S. Boyd Eaton,

"STONE AGERS IN THE FAST LANE": that is how modern humans appear to a diverse group of social scientists trying to understand human thought and behavior in Darwinian terms.



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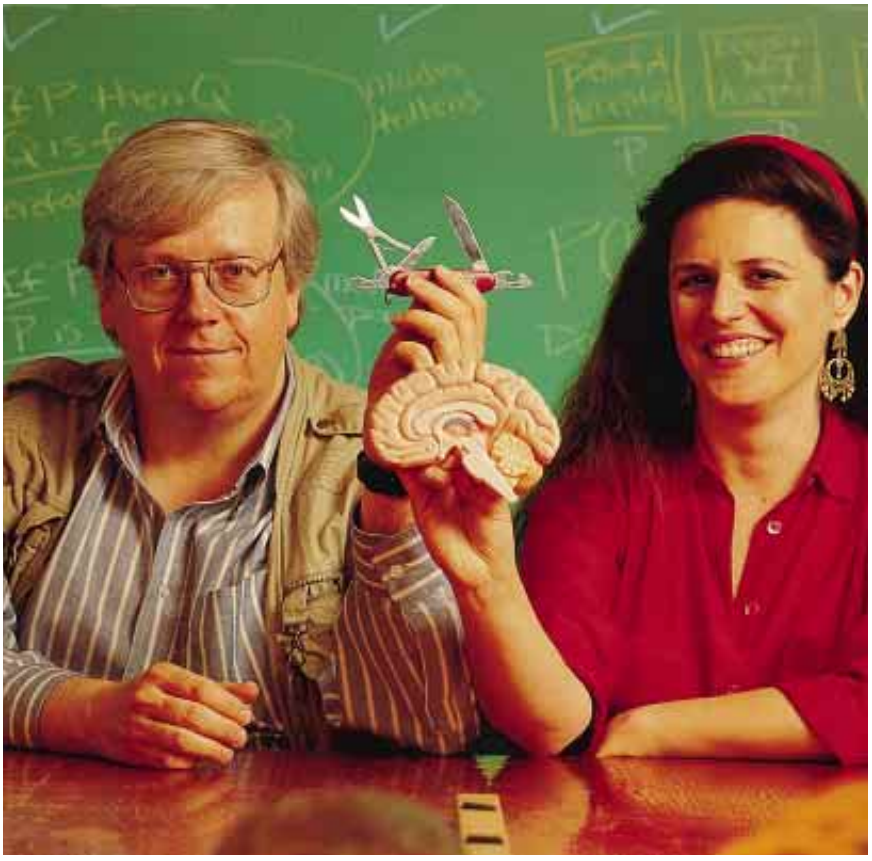


ALAN LEVENSON

THE MIND IS A SWISS ARMY KNIFE, crammed with tools designed for specific problems that faced our hunter-gatherer ancestors, say evolutionary psychologists Leda Cosmides and John Tooby of the University of California at Santa Barbara.

a physician at Emory University, puts it.

But just how much can the new social Darwinism tell us about our modern, culture-steeped selves? Even enthusiasts admit that the field has much to prove before it can shake the old complaint that it traffics in untestable "just-so stories" or truisms. Singh's work in "Darwinian aesthetics" is a case in point. His finding, once unpacked, hardly seems profound. Men desire young, healthy women—neither starving nor obese—who are not already pregnant and whose hips are wide enough to deliver a child. Do we really need Darwinian theory to tell us that?

Actually, we do, replies Randolph M. Nesse, a psychiatrist at the University of Michigan who helped to organize the first HBES meeting and one of the society's most respected members. Most social scientists, Nesse points out, still assert that our concepts of beauty are culturally determined; only Darwinists attempt to explain why certain aspects of beauty are universal. Nesse adds that just as it does for biology, Darwinian theory can also provide a much needed framework for the social sciences, which are now in disarray.

Yet Nesse admits that he often becomes frustrated by his field's inability to predict counterintuitive phenomena rather than to offer retroactive explanations of all too familiar ones. He would like to see researchers construct the rigorous "ladders of inference" that have made fields such as, say, molecular genetics so successful. "We're just getting started," Nesse says. "To see this as a mature field would be a mistake."

The Modular Mind

The HBES conference demonstrates, if nothing else, the astonishing ambition of the new social Darwinists. Topics range from the evolution of religious symbology to the resurgence of spouse swapping among middle-class Americans. The meeting sounds at times like a pep rally. There is much gleeful bashing of those deluded souls who think culture—whatever that is—determines human behavior. When anthropologist Lee Cronk of Texas A&M University derides cultural determinism as a "religion" rather than a rational stance, his audience roars with laughter.

But serious disagreements lurk beneath the seeming unity of the gathering. Just how malleable are our minds? To what extent are we creatures of instinct, as opposed to reason? Just how consciously do we pursue our genetic interests? To what degree do the differences between individuals and ethnic groups reflect genetic rather than cultural influences?

Moreover, some of the new social Darwinists, in their effort to avoid the political pitfalls into which their predecessors stumbled, have become hard to distinguish from culturalists. Most shun the naturalistic fallacy, the conflation of what is with what should and must be. This view was typified by the original social Darwinists of a century ago, who argued that those at the top of the Victorian heap deserved to be there.

Nesse and other HBES founders also deliberately chose not to include the controversial term "sociobiology" in the society's name. Sociobiology is closely associated with Edward O. Wilson of Harvard University, who was tarred as a genetic determinist for arguing in his 1975 classic *Sociobiology* and later works that evolutionary theory can illuminate the social behavior not only of termites and baboons but also of humans.

To be sure, the society's official journal is called *Ethology and Sociobiology,* and some of the veterans here still defiantly call themselves sociobiologists, out of loyalty to Wilson or sheer stubbornness. Others, while acknowledging their debt to sociobiology, contend that sociobiologists often ignored the mind's role in mediating the links between genes and human behavior. To reflect this emphasis on the mind, they call themselves evolutionary psychologists.

Leda Cosmides and John Tooby, a wife-and-husband team at the University of California at Santa Barbara, are leaders of evolutionary psychology. Some sociobiologists, they note, have implied that the human brain is a calculating machine dedicated to "maximizing fitness" in all environments. If that were true, they say, no one would forgo having children; in fact, men would all be lining up at sperm banks so that they might have as many offspring as possible.

In the (dare one say it) seminal 1992 book *The Adapted Mind,* which they coedited with Jerome H. Barkow of Dalhousie University, Cosmides and Tooby assert that the mind consists of a motley collection of specialized mechanisms, or modules, designed by natural selection to solve problems that faced our hunter-gatherer forebears, such as acquiring a mate, raising children and dealing with rivals. The solutions often involve such emotions as lust, fear, affection, jealousy and anger.

Cosmides and Tooby also emphasize,

as sociobiologists often did not, that Darwinian theory need not conflict with the liberal principle that all humans are created equal (more or less). "Evolutionary psychology is, in general, about universal features of the mind," they have written. "Insofar as individual differences exist, the default assumption is that they are expressions of the same universal human nature as it encounters different environments."

Gender is the crucial exception to this rule. Evolutionary psychologists insist that natural selection has constructed the mental modules of men and women in very different ways as a result of their divergent reproductive roles. David M. Buss, an evolutionary psychologist at the University of Michigan, says his research on sexual attraction and "mate choice" reveals a distinct gender gap.

Buss has surveyed men and women worldwide about their sexual attitudes. He has concluded that men, because they can in principle father a virtually infinite number of children, are much more inclined toward promiscuity than are women. Women, because they can have on average only one child per year, are choosier in selecting a mate. Men in all cultures place a greater premium on youth and physical attractiveness—which Buss calls cues to fertility—than do women, to whom male "resources" are more important. Similarly, because men can never be sure that a child is theirs, their jealousy tends to be triggered by fears of a mate's sexual infidelity. Women, on the other hand, become more upset at the thought of losing a mate's emotional commitment and thus his resources.

Buss realizes that these conclusions, which he spells out in his 1994 book *The Evolution of Desire,* might seem obvious to the "man in the street." But some influential social scientists, he notes, have held that the man in the street is wrong, that culture rather than nature determines sexual attitudes. This view was typified by Margaret Mead, who in her famous book *Coming of Age in Samoa* depicted a society in which men and women pursue sexual pleasure with equal abandon, and jealousy is unknown. Buss says work by him and others has shown that Mead's vision was a fantasy.

The persistence of male jealousy, Buss adds, also contradicts the suggestion of some sociobiologists that our minds rationally calculate how to maximize our reproductive prospects under any and all circumstances. Male jealousy made sense in a hunter-gatherer environment, Buss explains, because when acted on, it could improve the chances that a male's genes were propagated rather than a competitor's. But modern males, Buss says, will become enraged by a mate's unfaithfulness even if she is using birth control.

Our Cheating Hearts

One of the few HBES members who still calls herself a sociobiologist, Sarah Blaffer Hrdy of the University of California at Davis, accuses Buss of caricaturing the views of sociobiologists and even cultural determinists. If Mead saw the world through the filter of her own fantasies, Hrdy comments, so have many male investigators of sexual behavior—such as those who study the evolutionary significance of female breast symmetry.

"Men just love coming up with scenarios for female breasts because they love looking at them," Hrdy snaps. She complains that far too much time has been expended on "preference" studies like Buss's; sexual behavior is often more complex, and calculated, than such surveys suggest. For example, male jealousy may often be irrational, but the female preference for mates with money makes perfect sense today, given that women's economic opportunities are still limited in most societies. Hrdy concurs with the statement of one HBES speaker that evolutionary psychologists must move beyond their "discovery" that "men like pretty girls and women like wealthy men."

Some researchers think Cosmides has done just that. One of the mind's most useful modules, she proposes, is dedicated to detecting "cheating" by others. Her hypothesis is a corollary of a bracingly cynical concept called reciprocal altruism, first advanced in 1971 by Robert L. Trivers of Rutgers University. Trivers proposed that altruism could have arisen among our forebears only if it led to some "tit for tat" benefit.

Building on this insight, Cosmides argues that in a society bound by reciprocal altruism, natural selection would have favored both those who could cheat successfully and those who could spot cheaters. In tests with volunteers, Cosmides showed that humans are much more adept at solving problems if the solution requires the detection of cheating rather than some purely logical, abstract chain of reasoning.

At the meeting, economist Vernon Smith of the University of Arizona says his research supports the hypothesis of Cosmides. In Smith's experiments, volunteers have the opportunity to earn hundreds of dollars by successfully negotiating various complex transactions with others. (Needless to say, Smith has no trouble recruiting volunteers for his research.) The transactions are all variations of the famous Prisoner's Dilem-

Can Darwin Explain Everything?

At the annual meeting of the Human Behavior and Evolution Society, speakers invoked evolutionary theory to explain a broad range of phenomena.

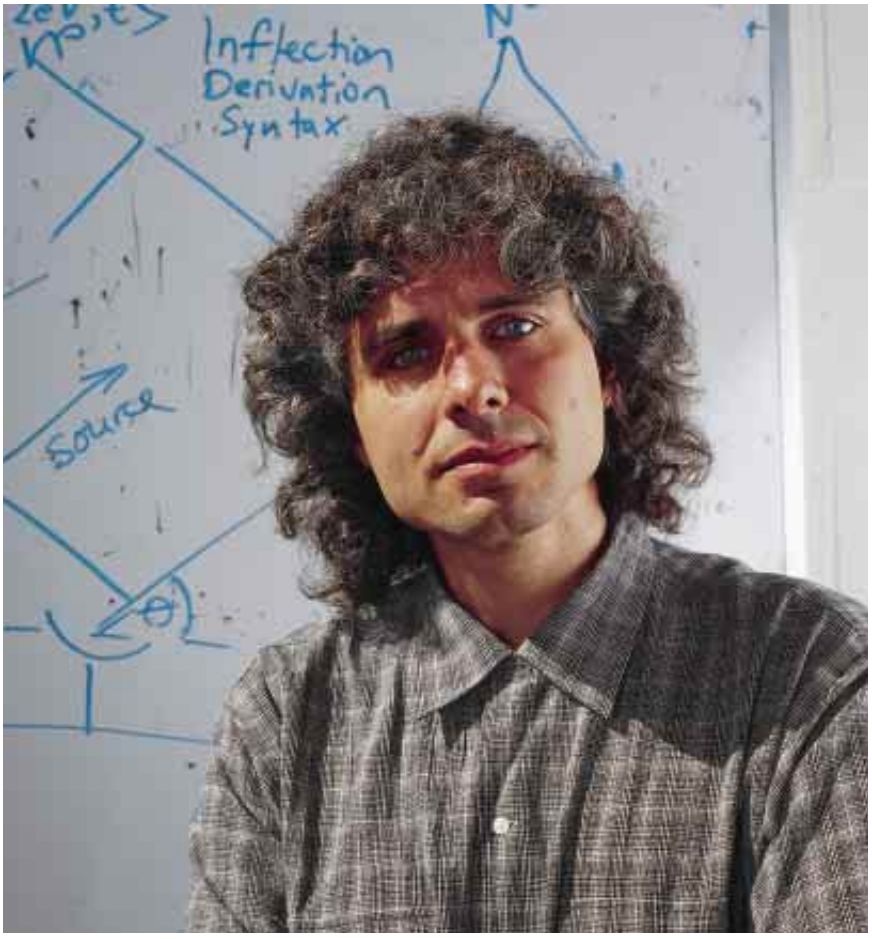
Sex, Politics and Religion. Secular and religious laws in societies such as imperial Rome and medieval England, asserts Laura Betzig of the University of Michigan, represented strategies of male rulers to accumulate and retain wealth and power, which led in turn to greater sexual opportunities.

Male Dominance of Culture. The fact that art, music and literature are produced largely by men between the ages of 20 and 40 suggests that culture "is primarily sexual display by young males," says Geoffrey Miller of the University of Nottingham.

The Amorous Female Tourist. The tendency of certain affluent women to pursue sexual liaisons with low-status men while on vacation, in seeming violation of Darwinian tenets, may actually be motivated by the women's innate desire for "social connectedness," according to April Gorry of the University of California at Santa Barbara.

Female Beauty. Men desire women with full lips and small chins, says Victor S. Johnston of New Mexico State University, because these attributes correlate with high estrogen levels and thus high fertility.

Problems during Pregnancy. The hypertension afflicting some pregnant women, suggests David Haig of Harvard University, may result from a "selfish gene" strategy of the fetus; the strategy causes the fetus to draw too heavily on the mother's resources—that is, the nutrients in her blood.



JESSICA BOYATT

STEVEN PINKER argues that language must be a creation of natural selection, but his M.I.T. colleague and fellow linguist Noam A. Chomsky demurs.

ma: each participant must decide whether to betray his or her counterparts and earn a guaranteed sum or trust them and possibly earn more—or even less—than the original amount.

Smith expected his subjects to calculate their selfish interests with cold rationality; that is the prediction of rational-choice theory, which is gospel among most economists. But the volunteers tended to be more trusting initially and, if their trust was betrayed, more unforgiving than they would be if behaving rationally. Smith was puzzled by his results until he discovered the writings of Cosmides and Tooby, who have emphasized the role of emotion in social transactions.

The modularity model has attracted mental health researchers as well. Alan M. Leslie, a psychologist at Rutgers, presents evidence that autism stems from a disorder of what he calls the theory-of-mind mechanism. According to this hypothesis, normal children have an innate ability to create internal representations, or "theories," of others' mental states. This ability has obvious adaptive value, Leslie explains, because it allows us more effectively to predict and manipulate the behavior of others. Autistic children often score well on intelligence tests—unless those tests require them to empathize with or predict the behavior of others.

Is Language an Instinct?

Another convert to evolutionary psychology is Steven Pinker, a linguist at the Massachusetts Institute of Technology. In a lecture at the HBES meeting, Pinker, who plans to spend the next year working with Cosmides and Tooby in Santa Barbara, delivers a Cliff Notes version of his well-received 1994 book *The Language Instinct.* Language is far too complex, Pinker contends, to be entirely learned; it must stem from an innate program hardwired into our brains. Moreover, language is common to all cultures (unlike reading and writing), and all physiologically normal children learn to speak fluently with little or no effort. Research has also shown that all languages share common features, suggesting that natural selection favored certain syntactic structures.

"I'm going to make some extremely banal points," Pinker adds. Language, he asserts, almost certainly arose because it was adaptive—that is, it conferred benefits on our hunter-gatherer ancestors. Language would allow early hominids to share learned skills related to toolmaking, hunting and other activities. Those especially adept at language would be able to manipulate others, form alliances and enjoy other advantages that would translate into more offspring. "I don't intend these points to be taken as revolutionary," Pinker says, "but they are generally denied when they are brought up at all."

In fact, these "banal" points are denied by none other than Pinker's legendary M.I.T. colleague and fellow linguist Noam A. Chomsky. Evolutionary psychologists are all, in a sense, heirs of Chomsky's. Almost 40 years ago Chomsky routed the behaviorists' tabula-rasa view of the mind by arguing convincingly that language is innate. But since then, Chomsky has cast doubt on the assumption that language is an adaptive trait, favored by natural selection.

Some Darwinists hint that Chomsky's position must be linked somehow to his leftist politics. Chomsky retorts that he simply recognizes, as Pinker and others do not, the limits of Darwinian explanations. He accepts that natural selection may have played *some* role in the evolution of language and other human attributes. But given the enormous gap between human language and the relatively simple communication systems of other animals, Chomsky says, and given our fragmentary knowledge of the past, science can tell us little about how language evolved.

Just because language is adaptive now, Chomsky elaborates, does not mean that it arose in response to selection pressures. Language may have been an incidental by-product of a spurt in intelligence that only later was coopted for various uses. The same may be true of other properties of the human mind. Evolutionary psychology, Chomsky complains, is not a real science but "a philosophy of mind with a little bit of science thrown in." The problem, he adds, is that "Darwinian theory is so loose it can incorporate anything."

Even at the meeting, some investigators find fault with the emphasis of evolutionary psychology on specialized rather than general-purpose abilities. James H. Fetzer, a philosopher at the University of Minnesota, argues that the subjects in the cheating experiments of Cosmides could have been displaying not some innate talent but a learned ability; after all, situations involving potential deception are common in the

modern era, too. Fetzer contends that evolutionary psychologists too quickly dismiss the possibility that humans may possess an all-purpose "heuristics" program; modern civilization and science itself testify to the power of our ability to learn through simple trial and error.

Steven J. Mithen, an archaeologist at the University of Reading, agrees. He faults evolutionary psychologists for implying that the "ancestral environment" was uniform and static rather than highly variable in space and time. The fluidity of the conditions under which our ancestors evolved, Mithen argues, might have favored those whose problem-solving skills, too, were adaptable rather than compartmentalized.

The Docile Yanomamö

But just how adaptable are we? In attempting to explain behavior that does not accord with Darwinian tenets, some theorists have postulated that conformity—or "docility"—is an adaptive trait. Those who go along, get along. In an article in *Science* in 1990 the economist and Nobel laureate Herbert A. Simon of Carnegie Mellon University conjectured that docility could explain why, for example, people obey religious tenets that curb their sexuality and why men fight in wars when as individuals they have little to gain and much to lose.

Although this hypothesis cleverly coopts the culturalists' position, it could also undermine the status of evolutionary psychology as a legitimate science. If a given behavior accords with Darwinian tenets, fine; if it does not, it merely demonstrates our docility. The theory becomes falsification-proof (thus demonstrating Chomsky's point that Darwin can account for anything). Acknowledging the tendency of humans to conform to their culture poses another problem for Darwinian theorists. Given the interconnectedness of all modern cultures, some of the universal, seemingly adaptive attitudes and actions documented by researchers such as Buss might actually result from docility. That is what the culturalists have said all along.

Indeed, Napoleon A. Chagnon, a prominent "Darwinian anthropologist" at Santa Barbara, sounds like a culturalist when he interprets his own work. For more than 20 years Chagnon has studied the behavior of the Yanomamö, one of the few Amazonian tribes still clinging to its primordial way of life. In this polygynous society, men in one village often raid other villages, killing men they encounter there and kidnapping women. Chagnon has found a correlation between the number of homicides that men commit and the number of offspring that they have. On the other hand, those who shrink from violent encounters—Chagnon calls them wimps—are usually "wiped out."

Chagnon has been accused of implying that male violence and even warfare are instinctual and therefore inevitable. He insists that is not his position. The Yanomamö men, Chagnon says, engage in aggressive behavior because it is esteemed by their culture. If they were raised in a society that revered not violence but, say, farming skills, they would quickly conform to that system. Chagnon acknowledges that his view is not so different from that of Stephen Jay Gould of Harvard University, who also emphasizes the malleability of human nature—and is considered by many HBES members to be an archenemy of their enterprise. "Steve Gould and I probably agree on a lot of things," Chagnon says.

The Wicked Stepfather Syndrome

Two other Darwinian researchers who warn against overinterpreting their findings are Margo Wilson and Martin Daly of McMaster University. This married couple has examined what Darwinists consider to be the most perverse of human acts, a parent's murder of his or her own child. Evolutionary theory predicts that we should be particularly solicitous toward those to whom we are

NAPOLEON A. CHAGNON

YANOMAMÖ MEN, shown here preparing for a raid on a neighboring village, are known for their ferocity. Yet anthropologist Napoleon A. Chagnon says they are conforming to their culture rather than acting on an "instinct" for violence.

most closely related. After analyzing murder records from the U.S. and Canada, Wilson and Daly determined that children younger than two were at least 60 times more likely to be killed by a stepparent—and almost always a stepfather—than by a natural parent. The results agreed with evolutionary theory after all.

Wilson and Daly, like David Buss, are sensitive to charges that they have "discovered" the obvious: people like their own children more than the children of others; this message, after all, is embodied in such fairy tales as *Cinderella* and *Snow-White*. Wilson contends that most social scientists have dismissed this "folk wisdom" about evil stepparents rather than trying to determine whether it has any basis.

Wilson and Daly's research is often cited as a model of Darwinian social science, because it addresses an important issue and rests on a large empirical foundation. But even they concede that their work raises some obvious questions. Families with a stepparent might be less stable financially and emotionally than families that have remained intact. Moreover, many stepfathers might have assumed the burden of stepchildren reluctantly when they married. Controlling for such factors is next to impossible, Wilson says.

Some critics have suggested that Wilson and Daly should compare the homicide rates for adopted children with that for natural children. Wilson responds that performing such a study would be extremely difficult, in part because many adoptive parents want to conceal their relationship to their children. If such data were available, she predicts, they would show little or no effect, because couples who adopt are carefully screened for financial security, emotional stability and other factors. They may also be more motivated to have children than many natural parents are.

Wilson and Daly have been contacted by both prosecutors and defense lawyers involved in cases in which a stepparent has killed a child. The defense lawyers are seeking to exonerate their clients on the grounds that "it was in their genes." Applying the same logic, prosecutors have asked whether Wilson and Daly would support stiff sentences to deter other stepparents inclined to commit such a crime. Wilson and Daly have declined to support either position. They emphasize that no one should infer from their results that stepparents are fated to abuse their children; after all, most stepparents treat their children benignly.

The Guy in the Black Hat

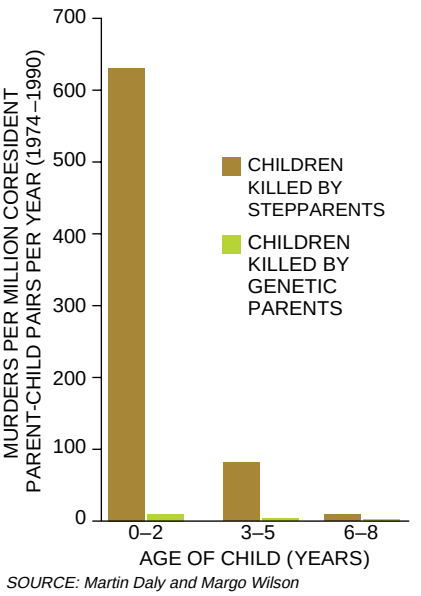
The work of Wilson and Daly—and of Chagnon—raises what is, for those who pursue genetic explanations of human behavior, another divisive issue. Why do some men resort to violence when others, faced with similar situations, refrain from doing so? Wilson, Daly and Chagnon all downplay the possibility that some men are more genetically inclined toward violence than others; the researchers cite environmental factors, such as differences in upbringing, as more likely causes of behavioral differences. This view conforms to the party line of evolutionary psychology, which holds that with the important exception of sex, all humans are born with essentially the same psychological endowment. Cosmides and Tooby have speculated that genetic variation among individuals may protect our species from disease or parasites but should have few significant behavioral consequences.

In fact, the surest way to annoy evolutionary psychologists is to lump them together with behavioral geneticists, who tend to ascribe differences among individuals and even ethnic groups to genetic variation. "I'm the guy in the black hat here," says David C. Rowe of the University of Arizona, one of the few behavioral geneticists invited to give a talk at the conference. (His talk is scheduled for the final session of the final day, after many attendees have left.)

Rowe understands why evolutionary psychologists disavow behavioral genetics: this position makes their work easier both politically and scientifically. If all commonalities can be ascribed to genes and all disparities to the environment, the task of constructing models is enormously simplified; evolutionary psychologists can also distance themselves from the race-obsessed science exemplified by last year's notorious best-seller *The Bell Curve*.

But Rowe still finds the position of Cosmides and Tooby a bit disingenuous. If genes can account for our commonalities, he points out, they can also account for our differences; moreover, evolution would not occur without individual variation. A growing body of evidence, Rowe notes, shows a correlation between genetic variation and such

SUSAN BONNERS



SOURCE: Martin Daly and Margo Wilson

EVIL STEPPARENTS, notorious from fairy tales such as the Grimm brothers' *Snow-White,* may have a basis in fact. Children age two or younger in Canada were some 60 times more likely to be killed by a stepparent than by a genetic parent.

significant behavioral traits as aggression, extroversion, intelligence, homosexuality and depression.

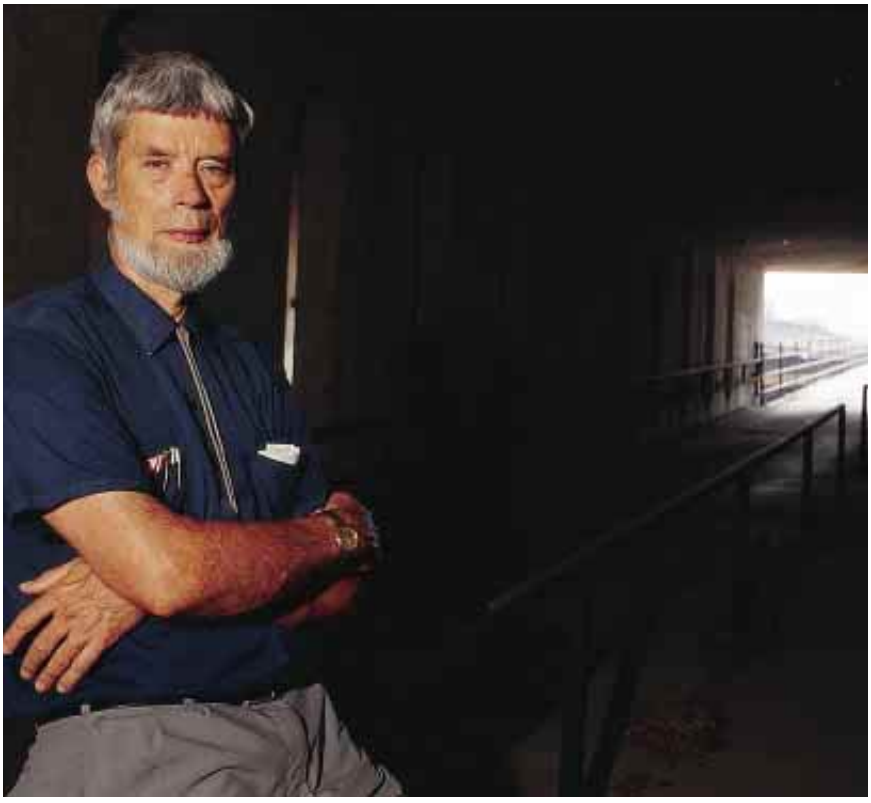
These findings—when combined with the obvious fact that humans conform to their culture—raise what for evolutionary psychologists must be a disturbing possibility. They assume that genes underlie our commonalities and environment our differences. But the reverse may also be true. Culture may account for many of our commonalities, and our differences may reflect genetic variation.

Given their aversion to behavioral genetics, it is no wonder that many evolutionary psychologists are enamored of the work of Frank J. Sulloway. He offers a more palatable explanation for individual variation: birth order. For almost 25 years Sulloway, a historian at M.I.T., has compiled data on links between birth order and personality. Firstborn children, he has concluded, are much more likely than their younger siblings to be conservative, to support the status quo and to reject new scientific or political ideas. Later-born children, in contrast, tend to be more adventurous, radical, open-minded, willing to take risks.

Sulloway acknowledges that in 1983 two Swiss psychiatrists surveyed all the previous literature on birth-order effects and concluded that they were illusory. Sulloway says his meta-analysis of their data turned up a "huge" effect that they missed. He contends that most of the great revolutions in modern history—scientific and political—have been led and supported by later-borns and opposed by "stubborn" firstborns. Darwin, for example, was the fifth of six children, and those who supported his theory also tended to be later-borns.

Evolutionary psychology, Sulloway says, accounts for these findings. The longer children survive beyond the perils of infancy, the more likely it is that they will reproduce and thus propagate their parents' genes (other factors being equal). Parents thus tend to invest more "resources" in older children. Firstborns seek to exploit this situation by maintaining a close relationship with their parents and other authorities. Later-borns, with less to lose, have more incentive to embrace change and disorder. "From a Darwinian point of view, it is just impossible that birth-order effects don't exist," declares Sulloway (who, needless to say, is a later-born).

Sulloway's theory, although acclaimed on the front page of the *Wall Street Journal,* has not undergone peer review yet. Sulloway has packed his analysis of history into an 800-page book, entitled *Born to Rebel,* scheduled to be published next year. Like many other listeners, George C. Williams of the State University of New York at Stony Brook is both fascinated by and skeptical of Sulloway's results. "I keep thinking of counterexamples," Williams says. Isaac Newton, for example, was a firstborn.



ROBERT PROCHNOW

GEORGE C. WILLIAMS, a leading evolutionary theorist, admits to feeling some "nervous hesitation" over the application of Darwinian concepts to humans.

The Darwinian Society

Williams is one of the most venerated elders of the HBES and of evolutionary biology in general. In his classic work *Adaptation and Natural Selection,* published in 1966, he posed a question that still inspires his younger colleagues: "Is it not reasonable to anticipate that our understanding of the human mind would be aided greatly by knowing the purpose for which it was designed?"

Williams remains active in the field he helped to create. In *Why We Get Sick: The New Science of Darwinian Medicine,* published this year, he and Nesse argue that evolutionary theory can help physicians understand and treat physical and mental disorders. Williams also has high hopes for what he calls Darwinian epistemology. Is there some adaptive reason, he asks, why we organize reality into space and time? After all, one profound lesson of modern physics is that our "commonsense" views of space and time are highly arbitrary. But Williams, noting how easy it is to misunderstand and misapply evolutionary theories of human nature, admits he has "some nervous hesitation about the whole business."

Lionel Tiger, an anthropologist at Rutgers, contends that Darwinian science inevitably will, and should, have legal, political and moral consequences; some of the most pressing issues of the 1990s—abortion, birth control, sexual discrimination, homosexuality—are "in Darwin's beat." Tiger says he knows of at least one Supreme Court justice and several high-ranking Pentagon officials who have taken an interest in evolutionary psychology and are considering applying it in their realms. Ready or not, here comes the Darwinian society.

Further Reading

THE RED QUEEN: SEX AND THE EVOLUTION OF HUMAN NATURE. Matt Ridley. Penguin Books, 1993.

THE MORAL ANIMAL: THE NEW SCIENCE OF EVOLUTIONARY PSYCHOLOGY. Robert Wright. Pantheon Books (Random House), 1994.

EVOLUTIONARY PSYCHOLOGY: A NEW PARADIGM FOR PSYCHOLOGICAL SCIENCE. David M. Buss in *Psychological Inquiry,* Vol. 6, No. 1, pages 1–30; 1995.

The Never-Ending Chess Game

Anyone who plays chess knows that some games just peter out: neither player seems able to win, nothing constructive can be done and there is no obvious way to end the game. If neither player agrees to a draw, the game might go on indefinitely. Foreseeing such situations, the bodies that frame the laws of chess have proposed many different rules to force games to end. The classic law states that the game shall be drawn if a player proves that 50 moves have been made on each side, checkmate has not been given, no men have been captured and no pawn has been moved.

But recent computer analyses have shown that the rule is not sufficient. There are some endgames in which one player can force a win after 50 moves, when no pieces have been captured and no pawns moved. So the laws of chess must specify certain exceptional situations. Any law that limits the number of moves permitted under particular conditions runs the same risk as the original, and so it would be nice to come up with a different approach altogether.

One alternative, suggested some time ago, was that a game should end if the same sequence of moves, in which the pieces are in exactly the same positions, repeats three times in a row. (Do not confuse this suggestion with the standard law that if the same position occurs three times, the player facing it can claim a draw. That law does not oblige this player to do so.) You can make a good case that any violation of this three-in-a-row rule ought to end the game. The question is whether there are pointless games that do not violate it.

Can a game of chess go on forever without checkmate and without repeating the same sequence of moves three times in a row? Chess is rather complicated, so any mathematician worth his or her salt would try to simplify the problem. Suppose we focus on just two possible moves, represented by 0 and 1. Can a sequence of 0's and 1's go on forever so that any finite block does not repeat three times in a row?

As it turns out, there are many ways to produce such a sequence, which I will call a tripleless sequence. Marston Morse and Gustav A. Hedlund invented the first tripleless sequence while investigating a problem in dynamics. Begin with a single 0. Follow it by the complementary sequence (every 0 changed to a 1 and vice versa), which here is just 1, so you get 01. Then follow 01 by its complementary sequence, 10, and so on, building up an infinite sequence such as

0
01
0110
01101001… and so on.

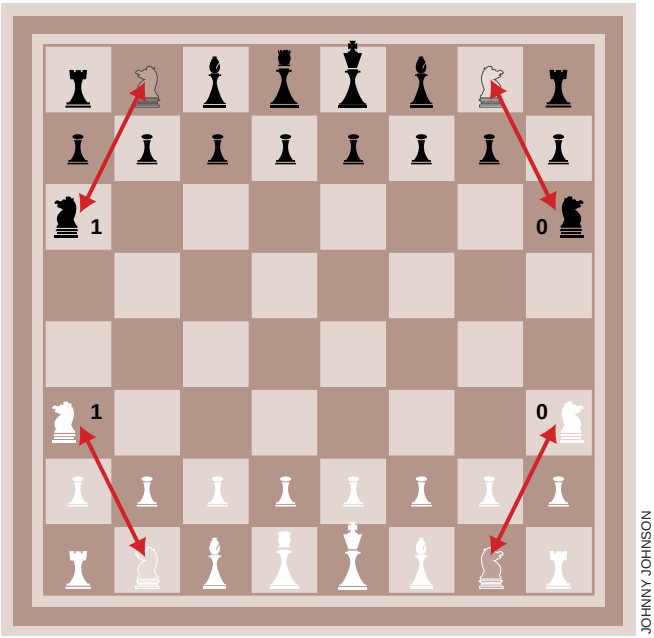
This sequence is genuinely tripleless, but proving it is tricky. So let's consider another tripleless sequence for which the proof is a bit easier. To describe it, we need some terminology. Recall that an even number is a multiple of 2, or of the form $2m$ for some m, and an odd number is one greater than a multiple of 2, or equal to $2m+1$. We need similar descriptions for multiples of three. Call a number a treble if it is a multiple of 3, or equal to $3m$; soprano if it is one higher than a multiple of 3, or equal to $3m+1$; and bass if it is one lower than a multiple of 3, or equal to $3m-1$. Every whole number is either treble, soprano or bass. If a number is soprano, we will call m its precursor. For example, $16=(3\times5)+1$ is soprano, and its precursor is 5, which is bass.

Using this terminology, we can write a recipe for a sequence that never repeats a block three times in a row:

Rule 1: The first term is 0.
Rule 2: The nth term in the sequence is 0 if n is treble.
Rule 3: The nth term in the sequence is 1 if n is bass.
Rule 4: If n is soprano and its precursor is m, the nth term in the sequence is equal to the mth term.

The first three rules tell us that the sequence goes 010*10*10*10*10…, where the pattern *10 repeats indefinitely and the starred entries are not yet determined. The fourth rule lets us work upward along the starred entries. Entry 4, for example, is the same as its precursor, which equals the first entry, or 0. Entry 7 is the same as its precursor, which equals the second entry, or 1, and so on. Because the precursors are smaller than their corresponding sopranos, their values will be worked out first, and so rule 4 does indeed determine all the stars.

These rules lead to what I will call the choral sequence: 010 **0**10 **1**10 **0**10 **0**10 **1**10 **0**10 **1**10 **1**10 **0**10 **0**10 **1**10. I have grouped the terms in threes, marking the soprano terms in boldface to show the structure more clearly. The choral sequence has the curious property that the soprano terms reproduce the entire sequence exactly. There are many double repetitions in this sequence—the first 18 terms, for example, repeat the sequence 010010110 twice—but no block ever repeats



JOHNNY JOHNSON

NEVER-ENDING CHESS GAME, in which knights move back and forth between two squares, is shown in the illustration above. Symbols 0 and 1 show the corresponding terms in the tripleless "choral sequence."

three times [*see box at right for the proof*].

How does this help resolve the never-ending chess game? There are, after all, many more moves in chess than two, and if you pick two (say, advancing the king's pawn and moving the king's rook three spaces forward), it is not at all clear that the sequence corresponds to legal moves. The way to get around this glitch is actually quite simple, but you might like to think about it before reading on.

Okay, here goes. Suppose that both players confine themselves to moving one or another of their knights out and back [*see illustration on opposite page*]. Depending on their position, either the outward move or the backward move is available for each knight. Suppose the players use the sequence of 0's and 1's to determine their moves so that a 0 represents "move the king's knight" (KN) and a 1 means "move the queen's knight" (QN), like this:

0 White moves KN (out)
1 Black moves QN (out)
0 White moves KN (back)
0 Black moves KN (out)
1 White moves QN (out)
0 Black moves KN (back)

It is not exactly an exciting chess game, but each individual move is legal. And because of its relation to the choral sequence, this game clearly goes on forever without ever repeating the same sequence of moves three times in a row. In fact, more strictly, it does not repeat the same sequence of pieces (KN or QN) three times in a row. So if you are looking for a truly watertight chess law to terminate pointless games—one that is proof even against players colluding to play stupidly—that old three-in-a-row proposal does not work.

This particular problem motivates mathematicians to ask related questions about symbol sequences. Is there a sequence of 0's and 1's that never repeats a block twice in a row? Does the answer change if you are allowed more symbols, say 0, 1 and 2? And although it won't change the laws of chess or produce better players, recreational mathematicians should have fun turning such questions into analogous ones about chess.

Proof That No Block Repeats Three Times

Call successive symbols 0 and 1 the terms of the choral sequence and say the nth term is treble, bass or soprano if n is as well. There are five cases to consider:

First, no single digit is repeated three times in a row, because any three consecutive terms must include both a treble and a bass term, which are different by definition.

Second, no block of two digits is repeated three times in a row, because any six consecutive terms contain a block of the form 0*1. Neither 010101 nor 101010, the only possible repeats, appears in the choral sequence.

Third, if a block of three digits is repeated three times, it will contain three soprano terms whose precursors are all the same and consecutive—which is ruled out by the first case.

Fourth, if a block whose length is some multiple of 3—say $3k$—is repeated three times, a similar argument shows that a block of length k must have been repeated three times earlier in the sequence.

The only remaining case is when a block of at least four digits, and of a number which is not a multiple of 3, is repeated three times. Here the proof gets more complicated. To see the idea, suppose that the length is four digits, so the sequence includes a block of the form *abcdabcdabcd*. One of the first three terms must be treble; imagine, for example, that it is *c*. Then the block actually goes *ab*0*da***b**0*d***a***b*0***d***.

But every third term after the first 0—marked in bold—is also treble, so $b = a = d = 0$. The entire block then is 000000000, which is ruled out by the first case. Similar arguments hold if *a, b* or *d* is treble. A more convoluted version of the same kind of argument works for any block whose length is not a multiple of 3.

Feedback

Over the past few years I have received a rapidly growing mailbag from readers, including novel games and puzzles, observations on recent columns and even computer software. In response, I have now introduced "Feedback"—your chance to make your ideas heard.

This month's correspondence is about the January 1995 column, "Daisy, Daisy, Give Me Your Answer, Do," which described a dynamical model explaining the occurrence of Fibonacci numbers in plants.

John Case of Ladysmith, Canada, pointed out that the golden ratio is found all over the place in the dodecahedron. It is, for example, the ratio of the radius of the inscribed sphere of the solid to the inscribed circle of a face. He also found a new approximate squaring of the circle based on the equation $\pi \cong 6\varphi^2/5$.

J. Th. Verschoor of Nijmegen in the Netherlands wrote a computer program to investigate divergence angles formed from "anomalous" Fibonacci sequences in which the second term is changed. He found some intriguing relations between different series of this type.

Ernest R. Schaefer of Wayland, Mass., discovered that a divergence angle of 400 degrees, applied to petals on the surface of a sphere, produced elegant and convincing chrysanthemums.

Kyle Timmerman of Shawnee Mission, Kan., programmed the growth dynamics suggested in the article and found that better results could be obtained if the distance from apex to primordium was proportional to the number of primordia and not its square root.

Sid Deutsch of the electrical engineering department of the University of South Florida at Tampa sent me a paper about a neural network, for which the boundary between stable and unstable behavior occurs at a parameter value of 0.6180, which looks suspiciously close to $\varphi - 1$. I'm still trying to work out why!

Finally, I can report that M. Kunz of the University of Lausanne has proved the occurrence of the golden angle in Stéphane Douady and Yves Couder's dynamical model of plant growth using purely analytic methods—that is, without computer calculations. This work fills the final gap in the story leading from dynamics to Fibonacci spirals.

I regret that I cannot reply individually to many letters. But I value your views, read every letter and have fun with your software. Please keep them coming! —*I.S.*

REVIEWS

Lunar Odyssey

Review by Andrew Chaikin

LOST MOON: THE PERILOUS VOYAGE OF APOLLO 13, by Jim Lovell and Jeffrey Kluger. Houghton Mifflin, 1994 ($22.95). **APOLLO 13**. Universal Pictures, 1995.

One of the most striking moments I can recall from almost a decade of conversations with the Apollo astronauts came in 1987, when I interviewed Jim Lovell about his two lunar journeys, Apollo 8 and 13. Speaking about Apollo 8, Lovell seemed almost bored at having to describe, yet again, the sights and experiences of the celebrated first manned flight around the moon. But he became noticeably energized when the topic switched to Apollo 13. That mission was to have been the third lunar landing. Instead it became a life-or-death struggle for Lovell, Jack Swigert and Fred Haise, after an oxygen tank on board their command ship *Odyssey* exploded while the spacecraft was more than 300,000 kilometers from the earth. For almost four days, ground controllers worked around the clock to bring them home, and Lovell and his crew faced a string of extraordinary crises, almost up to the moment of their safe splashdown. That achievement, Lovell felt, had never received the recognition it deserved. Now, 25 years later, Lovell's story gets a gripping retelling in not one but two media: as the book *Lost Moon* (co-written with journalist Jeffrey Kluger) and as a movie, *Apollo 13,* based on that book.

The fact that Apollo 13's drama remained untold for so long reflects the way in which our society put aside the triumph of the moon landing almost as soon as it happened. Neil A. Armstrong's "giant leap for mankind" was one of the 1960s' defining moments, a brief respite from political and social upheavals. Well before *Apollo 13* lifted off in the spring of 1970, however, Americans were distracted by more pressing issues, such as inflation, the crisis of the inner cities and especially the war in Vietnam. As Lovell recalls in *Lost Moon,* the television networks had grown so bored with the Apollo adventure that they did not even carry the astronauts' tour of their spacecraft on the night of April 13, 1970.

Just minutes later came the now famous transmission from Lovell signaling that Apollo 13 was no longer a normal mission: "Houston, we've had a problem." (In the movie, this line transformed into the more immediate "We *have* a problem.") The attention of the world again focused, for a brief time, on men going to the moon. But once Lovell's crew returned safely, the celebrations were short lived: less than three weeks later shots rang out at Kent State University. The National Aeronautics and Space Administration, anxious to recover from the accident, labeled Apollo 13 a "successful failure" and moved on to the next mission.

RON BATZDORFF *Universal City Studios, Inc.*

APOLLO 13 ASTRONAUTS peer out anxiously from their chilly, stricken spacecraft in this scene from the movie. From left to right, the actors are Bill Paxton (playing Fred Haise), Kevin Bacon (Jack Swigert) and Tom Hanks (Jim Lovell).

Even as Apollo 13 receded into the blur of history, it never faded in the minds of the young people who grew up captivated by the space program. One of those children of the space age is Jeffrey Kluger, now a contributing editor at *Discover* magazine. Kluger's interest in NASA's most dramatic space mission proved the catalyst for Lovell to write his memoir. Kluger's boundless enthusiasm for the subject, ability to delve into technical details and engaging interview style make him a worthy co-author. As a result, *Lost Moon* reads like the adventure story it is.

Unlike the crises that plagued other space missions—such as the computer problems that nearly aborted the first lunar landing—*Apollo 13*'s emergency was played out over a span of nearly four days. *Lost Moon* covers the drama on a day-by-day, sometimes hour-by-hour, basis. We see the crisis unfold in Houston, where flight controllers confronting the bewildering maze of malfunctions wondered if the whole thing might be an instrumentation problem, and in space, where the astronauts (who had heard and felt the explosion that jolted their spacecraft) knew the emergency was all too real. Lovell realized that the lunar landing that was to be the culmination of his spaceflight career was now lost.

That loss is especially poignant considering Lovell's boyhood fascination with rockets, which *Lost Moon* engagingly relates. Accompanied by a few high school friends, Lovell tested his science teacher's assertion that the ingredients for gunpowder, if mixed and packed just right, could be made into rocket fuel that would burn without exploding. The boys' first test launch, which ended in an explosion 80 feet up, preceded by more than 23 years the December morning when a giant Saturn V booster hurled Lovell toward lunar orbit. Between the two events, Lovell's ambitions took him into the air as a U.S. Navy jet pilot, where he routinely faced deadly risk. On one night flight, part of his airplane's electrical system failed, leaving Lovell in a darkened cockpit with no navigation instruments. In a moment that foreshadowed *Apollo 13*'s crises, he found his way back to his ship by following a trail of luminescent algae stirred up by the carrier's propellers.

When Lovell finally travels to the moon, as the navigator on *Apollo 8* (which orbited the moon but did not land), we go with him, to behold the beauty of a bright, distant earth and the starkness of the moon's ancient, cratered landscape. He returned with one

goal: to touch down on that alien ground. For Lovell, the accident on board *Apollo 13* had particularly personal implications.

But as the narrative makes clear, he had little time to think about that. After the accident, the astronauts retreated to the lunar module *Aquarius,* which was designed to keep two men alive for less than two days; now it would have to support three men for more than three days. The uncertainty of how long their lifeboat would sustain them hung over the astronauts for almost the entire mission. Lovell faced the added difficulty of maneuvering the lander while the dead *Odyssey* was still attached to its roof; the joined craft were sluggish and unwieldy. And the burden of command was ever present: of the three astronauts, Lovell probably slept the least and worried the most. Throughout the crisis, Lovell's calm demeanor rarely cracked, although an occasional edge of irritation broke through.

RON BATZDORFF *Universal City Studios, Inc.*

MISSION CONTROL was abuzz with technical heroics, as flight controllers and engineers labored to bring* Apollo 13 *home safely. The movie* (scene shown above) *effectively captures the look and sound of* NASA *in 1970.

Lost Moon vividly shows that the drama was not confined to the spacecraft (a fact that caused Lovell and Kluger to write in the third person). The armies of flight controllers and engineers that converged on Houston's Manned Spacecraft Center faced the toughest job of their careers. As the flight progressed, the rescue effort became a kind of siege. Led by flight director Gene Kranz, who confronted the crisis with almost superhuman confidence and determination, engineers split into teams to tackle everything from scripting the rocket firings to put *Apollo 13* on a homeward course to figuring out how to bring the deactivated command module back to life in time for reentry. In a brilliant display of innovation, they even crafted a makeshift air purifier made from materials available on the spacecraft, including plastic bags, cardboard and gray duct tape.

Meanwhile Lovell's wife, Marilyn, endured her own ordeal, one that *Lost Moon* relates in depth. For her friends and family, Marilyn Lovell displayed a remarkable calm, but the authors here convey her private anguish. Kluger's interviews with her and with other participants in the Apollo 13 saga give the book a richness of detail. We see former astronaut Wally Schirra summoned from a posh New York City restaurant to join anchorman Walter Cronkite in covering the crisis on live television. Tom Kelly, the engineer at Grumman Aerospace considered the "father" of the lunar module, is alerted to the emergency by a middle-of-the-night telephone call. He journeys to the factory to find it lit up and crowded with workers wanting to help. Through such vignettes, Lovell and Kluger convey the scope of the rescue struggle.

One of the ironies of *Lost Moon* is that Lovell's rock-solid stability, along with his test-pilot ability to screen out his own emotions, can make him seem less accessible than some of the less composed, earthbound counterparts he and Kluger describe. An hour into the crisis, mission controller Sy Liebergot, who has been monitoring *Odyssey*'s stricken electrical system, finds that he has been gripping the handle on his console so tightly that his hands have turned "a cold, bloodless white." It is a chilling moment.

I have a few minor stylistic and factual quibbles. Although Kluger's writing is generally vivid and engaging, there are passages where I felt the volume was turned up a bit too high. The story is most compelling when Kluger exercises restraint and lets the events speak for themselves. The authors made extensive use of NASA's audiotapes and transcripts, an essential source for quotations. Purists may chafe at some of the dialogue that was rewritten for the sake of clarity but that sounds inauthentic. And in a couple of instances, Kluger gets momentarily snagged in the trap lurking before any space historian: the astronauts sometimes rewrite history in their minds as time goes on. For

example, the famous photograph of the earth rising over the lunar horizon, taken from *Apollo 8,* was not the result of Lovell's ordering a reluctant Bill Anders to "get the cameras." As documented by *Apollo 8*'s onboard voice recorder, Anders noticed the spectacle first and snapped the picture of his own accord. But these are flaws that only the most detail-conscious reader would notice, and they do not diminish the power of *Lost Moon*'s narrative.

Director Ron Howard clearly felt that power, for the film version of *Lost Moon*—retitled *Apollo 13*—retains most of the book's virtues and, if anything, amplifies the story's emotional impact. The film is a celebratory epic that captures Apollo 13's mythical dimension while going full throttle on human drama, even before the mission begins. When Lovell (played by Tom Hanks) assures his youngest son, Jeffrey, that the causes of the fatal *Apollo 1* fire have been fixed, Hanks is wonderfully poignant. And the distress of astronaut Ken Mattingly, grounded only a matter of days before the mission by a suspected (but ultimately nonexistent) case of the German measles, is portrayed persuasively by Gary Sinise. Ed Harris gives Gene Kranz the larger than life portrayal that he deserves. And Hanks captures Lovell's affable, easygoing manner as well as his understated air of command.

The special effects are often dazzling. I was especially impressed by the shots of the stricken spacecraft drifting, amid a cloud of debris, in the sunlit void between the earth and the moon. The cabin interiors are accurate re-creations of the real thing. And *Apollo 13* is the first dramatic film to use real weightlessness, made possible by filming on NASA's KC-135 (also known, for obvious reasons, as the Vomit Comet), which can provide 25 seconds of free fall at a time by flying in a parabolic arc. The hassles of filming under such conditions, including a few cases of motion sickness, were worth it; these sequences give the film an unprecedented degree of realism. For the scenes of *Apollo 13*'s homeward voyage, the soundstage was chilled to three degrees Celsius in high humidity to re-create the conditions on board the unpowered spacecraft.

Having visited the set of *Apollo 13* during its production, I can vouch for the dedication of cast and crew to making the film as accurate as possible within the limits of a Hollywood movie. The balance between accuracy and entertainment is a difficult one to strike, but *Apollo 13* succeeds admirably. To be sure, events are highly condensed, and sometimes simplified, to fit within the standard two-hour format. And there are a few departures from reality. Some of these I found easy to excuse, such as dramatic dialogue that was entirely unrealistic but necessary to convey fine aspects of plot and character to the audience. (One example: Kranz is shown proclaiming that "failure is not an option"—something no self-respecting flight controller needed to be told.)

Other cinematic liberties were harder to overlook. Lovell and Haise did not, as the film portrays, distrust the abilities of replacement crewman Jack Swigert (played by Kevin Bacon). Swigert had literally written the book on command-module malfunction procedures, and his competence was never in doubt. The portrayal of the film's sole Grumman representative as a doubter who was only looking out for his job is an unfortunate fiction. And I thought the wild gyrations depicted during the astronauts' midcourse correction rocket firing went beyond the bounds of dramatic license. (During the real firing, the spacecraft was never out of alignment by more than a degree, but such a small deviation would not have conveyed the tension of the moment.)

For storytelling reasons, the movie does not address in detail the natural question of what went wrong. The kind of epilogue that can work well in a book would have spoiled *Apollo 13*'s dramatic flow. Interested viewers will have to turn to Lovell and Kluger's account to learn about the unlikely combination of technical problems that afflicted *Apollo 13* and nearly cost the lives of the three astronauts.

The look of *Apollo 13* aptly captures the NASA of 1970, complete with Ban-Lon shirts and long sideburns. When a flight controller making a critical calculation pulls out a slide rule, it reminds us that this entire enterprise was built on 1960s technology. (A group of self-proclaimed NASA dweebs has pointed out, in a list of the movie's factual lapses, that slide rules are not used for addition and subtraction, as shown.) Perhaps *Apollo 13*'s greatest achievement, however, is that it is full of heroes, the nerdy geniuses who manned the trenches of mission control as much as the three men in translunar space. Rarely has a Hollywood film captured so accurately and affectionately the way that engineers work.

In declining to glamorize the ground crew or invent a lone savior, the movie hits on the true meaning of the Apollo program: it defined a time when thousands of people pulled together to achieve something that seemed impossible. That harmonious effort, more than

anything, is what got us to the moon.

As I write this, *Apollo 13* is number one at the box office, and the renamed paperback edition of *Lost Moon* (now also called *Apollo 13*) sits at the top of the *New York Times* best-seller list. A new generation of young people is discovering the power of the Apollo epic, while those who were distracted the first time around now have a chance to celebrate its triumphs. Of course, the story does not end with Apollo 13. Little more than a year after Lovell and his crew stood smiling on the deck of the recovery ship, Apollo 15 astronauts Dave Scott and the late Jim Irwin were living on the moon for three full days, taking moon walks lasting up to seven hours and driving a battery-powered lunar rover for miles across the moon in search of geologic treasure. If that sounds like science fiction, maybe it is time to do a little more looking back.

ANDREW CHAIKIN has conducted extensive interviews with the lunar astronauts and with other Apollo participants for his book A Man on the Moon: The Voyages of the Apollo Astronauts *(Penguin, 1994).*

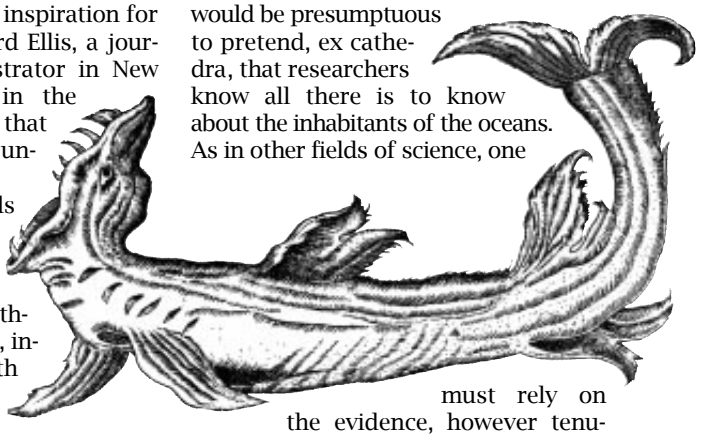
Deep Mysteries

Review by Paul H. LeBlond

MONSTERS OF THE SEA, by Richard Ellis. Alfred A. Knopf, 1994 ($30).

In recent years, deep-sea exploration has unveiled many of the oceans' long-hidden secrets. We have witnessed new ecosystems that thrive around deep hot-water vents; we have peeped into famous historical wrecks; we have glimpsed strange animals hiding in the dark abyss. Global research programs, such as the World Ocean Circulation Experiment, have shrunk the oceans to fit within the silicon brain of a supercomputer. The recent proclamation of the Law of the Sea Convention has affirmed human dominion over the world's oceans.

In counterpoint to this triumphalist view of the progress of discovery, one should recall the coarseness of oceanographic sampling grids, which stretch as thin as spiderwebs on a map of the seas, and the relatively minuscule volumes illuminated by the beacons of submersibles, mere pinpoints of light in a universe of darkness. Vast volumes of the ocean remain unexplored, leaving room for a lingering feeling that somewhere in the deep shadows, perhaps just beyond the reach of the television cameras, undiscovered creatures may be hiding, shying away from human intrusion. The belief that there is more to be discovered in and about the ocean certainly fires the enthusiasm of most oceanographers and ensures a healthy flow of research funding. It also serves as the inspiration for the new book by Richard Ellis, a journalist and marine illustrator in New York City interested in the mysterious creatures that may or may not inhabit unexplored waters.



Large marine animals do continue to be discovered. In the half century since the capture of the coelacanth, other unexpected creatures, including the megamouth shark, have been accidentally plucked from the sea. Others are seen, and sometimes photographed, in deep-sea dives. And still others continue to be glimpsed—fleetingly, rarely and inconclusively—at the surface, as they have been for centuries. These are the sea monsters of legend, the focus of keen cryptozoological interest. Do sea serpents and other such creatures really exist, and is it just a matter of time before they, too, are captured, on film or in the flesh?

The question of existence is clearly of fundamental importance in scientific inquiry. Just because some unexpected animals have been found in the sea certainly does not imply that others must turn up. On the other hand, it would be presumptuous to pretend, ex cathedra, that researchers know all there is to know about the inhabitants of the oceans. As in other fields of science, one must rely on the evidence, however tenuous and uncertain. In contrast with many more arcane scientific questions, however, that of the existence of sea monsters generates widespread interest among the general public, for whom it often serves as an introduction to natural history as well as to the subtle logic of data interpretation.

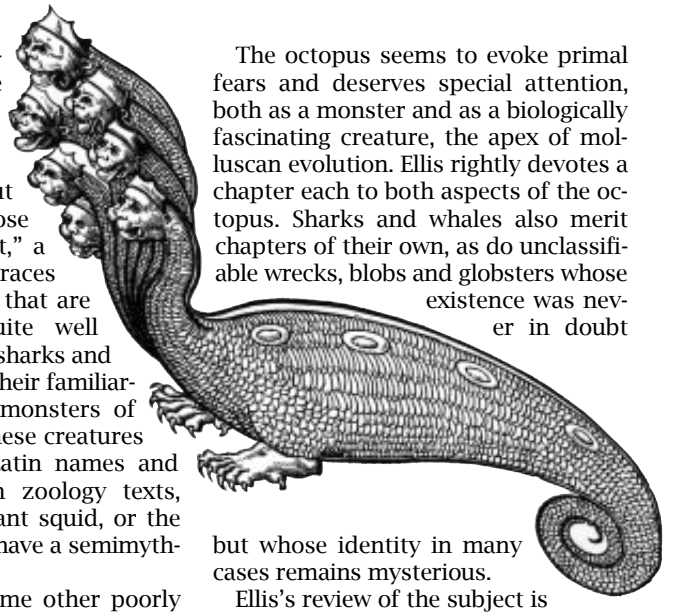
In this captivating volume, Ellis introduces the lay naturalist to sea-monster lore. Although others have broached the topic before, he brings to the discussion

a broader and refreshingly new view of the subject. The author defines sea monsters as creatures "large and mysterious" but also as likely "to pose some sort of a threat," a description that embraces a number of animals that are in certain ways quite well known. Whales, large sharks and giant squids, despite their familiarity, are indeed true monsters of the deep. Although these creatures have now received Latin names and found their place in zoology texts, some, such as the giant squid, or the kraken of Norse lore, have a semimythical history.

The kraken and some other poorly documented species have only recently been officially described and fully accepted by the scientific community; before that, they were just reported creatures, not clearly distinguished from the sea monsters of fables. By grouping together known and cryptic monsters (now often described by the more neutral term "cryptids"), Ellis provides a balanced perspective and avoids the argumentative tone of many accounts that have a narrower cryptozoological focus. Placed in the company of similar but known creatures, undiscovered sea monsters seem more plausible than they do standing on their own.

Monsters of the Sea begins, quite appropriately, with the Loch Ness monster. As Ellis points out, St. Columba's supposed encounter with the creature actually took place in the *river* Ness, not in the loch, and has been widely misinterpreted by overenthusiastic cryptozoologists. The recent revelation of the hoax behind the famous "Surgeon's Photograph" of Nessie has not discouraged its fans, who note that this was by no means the only piece of evidence for its existence.

Nessie's marine cousins come in many shapes and forms. Ellis describes a few of the more reputable accounts before introducing the reader to mermaids and their modern zoological avatar, the manatee. There is often a presumption on the part of zoologists that the description of some unknown sea monster is merely a misidentification of a known creature. Hence, the siren becomes a manatee; similarly, the dreaded kraken is revealed to be a giant squid. Ellis follows in that vein but admits that such explanations are not always sufficient. Perhaps some "sea serpents" are actually giant squids, he suggests, without pretending that this explanation covers all sightings.



The octopus seems to evoke primal fears and deserves special attention, both as a monster and as a biologically fascinating creature, the apex of molluscan evolution. Ellis rightly devotes a chapter each to both aspects of the octopus. Sharks and whales also merit chapters of their own, as do unclassifiable wrecks, blobs and globsters whose existence was never in doubt but whose identity in many cases remains mysterious.

Ellis's review of the subject is masterful, cleverly illustrated and up-to-date; it will delight even those readers who think they are already familiar with marine cryptozoology. Historical and zoological details abound, especially regarding the better known monsters. Ellis brings the same eye for apt illustration and historical perspective that characterizes his earlier volumes on whales and sharks. He also ventures well beyond zoology into the realm of art and entertainment, where sea monsters have often starred as archetypal villains. An extensive bibliography offers the reader access to a wide range of information and original sources.

The prospect of discovering large marine creatures—perhaps one of the legendary sea serpents glimpsed by so many mariners—continues to excite scientists and the general public alike. Everyone has his or her own opinion on the probability of the existence of such animals, yet it is hard to disagree with Ellis's view that, beyond scientific curiosity, there is in today's world concern for the safety of as yet undiscovered creatures, as well as for that of their cousins, the whales, sharks and manatees. "Instead of fearing them," Ellis writes, "we fear *for* them." Concerns about the protection of endangered species now extend even to those whose reality remains in doubt!

We need sea monsters, Ellis concludes, "to remind us of our frailty… [and] our responsibility to preserve the planet." One might even argue, as John Steinbeck did in *The Log from the Sea of Cortez,* that "an ocean without its unnamed monsters would be like a completely dreamless sleep"—a far less exciting object of scientific curiosity.

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ESSAY by Gerald Holton

The Controversy over the End of Science

Even while science is asserting ever greater success in explaining natural phenomena, the cry is being raised that it may now be coming to a close—not merely to the recognition of the limits of its intellectual power but to a true "end" of science as a productive activity. Such attacks are often associated with postmodern thought or "New Age" concepts. But historians recognize that the notion of the possible decay and death of science has ancient and robust roots.

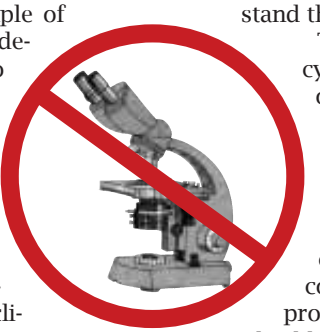
Virtually all attitudes regarding a possible end of science have been driven by one of two thematic ideas. Scientists themselves often take a "linearist" view, conceiving of science as an endeavor intended to provide eventually a coherent and complete understanding of the natural world. An opposing camp perceives a process of ebb and flow. These "cyclicists" think of science as developing from its childhood and youth to old age and death, or at best as a sequence of changes of commitment that leave little hope for certifiable progress or even for the idea of progress itself.

Cyclicist views abound in the literature of the 19th-century Romantic movement and in its recent revival and seem to grow strongest during periods of political and economic uncertainty. So it is instructive that one of the most fascinating and outrageous explications of cyclicist thought—one that has uncanny analogies within the current debate—was published at another turbulent time, just as World War I was grinding to its bitter ending in 1918. The author was an obscure and impoverished German high school teacher named Oswald Spengler.

Spengler's 1,200-page book, *Der Untergang des Abendlandes* (translated as *The Decline of the West*), caused an immediate and lasting sensation. In it we find precursors of today's arguments, familiar from the writings of thinkers ranging from Arnold Toynbee (Spengler's direct successor) to various New Age authors and other critics. Spengler's key conception is that in every epoch, history has taken fundamentally the same course, obeying the same morphology. Each of the mighty cultures of humankind was not only as valid and significant as Western civilization, but each in turn followed a parallel, season-like cycle. The 20th century, according to Spengler, corresponds to Rome under the brutal Caesars; we are at the last days of our winter.

Scientists play a special role in Spengler's somber drama. In their Faustian desire for knowledge, they turn away from nature as appreciated by "intuitive perception" and replace it with a structured, measurable order. Spengler points to the famous confession of the 19th-century physicist Hermann von Helmholtz, who wrote that "the final aim of natural science is…to dissolve all natural science into mechanics." Such quests to reduce the variety of phenomena to mathematical formula, Spengler believes, are a sign of science's internal tendency to degenerate into a kind of number mysticism.

In Spengler's eyes, the signs of decay and disintegration of science were already clear by 1918. Physics, he says—and note how familiar this view also has become—has been infected by an "annihilating doubt," as shown by "the rapidly increasing use of statistical methods, which…forgo in advance the absolute scientific exactitude that was a creed to the hopeful earlier generations." Relativity theory strikes at the very heart of dynamics. Quantum ideas are equally destructive; our inability to specify which atom in a sample of radioactive material will decay next points directly to the Achilles' heel of modern science, by abandoning causality and reintroducing the prescientific idea of destiny.



One could cite from any number of sources to rebut Spengler's cyclicism. But it is singularly appropriate to select as the linearist exemplar an essay that also appeared in 1918, written by a man of almost the same age as Spengler and one who was then also still almost unknown outside his circle. The name of the young writer, whose research Spengler had singled out as a symbol of civilization's collapse, was Albert Einstein.

In that essay, "Principles of Research," Einstein metaphorically describes the origin of scientific method: "Man seeks to form, in whatever manner is suitable, a simplified and lucid image of the world, a world picture." Once a world image has been achieved on the basis of that simplification, it is extended to every natural phenomenon as it actually occurs, in all its complexity.

From general laws, Einstein argues, "it should be possible to obtain by pure deduction the description, that is to say the theory, of every natural process, including those of life." The journey toward that goal will be neither fast nor direct, in part because "to the [grand] elemental laws there leads no logical path, but only intuition." Yet despite the limitations of the human mind, the order we put in our theories can, and often remarkably does, correspond to the order others find in nature when they check our predictions.

Why is that possible? Einstein boldly suggests that our minds are guided by "preestablished harmony," a concept postulated by Gottfried Wilhelm Leibniz holding that God allows productive resonance between the material and spiritual realms. Scientists today are likely to invoke a less theological argument, one relying on the evolutionary basis of a correspondence between our ideas and our environment. Either way, for the linearist the *synthesis* of rationality and intuition—rather than their opposition—is the key to answering all questions of science, as we now understand the term.

The pessimism of the cyclicist and the optimism of the linearist are not the only current models. Some scientists can live quite comfortably with a third, hierarchical view of their practice. In it, each level of scale and complexity has its own properties and laws, not reducible to those on the next level. But linearists and hierarchists agree on one thing: the cyclicists' view of the imminent, ignominious end of science is an ominous fantasy.

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JOHNNY JOHNSON