MALAYSIA'S MYSTERY VIRUS: an eyewitness report from the plague zone

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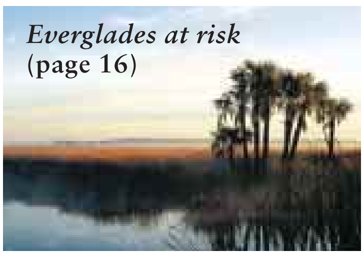
A sneak preview of M.I.T.'s vision for the future of computing

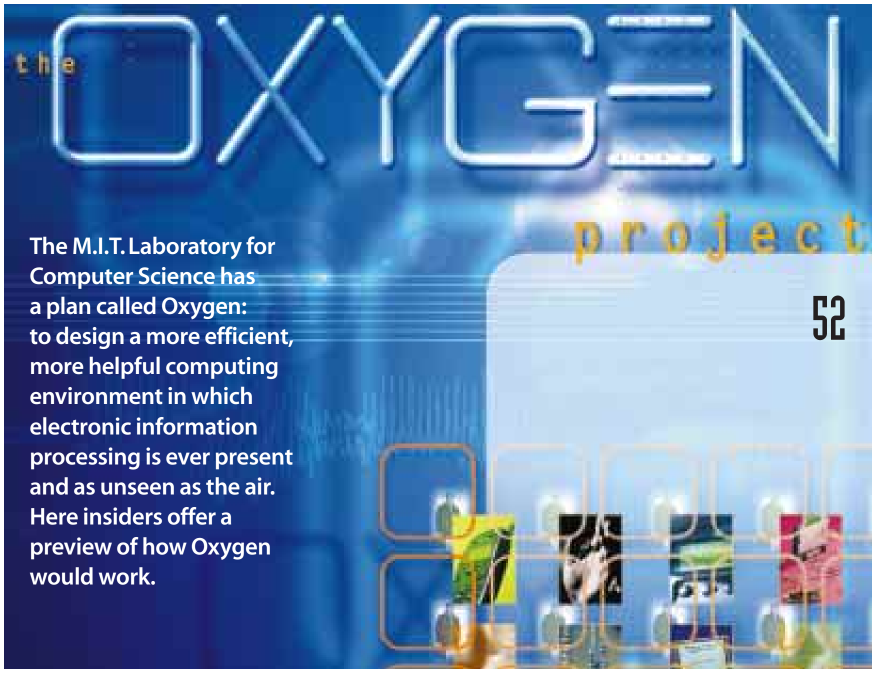
SCIENTIFIC AMERICAN

August 1999 Volume 281 Number 2

NEWS AND ANALYSIS



Everglades at risk (page 16)



The M.I.T. Laboratory for Computer Science has a plan called Oxygen: to design a more efficient, more helpful computing environment in which electronic information processing is ever present and as unseen as the air. Here insiders offer a preview of how Oxygen would work.

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REVIEWS AND COMMENTARIES

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Check every week for original features and this month's articles linked to science resources on-line.

From the Editors

The Detectives Wore White

Robin Cook and other novelists have made their careers by writing medical thrillers, which can be perfect beach reading during these hot summer months. Broadly speaking, those thrillers revolve around some mysterious illness or other medical puzzle, which heroic physicians and nurses scramble to solve against all odds and at peril of their own lives. (The world may or may not hang in the balance.) This month's issue contains two narratives of real medical detective work, in which the stakes and the story lines are not too different from what you might find in fiction. Pull up a beach chair.

In JoAnn M. Burkholder's "The Lurking Perils of *Pfiesteria*" (see page 42), the killer is a one-celled parasite. Although its primary victims are fish, its virulent toxins also endanger humans, as Burkholder learned firsthand. Our writer W. Wayt Gibbs, in "Trailing a Virus" (see page 80), followed the neurologists and epidemiologists who combated the unexpected encephalitis outbreak in Malaysia earlier this year. In this case, the culprit was a previously unknown virus that had apparently jumped from pigs to people, claiming more than 100 lives.


CHRIS BROWN *SABA*

SELECTIVE SLEUTHS in Malaysia pursue an elusive killer virus.

Both of these detective stories have similar cliffhanger endings: the killers have been identified by the authorities and yet they elude confinement or control, and no one can say when or how they may strike again. We do not even know whether the survivors of the initial attacks may suffer relapses or worse in the future. Expect sequels.

When "genius" can be applied to everyone from Murray Gell-Mann to Quentin Tarantino, it's a sure bet that the word is sometimes being misused. The people at the John D. and Catherine T. MacArthur Foundation actively distance themselves from it: the coveted MacArthur fellowships handed out each year are not "genius grants." Oh, the recipients are "exceptionally talented and promising individuals who have shown evidence of originality, dedication to creative pursuits, and capacity for self-direction." But the Fellows Program avoids the term "genius" because it is reductive and does not take dedication, intention and hard work into account.

So noted. Whether or not this qualifies him as a genius, however, Shawn Carlson, our "Amateur Scientist" columnist, has been named as a 1999 MacArthur Fellow. Longtime fans of his work have enjoyed his creativity and enthusiasm every month; the editors who work with him can testify to his dedication and hard work, too. Shawn is committed to the idea that universities, businesses and other institutions do not have a monopoly on science and that individuals can still contribute to fields as diverse as astronomy, biology, chemistry and geophysics. It's an honor to have him show amateur scientists the way in his column.

JOHN RENNIE, *Editor in Chief*
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Our special report on tissue engineering in the April issue generated quite a bit of reader interest, but one assertion left a number of you dissatisfied. In his sidebar entitled "Ethics and Embryonic Cells," Roger A. Pedersen concludes that "embryonic stem cells provide a source of medically useful differentiating tissues that lack the awesome potential of an intact embryo." But to Donita I. Bylski-Austrow of Children's Hospital in Cincinnati, among others, that statement seems to hinge on some flawed logic. "The researcher is the agent who, in Pederson's words, 'eliminates any possibility that the remaining inner cells can develop in a uterus,' and destroys the embryo's potential," she writes. "What is the difference between eliminating this possibility early on, at the blastocyst stage, versus later in development?" The rest of the issue prompted interesting comments as well, including a dispute over the reasons behind Alan Turing's untimely death (*below*).

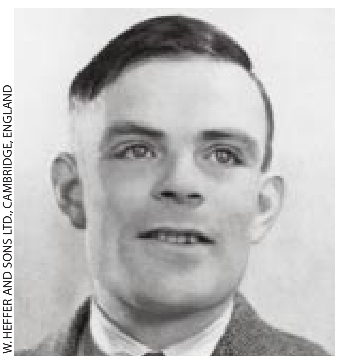
TURING'S TRAGEDY

In their article "Alan Turing's Forgotten Ideas in Computer Science," B. Jack Copeland and Diane Proudfoot neglected to explain the circumstances surrounding Turing's tragic death. In a climate of intense hatred and public vilification of gay people in Britain, Turing committed suicide in 1954 after a conviction related to his homosexuality. Were it known that he had been a war hero (having deciphered Enigma), the prosecution would never have taken place, and this great man might still be alive today. But because Enigma's decoding was still a state secret, Turing never told the prosecutors of his pivotal role in the war. And although his wartime superiors could have blocked the prosecution, they did not. In failing to mention this, the authors have hidden from readers Turing's exceptional heroism and moral courage—even when at great cost to himself.

THOMAS BUSHNELL
Information Systems
Massachusetts Institute of Technology

Copeland and Proudfoot reply:

Turing was indeed a courageous man, and he was open about his sexual orientation at a time in Britain when homosexuality was a crime. Treated wretchedly by the country that he helped to save, Turing was convicted of "gross indecency" and sentenced to a year of hormone "therapy" (which he seems to have borne with amused fortitude) in March 1952. But it was more than two years after his conviction that he died of cyanide poisoning. (A homemade apparatus for silver-plating teaspoons, which included a tank of cyanide, was found in the room adjoining that in which Turing's body was discovered.) A man who lived for his work, he was then in the midst of exciting research, and a close friend who visited him a few days before he died found him jolly. We wish we could explain Turing's death, but having examined the depositions made at the inquest as well as other material, we are less certain than Bushnell that the coroner's verdict of suicide was correct.



ALAN TURING, artificial-intelligence pioneer, died just before his 42nd birthday.

EXPLAINING HEALTH COSTS

I was appalled at the oversimplified and misleading information provided by Rodger Doyle's report "Health Care Costs" [News and Analysis, April]. Doyle states that the relatively high cost of health care in the U.S. can be blamed mostly on "overinvestment in high technology and personnel." In fact, the cost has more to do with the style of medicine practiced in the U.S., including enormous emphasis on care for the aging (which results in the largest single category of expense) and the use of expensive medical procedures that either do not exist or are infrequently employed in other countries.

JEFFREY R. FITZSIMMONS
Department of Radiology
University of Florida

Doyle replies:

Fitzsimmons implies that the "real" cause of high U.S. costs is money spent on the elderly. This is undoubtedly an important cost factor and is obviously related to overinvestment. But how important it is as an explanation of higher costs in the U.S. is impossible to know, for there are no reliable comparative statistics.

VENUS'S DEEP IMPACT?

"Global Climate Change on Venus," by Mark A. Bullock and David H. Grinspoon [March], describes evidence that "a geologic event of global proportions abruptly wiped out all the old craters some 800 million years ago." The article notes that "the idea of paving over an entire planet is unpalatable to many geologists," and alternative explanations such as planetwide volcanism are discussed. There is, however, an event that could repave the entire surface of a planet—an impact by a comet hundreds of kilometers in diameter. This would not necessarily cause a recognizable impact crater, but it could severely disrupt the crust and trigger volcanism. Research into this possibility would need to explain how Venus subsequently acquired its very dense atmosphere (the original atmosphere would have been stripped away) and what happened to the impact debris in space: Why didn't a small moon or ring form? Perhaps 800 million years is sufficient time for Venus to "recover."

MICHAEL PAINE
The Planetary Society Australian Volunteers

Bullock replies:

Paine makes an excellent point about the potential for a large impactor on Venus to have altered the planetary cli-

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mate. David Grinspoon and I have calculated that the largest comet one would expect (based on statistics) to have impacted Venus in the past billion years would have increased the atmospheric water inventory 10- to 100-fold. Such a comet would have been smaller than hundreds of kilometers in diameter—perhaps 40 kilometers or so—but certainly could have caused some kind of lithospheric disruption.

A 40-kilometer comet would not have put a prelunarlike ring around Venus but would definitely have been capable of precipitating volcanic events and climate change. Investigating the effects of impact-induced climate change on the terrestrial planets is currently a major subject of research at NASA's Astrobiology Institute.

MAKING MUTATIONS COUNT

In "Mutations Galore" [News and Analysis, April], writer Tim Beardsley reports that the human population could not sustain the death toll resulting from three harmful mutations per person per generation. If you consider that most harmful mutations result in a zygote's failure to develop into a viable embryo, this number does not seem so high. The relevant mortality rate should be calculated per conception, not per birth.

DAVID R. STOCKTON
Whittier, Calif.

James F. Crow of the University of Wisconsin replies:

Stockton is correct that the mortality rate should be calculated per conception, and I have no doubt that some of the most drastic mutations are eliminated by early embryonic death. Yet I suspect that most of the mutations that Beardsley discussed are very mild, so for these, early embryonic death seems a less likely hypothesis. Instead I believe that by lowering survival or fertility, selection has removed those individuals with the largest number of mutations.

Letters to the editors should be sent by e-mail to editors@sciam.com or by post to Scientific American, 415 Madison Ave., New York, NY 10017. Because of the considerable volume of mail received, we cannot answer all correspondence.

50, 100 AND 150 YEARS AGO

AUGUST 1949

BRINGING UP BABY—"Cultural influences begin to operate on the infant from the moment of birth. According to the customs of his society, he may be laid naked on a hard plank (New Caledonia), tucked into a padded cradle (Plains Indian), or tightly bandaged from the neck down (southern Europe). He may be fed whenever he cries (Malaya), on schedule (modern America), or simply when it suits his mother's convenience (New Guinea). He may be the petted center of the family's attention (Japan), or receive only the minimum care necessary to ensure his survival (Alor). Such early experiences are important in laying the groundwork for the developing personality."

DO MONKEYS THINK?—"Psychologists studying higher mental processes have suggested an organizing mechanism or principle that would explain learning and thinking: the learning set. Our experiments suggest that words are stimuli or signs that call forth the learning sets most appropriate for solving a given problem. Though monkeys do not talk, they can learn that certain symbols represent specific learning sets. In one test, a monkey was handed an unpainted triangle as a sign to pick out all the red objects sitting in front of the cage [*see illustration*], and an unpainted circle as a sign to select all blue objects. —Harry F. and Margaret Kuenne Harlow" [*Editors' note: Harry Harlow was awarded the National Medal of Science in 1967.*]

A monkey learns to respond to a symbol

AUGUST 1899

HELEN KELLER—"Miss Helen Kellar [sic], the girl who is so remarkably afflicted and so talented, has just completed her preparations for college. It is probable that no person ever before took any examination under such strange conditions. She is blind, deaf, and dumb, so a gentleman of the Perkins Institute who never had met her took the examination papers as fast as they were presented, and wrote them out in the Braille characters. She passed the examination in every subject; in advanced Greek she received a very high mark."

FORBIDDEN AMMUNITION—"The Peace Congress considered the 'Dum-dum' [hollow-point] bullet at considerable length, and England strongly opposed any restrictions against its use among savage tribes. Nowadays all the chief powers are liable to become involved in warfare with more or less savage races, as when their colonial possessions are menaced, so that many of them doubtless desire to use the most effective bullet possible. The English 'Mark IV' cartridge contains a cordite charge; the bullet has a hollow in the head, and the nickel sheath ends on a lip at the entrance. This bullet when it comes in contact with any moist substance, such as the living body, spreads out into a sort of rounded knob." [*Editors' note: The Hague Conventions of 1899 and 1907 prohibited the use of these projectiles in warfare.*]

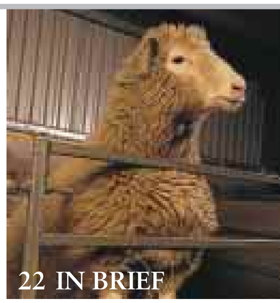
THE GARDENER OF KARNAK—"One tomb discovered at Thebes is of a man named Nekht, head gardener attached to the Temple of Karnak, about 1500 B.C. One elaborately painted wall shows Nekht's private house, a mud-brick, two-storied edifice, whitewashed on the outside, with a great wooden front door. To the left of the house is the garden, surrounded by shady trees and with a tiny canal that feeds two small ponds in which white and blue flowered water lilies flourish. The trees were not feathery date palms, but full-foliaged sycamore fig trees, under whose dense growth, Nekht says, he 'cooled himself during the heat of summer, and breathed the air of the sweet north wind.'"

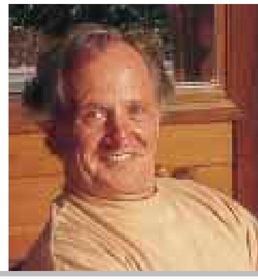
AUGUST 1849

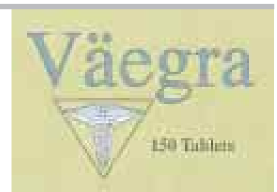
OBSOLETE SAWMILLS—"One of the greatest curiosities in Zealand, the flourishing Holland colony in Ottawa County, Michigan, is the great, awkward and unmanageable concern called the Windmill. This is a monstrous wooden pile in the form of an octagon tower. The mill is moved by the force of the wind striking against four winding slats, covered with canvas. They were sawing, or attempting to saw, while I was there. Occasionally, with a fair wind, the saws would strike a few minutes quite lively, then draw a few slower strokes and then entirely stop, perhaps for half an hour. An enterprising individual is now putting up a steam sawmill, which will do a better business."

MEDICAL SHOCKER—"The medical community of Paris has been set a-talking by the arrival of the celebrated American doctress, Miss Blackwell. The lady has quite bewildered the learned faculty by her diploma, authorizing her to dose and bleed and amputate with the best of them. Some of them are certain that Miss Blackwell is a socialist of the most furious class and that she is the entering wedge to a systematic attack on society by the fair sex. Others who have seen her say that there is nothing very alarming in her manner; that on the contrary, she appears modest and unassuming and seems to have entered on her singular career from motives of duty, and encouraged by respectable ladies at Cincinnati."

NEWS AND ANALYSIS







IN FOCUS

IS OUT OF AFRICA GOING OUT THE DOOR?

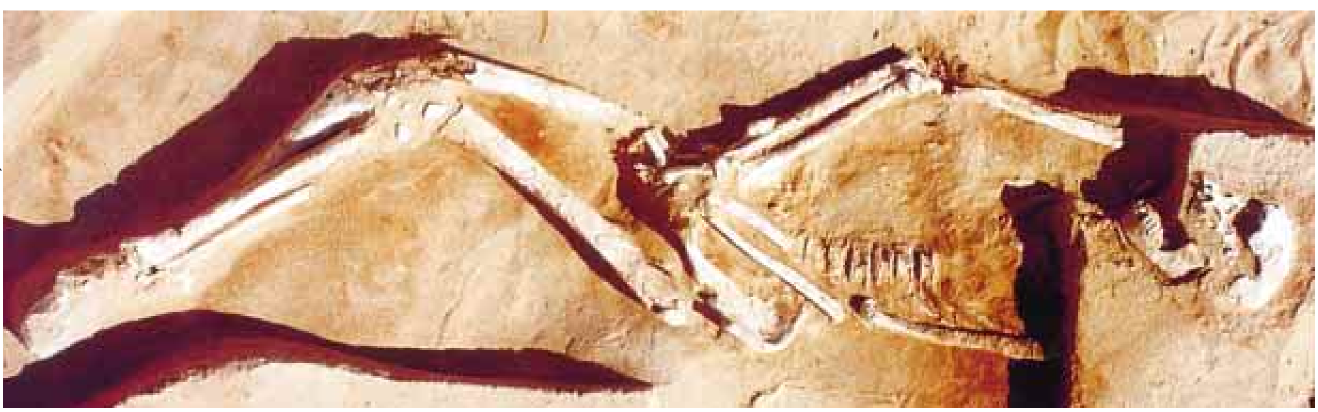
New doubts on a popular theory of human origins

Anthropologists have long debated the origins of modern humanity, and by the mid-1980s two main competing theories emerged. One, Multiregional evolution, posits that humans arose in Africa some two million years ago, evolved as a single species spread across the Old World and were linked through interbreeding and cultural exchange. The Out of Africa hypothesis, in contrast, proposes a much more recent African origin for modern humans—a new species, distinct from Neanderthals and other archaic humans, whom they then replaced. Emphatic support for Out of Africa came in 1987, when molecular biologists declared that all living peoples could trace a piece of their genetic legacy back to a woman dubbed "Eve," who lived in Africa 200,000 years ago. Although that original Eve study was later shown to contain fatal flaws, Out of Africa has continued to enjoy much molecular affirmation, as researchers have increasingly turned to DNA to decipher the history of our species.

But a closer look at these genetic studies has led some researchers to question whether the molecular data really do bolster the Out of Africa model. And striking new fossil data from Portugal and Australia appear to fit much more neatly with the theory of Multiregional evolution.

The DNA from mitochondria, the cell's energy-producing organelles, has been key Out of Africa evidence. Mitochondria are maternally inherited, so genetic variation arises largely from mutation alone. And because mutations have generally been thought to occur randomly and to accumulate at a constant rate, the date for the common mitochondrial DNA (mtDNA) ancestor can theoretically be calculated. This "molecular clock" indicates that the mtDNA ancestor lived a a mere 200,000 years ago, and the root of the gene tree traces to Africa. These results, along with the observation that variation is highest in Africa (indicating that modern humans had been in Africa the longest), seemed to offer unambigu-

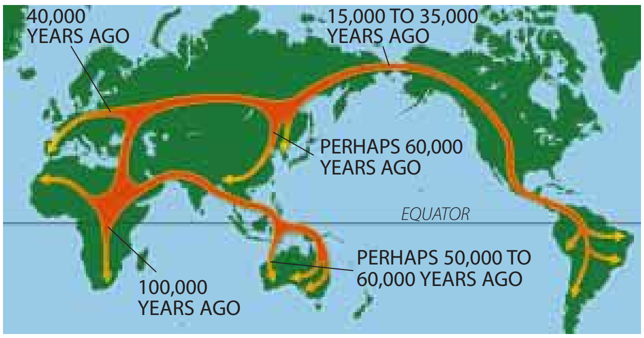
***OLDEST AUSSIE**, buried 60,000 years ago, displays delicate, modern features that suggest Asian, not African, ancestry.*



ALAN THORNE *Australian National University* ous support to a recent African origin for all modern humans.

But the significance of each finding has been questioned. The date is suspect because the molecular clock depends on problematic assumptions, such as the calibration date and mutation rate. And if natural selection has shaped mtDNA, as some studies suggest, then the rate of mutation accumulation may have differed at different times. The African root for the mtDNA gene tree is compatible with Out of Africa, but it does not exclude Multiregionalism, which predicts that the common ancestor lived somewhere in the Old World, probably Africa. And neither does the high mtDNA variation in African populations as compared with non-Africans uniquely support Out of Africa, according to anthropologist John H. Relethford of the State University of New York College at Oneonta. "You could get the same result if Africa just had more people living there, which makes sense ecologically," he asserts.

Another problem plaguing the genetic analyses, says geneticist Alan R. Templeton of Washington University, lies in a tendency for researchers to draw conclusions based on the particular genetic system under study. "Very few people try to look across all the systems to see the pattern," he observes. Some nuclear genes indicate that archaic Asian populations contributed to the modern human gene pool, and Templeton's own analyses of multiple genetic systems reveal the genetic exchange between populations predicted by Multiregionalism.



TOM MOORE

***OUT OF AFRICA THEORY** posits that modern humans arose in Africa and replaced other human species across the globe.*

Still, Relethford and Templeton's arguments haven't convinced everyone. Henry C. Harpending, a population geneticist at the University of Utah, finds Multiregionalism difficult to swallow because several studies put the prehistoric effective population size—that is, the number of breeding adults—at around 10,000. "There's no way you can get a species going from Peking to Cape Town that's only got 10,000 members," he remarks. (Other researchers counter that this number, based on genetic diversity, may be much smaller than the census size of the population—perhaps by several orders of magnitude.) And many geneticists, such as Kenneth K. Kidd of Yale University, insist that "the overwhelming majority of the data is incompatible with any ancient continuity."

But those who believe that Out of Africa's genetic fortress is crumbling find confirmation in fresh fossil data that pose new difficulties for the theory's bony underpinnings. Last December researchers unearthed in western Portugal's Lapedo Valley a fossil that preserves in exquisite detail the skeleton of a four-year-old child buried some 24,000 years ago. According to Erik Trinkaus, a Washington University paleoanthropologist who examined the specimen, the team fully expected the remains to represent a modern human, based on its date and the style of the burial. But subsequent analysis, published in the June 22 *Proceedings of the National Academy of Sciences USA*, revealed a surprising combination of features, such as a modern-looking chin and Neanderthal limb proportions. After reviewing scientific literature on primate hybrids, Trinkaus concluded that this child resulted from interbreeding between Neanderthals and modern humans.

Not everyone is persuaded. Christopher B. Stringer of London's Natural History Museum, lead proponent of the Out of Africa model, wonders whether the fossil might simply represent a cold-adapted modern human, because Portugal then was colder than it is today. In any case, Stringer maintains that his model does not exclude occasional interbreeding.

Yet Trinkaus notes that because the fossil is dated to thousands of years after these groups came into contact, "we're looking at populations admixing." Furthermore, adult fossils from central and eastern Europe show the effects of mixing, too, states paleoanthropologist David W. Frayer of the University of Kansas. And if the groups were interbreeding across Europe, asserts University of Michigan multiregionalist Milford H. Wolpoff, "that would mean you could make a strong case that [contemporary] Europeans are the result of the mixture of these different groups." Another name for that, he says, is Multiregional evolution.

Multiregionalism also best explains the surprising new date for a previously known fossil from western New South Wales, according to paleoanthropologist Alan Thorne of the Australian National University. In the June *Journal of Human Evolution* Thorne and his colleagues report that the fossil, known as Lake Mungo 3, now looks to be some 60,000 years old—nearly twice as old as previously thought—and unlike the other early Australian remains (all of which date to less than 20,000 years ago), this one bears delicate, modern features. To Stringer, this gracile form indicates the arrival of modern humans from Africa, albeit an early one. Over time, he reasons, selection could have led to the robust morphology seen 40,000 years later.

But Thorne argues that such dramatic change is unlikely over such a short period and that fossils from the only environmentally comparable region—southern Africa—show that people have remained gracile over the past 100,000 years. Moreover, Thorne maintains, "there is nothing in the evidence from Australia which says Africa"—not even the Mungo fossil's modern features, which he believes look much more like those of contemporaneous Chinese fossils. And Thorne observes that living indigenous Australians share a special suite of skeletal and dental features with humans who inhabited Indonesia at least 100,000 years ago.

Therefore, he offers, a simpler explanation is that the two populations arrived in Australia at different times—one from China and the other from Indonesia—and mixed, much like what has been proposed for Neanderthals and moderns in Europe. Exactly the same pattern exists in recent history, Thorne adds, pointing to the interbreeding that took place when Europeans arriving in North America and Australia encountered indigenous peoples. "That's what humans do."

The mystery of human origins is far from solved, but because DNA may not be as diagnostic as it once seemed, Thorne says, "we're back to the bones." University of Oxford geneticist Rosalind M. Harding agrees. "It's really good that there are things coming from the fossil side that are making people worry about other possibilities," she muses. "It's their time at the moment, and the DNA studies can just take the back seat." *—Kate Wong*

ECOLOGY

REPLUMBING THE EVERGLADES

An $8-billion restoration plan may not go far enough

There's a good reason why the Everglades is called the "River of Grass." Until the latter half of this century, water flowed down the Florida peninsula in a shallow, 60-mile-wide sheet, slowly gliding south from Lake Okeechobee to Florida Bay. This sheet flow gave rise to a uniquely rich ecosystem, a freshwater marsh covered with sawgrass and teeming with fish, alligators and wading birds. But in the 1950s and 1960s, the Army Corps of Engineers built a web of canals and levees to prevent flooding and to drain large sections of the area for farming. The canals diverted water to the Atlantic Ocean and the Gulf of Mexico, shunting hundreds of billions of gallons away from the Everglades every year. The result was an environmental disaster: the marshland has now shrunk to about half its original size, and the number of wading birds has decreased by an estimated 90 percent.

For the past decade, federal and state officials have been struggling to put together a plan to save the Everglades. The lead agency in this effort is none other than the Army Corps, which is expected to submit its final report to Congress this summer. The agency has proposed a $7.8-billion, 20-year replumbing project that would tear down more than 240 miles of canals and levees and increase the water flow in the Everglades to nearly its original volume. But the Army Corps plan would not eliminate all the man-made barriers that compartmentalize the region. Under the proposal, water would be stored in reservoirs and underground aquifers and periodically released to mimic the marshland's historical wet/dry cycle.

Some scientists say the project will not even come close to returning the Everglades to its natural state. "The plan will maintain a managed, fragmented structure instead of restoring the natural system," says Stuart Pimm, an ecologist at the University of Tennessee who has studied the Everglades extensively. "We should just take out the damn dikes, for God's sake, and leave the area alone." Gordon Orians, an ecologist at the University of Washington, worries that the plan's environmental goals have been compromised by concerns over flood control and the need to supply water to Florida's burgeoning population. "If restoring the Everglades was the only problem, it wouldn't be that tough to do," he says. "But that's not the real world."

Earlier this year Pimm, Orians and other scientists persuaded Interior Secretary Bruce Babbitt to establish an independent panel to review the restoration plan. In April the Army Corps agreed to accelerate its timetable for removing some of the canals and levees; environmentalists are still pushing for more concessions, but many acknowledge that the current plan is probably the best they can get. Charles Lee, senior vice president of the Florida Audubon Society, noted that eliminating every man-made barrier in the Everglades would flood many residential areas in southern Florida. "We'd have to move a lot of people, and that's not politically doable," Lee says.

Another major obstacle to the restoration of the ecosystem is the Everglades Agricultural Area, a 750,000-acre spread of farms and sugarcane fields just south of Lake Okeechobee. The agricultural area acts as a giant cork, blocking the flow of water to the Everglades. Environmental groups had wanted to revive the sheet flow by converting large portions of this agricultural area into reservoirs, but the U.S. was able to wrest only 60,000 acres from the sugar growers, who have fiercely resisted government attempts to acquire more land.

This acreage was not enough to store all the water needed to revitalize the Everglades, so the Army Corps came up with an alternative: pumping as much as 1.6 billion gallons a day into underground storage zones. The injected water would float above the denser saline water in the aquifer and could be pumped back to the surface during dry periods. Aquifer storage has been tested at sites in southern Florida, but the restoration plan calls for storage zones with 100 times the capacity of any current project. Many environmentalists worry that the technology just won't work on such a large scale. "That's one of our biggest concerns," Lee says. "The Army Corps doesn't have a well-developed backup plan in case aquifer storage doesn't live up to its potential."

Stuart Appelbaum, restoration chief for the Jacksonville district of the Army Corps, contends that the agency could deepen surface reservoirs if underground storage does not prove feasible. He emphasizes that the restoration plan is not "written in stone." If all goes smoothly, Appelbaum says, Congress will give its approval by the fall of next year.

For some Everglades species, however, that may be too late. The changes in water flow have devastated the breed-

NICOLE DUPLAIX *Peter Arnold, Inc.*

FLORIDA EVERGLADES has shrunk to about half its original extent.

ing grounds of the Cape Sable seaside sparrow, which lives almost exclusively in the Everglades. The birds' nests have been flooded during the wet seasons, and much of their habitat has gone up in flames during the dry seasons. The number of Cape Sable sparrows has dropped from tens of thousands a few decades ago to about 3,000 today, and some fear the species is headed for extinction. Pimm says he has met tourists in Everglades National Park who were stunned by the losses to the region's wildlife. He blames the catastrophe on the flood-control system built by the Army Corps, and he is not yet convinced that the agency can now correct its own mistakes. *—Mark Alpert*

GEOPHYSICS

MAKING WAVES

An undulating layer of hot rock cools the controversy over how the earth's mantle moves

It's what's inside that counts, so the saying goes, and the earth is no exception. Solid rock in its mantle, hot enough to flow like warm taffy, sculpts the planet from the inside out by pushing tectonic plates across the surface. Crashing plates crumple into mountain ranges or plunge into the sticky rock below, only to rise again millions of years later as bits of the lava that billows from mid-ocean ridges.

Without this rocky recycling program, the earth would be as sterile and pockmarked as the moon. But exactly how the nearly 3,000-kilometer-thick (1,865-mile-thick) mantle moves remains one of our planet's great mysteries. After three decades of heated debate, an emerging hypothesis may quiet the conflict.

Since the 1950s geochemists have imagined that the mantle works like a double boiler: a layer depleted in radioactive elements churns above—but never mixes with—a radioactive layer below. Early seismic snapshots of the mantle revealed a sudden density increase about 670 kilometers deep—just the boundary that could keep the layers from blending. What is more, a layer of radioactive elements could explain why the planet makes more heat than it otherwise should.

But with better seismic data to focus the picture, seismologists began to see the mantle as one giant boiling pot of soup. They saw hints of tectonic slabs diving deep below that boundary. "It's hard to maintain layers if you're stirring things up all the time," says mantle modeler Louise H. Kellogg of the University of California at Davis. Slabs pierce the 670-kilometer barrier because minerals below it are more compact forms of those above—a weaker obstruction than if minerals below were a different type.

"For a long time, people just did not consider other models," says seismologist Rob D. van der Hilst of the Massachusetts Institute of Technology. Recently, however, researchers have begun to find clues that might reconcile the seismological picture of deep-sinking slabs with the geochemical need for an isolated, heat-producing layer.

About two years ago van der Hilst noticed that seismic patterns tend to break up below about 1,700 kilometers. "If there were simple, whole-mantle flow, the same patterns would go down all the way," he says. This seismic breakup could have been explained by an idea proposed by Harvard University geophysicist Richard O'Connell and his team: buoyant blobs of radioactive rock bob in the lower mantle.

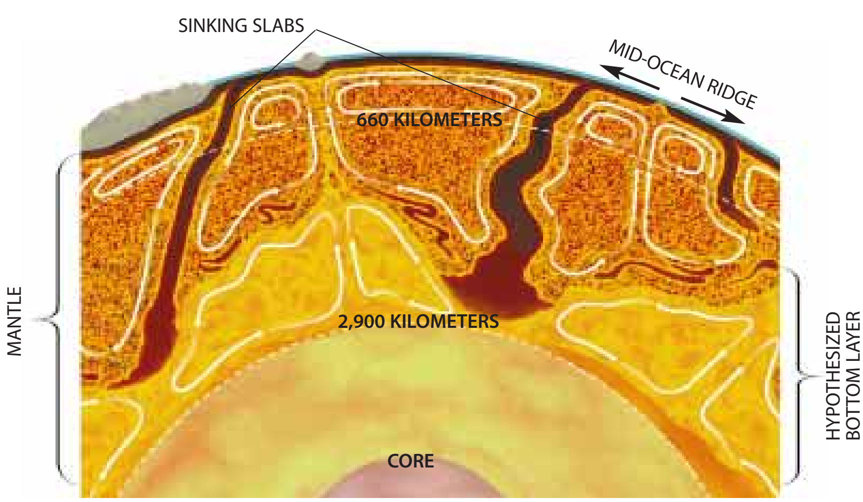
But van der Hilst suspected that as these blobs heated up they would seep into the surrounding rock and disappear. He thought that an isolated layer in the bottom third of the mantle might hold together better. Using computer simulations, van der Hilst, Kellogg and their M.I.T. colleague Bradford H. Hager discovered that a layer only about 4 percent denser than the overlying mantle could stay intact over billions of years. Hotter than the layer above, this layer would contain regions that swell upward like the wads of heated wax at the bottom of a lava lamp but never actually separate into blobs like O'Connell's.

"One of the best things about the model we have is that it allows the presence of reservoirs of different composition *and* allows for slabs to penetrate quite deep in some places," Kellogg says. The hypothesized bottom layer thins below cold, sinking slabs, sometimes all the way to the core-mantle boundary.

But Don L. Anderson of the California Institute of Technology is not convinced that the slabs would go so deep if Kellogg's team had considered pressure as well as temperature and density. "At very high pressure, it takes a lot of temperature variation to make things sink or rise," he maintains. Still, a seismologist who has long argued that a distinct layer exists in the deep mantle, Anderson is not surprised by the findings. "I've been trying for years to get modelers to use layered fluids," he says.

At least one geochemist also embraces the new mantle layer idea. A deep layer could serve as the radioactive reservoir just as well as one that begins only 670 kilometers down, suggests Albrecht W. Hofmann of the Max Planck Institute for Chemistry in Mainz. "The constraints we had have basically fallen," Hofmann told a crowd at the June meeting of the American Geophysical Union.

At the same meeting, O'Connell's group showed through calculations that when their blobs reach a certain density, they sink into a layer like Kellogg's. Perhaps blobs and layers have each existed at different points in the earth's history, O'Connell says. *—Sarah Simpson*



***EARTH'S STICKY MANTLE** may flow* (arrows) *in two layers. Tectonic slabs sink through the top layer but never penetrate a hypothesized denser layer below.*

A POUND OF FLESH

For a Danish study of human athletic performance, our reporter donates some muscle to the cause

During 14 years of interviewing scientists and engineers and writing about their work, I have probably left a few with the desire to stick a knife in me. But now Bengt Saltin is actually doing it. After making an incision about half a centimeter long in my right thigh, he digs down three centimeters to snip off and scoop out a piece of muscle about the size of a large matchhead.

"If this had been in America," he chuckles, "I would have had to have you sign something saying you won't sue me for making a hole in your leg. But we are not so formal here."

"Here," specifically, is the Copenhagen Muscle Research Center (CMRC), and I am beginning to understand why Scandinavia is to skeletal muscle researchers what France is to chefs. Denmark, in particular, is an oasis of tissue-removal permissiveness in a desert of first-world litigiousness.

Saltin, whom some regard as the world's foremost researcher on human skeletal muscle, shows me the tiny piece of my quadriceps (looks just like chicken) and says approvingly, "It looks like you have lots of fast fibers." I take it as a compliment and as a reason never to bother training for a marathon.

Most Ph.D. candidates can gripe about surrendering the proverbial pound of flesh to their faculty adviser, but few can do it as literally as Saltin's Ph.D. student Morten Zacho. The muscular Zacho, as much human pincushion as doctoral student, has endured more than 80 biopsies in the past three years. He explains that I will be part of a control group for an extensive set of experiments on how the human body responds to reduced oxygen availability during exercise. CMRC researchers carried out the main series of tests in the summer of 1998 at an altitude of 5,260 meters in Chacaltaya, Bolivia.

After graduate student Hans Søndergard inserts a catheter with a valve into a vein in my left arm, we are ready to continue. My job is to pedal a stationary bicycle at a constant 80 revolutions per minute. Of course, there are complications: every two minutes the researchers increase the pedaling resistance by 40 watts, after a starting work rate of 120 watts. By monitoring the air I inhale and exhale, the researchers measure my V_{O2}max, the maximum rate at which my muscles can use oxygen and an important indicator of my level of physical fitness. Every four minutes they take a blood sample from my left arm. The samples will reveal concentrations of lactate, a waste by-product of metabolism in muscle cells.

***BLOODLETTING AND BICYCLING** go together in a test simulating muscle performance at altitude. Here graduate student Hans Søndergard takes a blood sample from test subject Glenn Zorpette.*

I hit the wall at 280 watts. As Zacho and Søndergard, the two great Danes, bark encouragement at me, my pulse hits 187, I gasp for breath, sweat pours off me and my legs sear with pain. When I quit pedaling, the two students prop me up while Saltin takes another biopsy, which he'll check for lactic acid (a precursor to lactate).

That was the easy part. After an hour's rest, it is time to do it all over again, but while breathing a mixture of 90 percent nitrogen and 10 percent oxygen, rather than air's 21 percent oxygen. I peter out at a measly 200 watts, utterly fatigued, sucking at the thin air, my peripheral vision fading out. I hardly remember Saltin taking the final biopsy. Zacho later confides sheepishly that he was once so dazed at the end of a similar hypoxia experiment that he flailed at the person who was trying to remove him from the bicycle. (Fortunately for his academic career, it was not Saltin.)

Some weeks later Zacho faxes me the results. My relative V_{O2} max breathing normal air was 56 milliliters of oxygen per minute per kilogram of body weight. It exceeds that of sedentary Danes in their thirties, who average 43, and is considerably higher than the average for couch-potato Americans in that age group. On the other hand, Olympic cross-country skiers and Tour de France cyclists score around 80. Zacho is pleased with my lactate level, which hit 13.9 millimoles per liter of blood, up from a resting value of 2.4.

While breathing 10 percent oxygen, I became exhausted at a much lower work level, and my lactate level was lower. Although this result may sound logical, it is actually inconsistent with previous research going back to the 1930s. According to those findings, I should have had similar lactate levels at exhaustion while breathing the thin air—even though I gave out at a lower work level. Had I lingered at high altitude for several weeks, however, my lactate levels should have become progressively lower at exhaustion. No one has ever explained this phenomenon, known as the lactate paradox.

Bafflingly, preliminary analysis of the Chacaltaya experiments showed that after nine weeks of acclimatization there was nothing paradoxical about the subjects' lactate levels at exhaustion: they were still as high as they had been before the subjects became acclimatized.

Saltin and company are at a loss to explain their findings. "August Krogh said that it is not worth publishing data that are different from the literature if you cannot explain what your data mean," Saltin says. "If that is true, we may never be able to publish these data."

—Glenn Zorpette in Copenhagen

IN BRIEF

Age-Old Debate

Two recent measurements of the universe's age have produced conflicting estimates. Wendy L. Freedman of the Carnegie Observatories and her colleagues used the Hubble Space Telescope to spy NGC 4603—the farthest galaxy to contain distance-marking stars called Cepheid variables—and other stellar objects. In a May briefing, they announced that the universe was 12 billion to 14 billion years old. But at the June American Astronomical Society meeting, astronomers using a series of radio telescopes called the Very Long Baseline Array said the universe was 15 percent younger. Their estimate comes from radio "hot spots" in galaxy NGC 4258, putting its distance at 23.5 million light-years. The figure raises questions about age calibration based on Cepheids: those in this galaxy yielded a distance of 27 million to 29 million light-years. —*Philip Yam*

NGC 4603

J. NEWMAN *University of California at Berkeley* AND NASA

McGwire's Drug Strikes Out

The over-the-counter steroid substitute androstenedione, made famous by home-run slugger Mark McGwire, does not help novice weight-trainers build muscle or boost testosterone levels. Reporting in the *Journal of the American Medical Association*, Douglas King of Iowa State University and his colleagues instead found that androstenedione decreased high-density lipoprotein levels and increased estrogen concentrations, suggesting a link to heart disease, stroke, pancreatic cancer and breast enlargement. —*Christina Reed*

Pricking for Endorphins

When acupuncture needles prick nerve endings, the body reacts with a release of endorphins, according to the June *American Journal of Physiology*. The study found that blood pressure artificially raised in 12 cats was reduced using acupuncture. But when the drug naloxone, which blocks endorphin nerve cells, was put into the cats' bloodstream, acupuncture had no effect. The next step: to determine which nerve cells can help heart disorders. —*C.R.*

More "In Brief" on page 24

ANTI GRAVITY

Thinking Outside the Box

Who knew? Turns out that some six million General Motors cars have been traversing the highways and byways of America this decade while carrying hidden black boxes, stripped-down versions of the flight-data recorders that sometimes reveal the causes of airline catastrophes. The latest version of the recorder, known as a sensing and diagnostic module (SDM), keeps track of the last five seconds before an impact. It catalogs speed, the position of the gas pedal, when the brakes were finally applied and whether the driver was belted, all in an attempt to improve safety through research.

Unfortunately, the fundamental flaw in the automobile black box business remains the quality of the available information. The skeletal data about the car leave virtually untold the story of the weak link: the driver. A truly valuable system might be able to give detailed data about the man or woman, or pet, behind the wheel. For example:

Case I. Lysergically enhanced Deadhead driving original Volkswagen Beetle down San Francisco's Lombard Street thinks he sees Jerry (Garcia). Makes beeline for same. Destroys $76,000 worth of floral arrangements.

Case II. Woman in Scottsdale, Ariz., driving Mercury Marquis has parakeet perched on middle finger of left hand, mirror between thumb and forefinger of left hand for parakeet to observe self. Cigarette in right hand burning down. Attempt made with right hand to manipulate fresh cigarette into position to be ignited by currently lit cigarette. Artificial knees provide insufficient steering proficiency.

Case III. New York City cab driver uses both hands to flip off second cab driver, who hails from neighboring country of origin.

Case IV. Cornell University student skids down entire length of ice-covered State Street with both feet jammed on brake pedal, comes to stop in snowdrift on the Commons.

Case V. Left engine flameout on final approach to LAX. Wrong data recorder.

Case VI. Little old man in Boca Raton, Fla., driving black Lincoln Continental at 2 mph in Publix parking lot thinks he sees Jerry (Seinfeld), signals left, goes right. Second little old man trailing first little old man, also driving black Lincoln Continental, veers to right at 4 mph in attempt to pass first little old man while still in presumed left turn. Ensuing fender-bender sets off 23-car pileup within parking lot. Vehicle damage limited to scratches, but paramedics treat 14 drivers for palpitations.

Case VII. Illinois man driving used police car tries to jump open drawbridge over Chicago River.

Cutting to the car chase, good data concerning what drivers were up to just before totaling on the turnpike are hard to come by: not everyone will admit to their dopey stunts just before impact, and investigators can only do so much in reconstructing a driver's multitasking.

Quality data may appear soon, however. The National Highway Traffic Safety Administration is currently experimenting with an unobtrusive onboard camera system designed to get good looks at the kinds of things drivers do in addition to driving.

The bet here, if people truly forget that they are being watched, is that the record will show drivers conspiring in their own misery via brewskies, lead foots, mascara, cassettes, cellular telephones, doggies, children, cigarette lighters, sexual activity and trying to use the wipers to move one of those annoying leaflets, placed on your windshield while you were busy shopping, into position to be snatched off with your left hand as you're driving. Because, as usual, the infinite variety of questionable human behavior remains the ultimate black box. —*Steve Mirsky*

MICHAEL CRAWFORD

CONSERVATION

A PATCH FOR LOVE

Hormone-delivering patches could help endangered animals breed

For years, people have been able to wear patches that help them quit smoking, prevent seasickness or replace hormones in their aging bodies. But now patches might help out when it comes to the birds and the bees—especially the birds. Rebecca L. Holberton, a biologist at the University of Mississippi, is developing a patch that can safely deliver hormones to encourage reproduction in endangered birds.

M. F. SOPER *Bruce Coleman Inc.*

***ENDANGERED KAKAPO** might thrive with a hormone patch.*

Free of surgical complications that may affect other methods, the patch delivers hormones directly through the skin and is light and easy to make: it is derived from Band-Aids. The hormone is mixed with vegetable oil and added to the gauze. The completed patch is attached just under the wing; it falls off three to four days later.

The first target for Holberton and her colleague John F. Cockrem of Massey University in New Zealand is the endangered kakapo, *Strigops habroptilus,* which lives on the islands of New Zealand. Like the dodo, this eight-pound, flightless nocturnal parrot survived without worries of predation until humans and other nonnative animals arrived. The kakapo numbers dropped from hundreds of thousands to 56 adults today.

In 1975 the New Zealand Department of Conservation gathered kakapos from their habitats and transported them to islands that are now regulated for nonnative predators. In 1980, with the discovery of a female still alive, breeding efforts began. But regardless of all the booming, foghornlike calls of the males, the females are interested in food first, sex later. They care for their chicks alone and will often hold off breeding unless fruit is abundant.

When the birds are too concerned about food to mate, the patch might change their attitude. "It could possibly be used whenever the food crop is bad," Holberton remarks. She and Cockrem are applying the patch on quails this summer to determine how stress affects reproduction. They are testing dosages for protein hormones such as luteinizing hormone, which stimulates the ovaries to produce estrogen. Holberton has also used dexamethasone, a synthetic stress hormone, to keep birds from becoming anxious. Hormonal changes may help the females respond to the males' call. Holberton anticipates two years of study before a kakapo patch will be readied.

Luckily, 1999 has been a productive fruit and nesting season. One kakapo, named Lisa, was found on Little Barrier Island with three viable eggs after she had lost her transmitter and disappeared for 13 years. Her eggs are being artificially incubated along with five others on Pearl Island, where three have already hatched. *—Christina Reed*

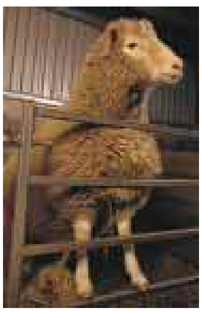
In Brief, *continued from page 22*

Blocking T Cells for Transplants

Transplantation with only partially matched donors and no antirejection drugs may soon be feasible. As described in the June 3 *New England Journal of Medicine,* researchers kept the immune system's T cells from attacking foreign tissue. T cells go into battle when specialized cells present an antigen and a "co-stimulatory" signal. Blocking the signal—inducing what is called anergy—kept the recipient's immune system from destroying donated bone marrow while preserving the recipient's ability to fend off disease. Of 12 patients, only one developed graft versus host disease (ordinarily, 60 to 90 percent do). *—P.Y.*

Senescent Sheep

Dolly's cells seem to be older than Dolly herself. The researchers who cloned the sheep describe in a correspondence in the May 27 *Nature* that her telomeres are shorter than expected. Telomeres are end caps of chromosomes that shorten with each cell division, giving an indication of age. Dolly's prematurely truncated telomeres probably reflect the fact that she came from an udder cell of a six-year-old sheep. Other biologists are not fully convinced of the finding, because the length difference is less than 20 percent and may represent a normal variation. *—P.Y.*



ROBERT WALLIS *SABA*

Older than she looks

Mars on Earth

Tim Kral and Curtis Bekkum of the University of Arkansas have grown a garden of methane-producing microorganisms in a simulated Martian Eden. They added hydrogen and carbon dioxide to volcanic ash from Hawaii to simulate Mars's soil composition, grain size, density and magnetic properties. The bacteria grown, *Methanobacterium wolfei*, ordinarily live in harsh, anaerobic conditions found deep below Earth's surface, at hydrothermal vents, in swamps and in the rumen of cows; they successfully gained their nutrients from the Mars-like soil, even with a limited water supply. The study, presented at the June meeting of the American Society for Microbiology, raises hope that subsurface life might exist on Mars. *—C.R.*

SA

PHYSICS

QUBIT CHIP

A superconducting chip suggests a practical path to medium-scale quantum computing

For several years, physicists have been enthusiastically pursuing the technology of quantum computers—devices that promise to exceed the theoretical abilities of conventional computers by exploiting the quantum nature of reality. Some labs have even built working models of quantum bits, or qubits (pronounced "cue bits"), the fundamental elements of a quantum computer, using ions trapped in special cavities or nuclear magnetic resonance techniques. Unfortunately, most of these tabletop qubit systems make the hefty vacuum tubes of the ENIAC era look positively svelte by comparison, not to mention sturdy and easy to wire together. (A contemporary of ENIAC, the Harvard Mark II, was once bothered by a literal bug flying into a relay; quantum bits tend to fall like a house of cards at the touch of an unwanted photon.)

Now Yasunobu Nakamura and his co-workers at the NEC Fundamental Research Laboratories in Tsukuba, Japan, have demonstrated a nanometer-scale qubit built on a silicon chip. The device combines the properties of a quantum dot—a box so small that adding a single electron is a significant change—with the quantum purity of the superconducting state, in which electricity flows without resistance.

In light of the world-transforming success of microelectronics, it may seem natural to try to develop silicon-based designs for quantum circuitry. But this is not a simple task. The essential property of a qubit is its ability to exist not only in the usual two binary states, 0 and 1, but also in an arbitrary superposition of these. A quantum computer would derive its computational power from this indeterminacy, in essence running an algorithm on many different numbers at once, using only as many (qu)bits as a regular computer would need to do the computation for a single number.

Unfortunately, the electrons in semiconductors can assume a vast range of quantum states and instead of a clean superposition of two states, an incoherent mix of thousands occurs. The quantum dot is one solution, because its tight confines split the continuum of electron states into discrete levels, making it much easier to single out two states for 0 and 1. Still, loss of quantum coherence in less than a nanosecond remains a problem, although recent work using the electrons' spins suggests one solution.

The approach by Nakamura and co-workers, reported in *Nature,* makes use of a superconducting quantum dot to solve these problems. In a superconductor the relevant electrons link up to form so-called Cooper pairs, which all collect in a single quantum state (a Bose-Einstein condensate of electron pairs).

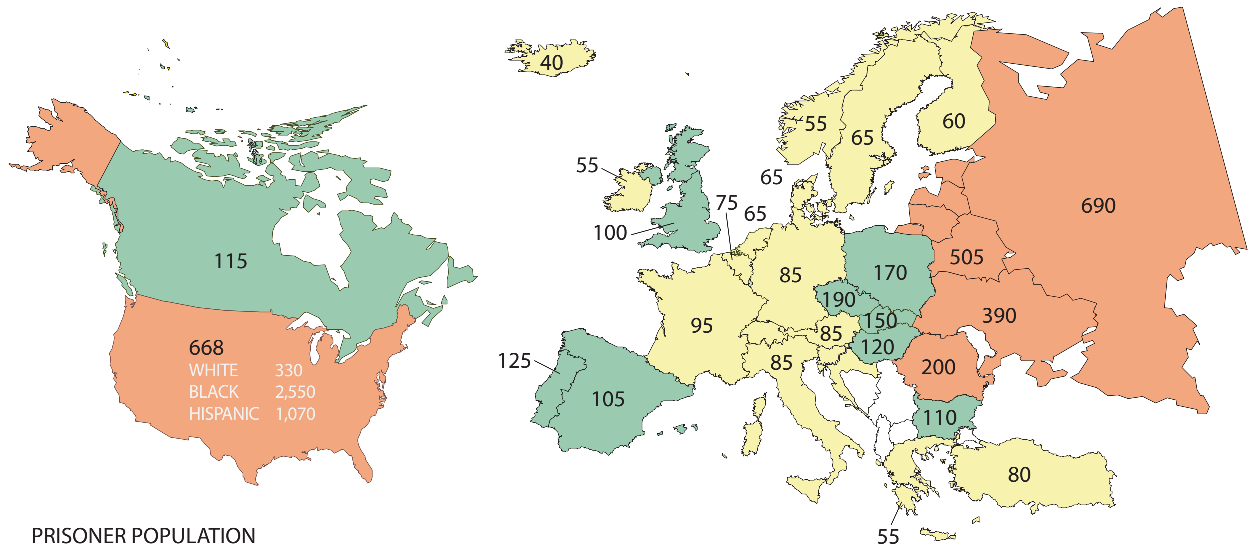
The quantum dot is a tiny finger of aluminum deposited on an insulating layer on the chip. Aluminum is superconducting at the operating temperature of the device—three hundredths of a degree above absolute zero. Two small junctions connect the dot to a larger aluminum reservoir, and an applied voltage aligns the energy levels in dot and reservoir so that a single Cooper pair can tunnel back and forth from reservoir to dot. This forms the 0 and 1 of the device—the absence or presence of one extra Cooper pair in the finger, which is then called a single-Cooper-pair box.

The researchers test that their device has the right quantum properties by using a voltage pulse to kick the Cooper pair into a superposition, the duration of the pulse controlling the relative proportions of 0 and 1 that are created. So far they have evidence that their qubit maintains its properties for up to two nanoseconds, time enough for their voltage pulses to switch its state about 25 times.

Michel Devoret, head of the Quantronics group at the Saclay Research Center in France, calls the work "a fantastic achievement. This is a key piece in a puzzle that has taken many years to assemble." Dmitri Averin of the State University of New York at Stony Brook believes this type of qubit is well suited for developing quantum computers of medium complexity, which would be an important step on the very difficult path toward full-scale quantum computers, and perhaps of use for less demanding functions such as increasing the security of a quantum communications channel.

Those goals, however, are still a way off. The next order of business is to study how to extend the qubit's lifetime and to start wiring up qubits to make simple logic gates. *—Graham P. Collins*

Behind Bars in the U.S. and Europe

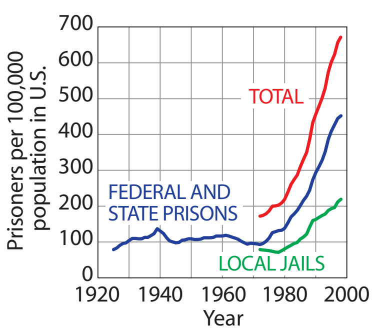


SOURCE: Data on map are from Americans behind Bars: U.S. and International Use of Incarceration, 1995, *by Marc Mauer, The Sentencing Project, Washington, D.C., 1997; and U.S. Bureau of Justice statistics. Data are for 1995, except for the U.S., which are for 1998. U.S. data by race are estimates. The chart shows data from the U.S. Bureau of Justice statistics for federal and state prisons (sentences of a year or more) and local jails (stays of under a year). The statistics for other countries shown on the map do not distinguish between local jails and long-term prisons.*

Most Western countries have put more people behind bars in recent years, but in none has the incarceration rate risen more than in the U.S. The cause of the extraordinary American figure is not higher levels of crime, for the crime rate in the U.S. is about the same as in western Europe (except for the rate of homicide, which is two to eight times greater, mostly because of the ready availability of guns).

The high U.S. rate—which rivals those of former Soviet nations—can be traced primarily to a shift in public attitudes toward crime that began about 30 years ago as apprehension about violence and drugs escalated. Politicians were soon exploiting the new attitudes with promises to get criminals off the streets. Presidents Ronald Reagan and George Bush promoted tough-on-crime measures, including the "War on Drugs." Bill Clinton, breaking with previous Democratic candidates, endorsed the death penalty and as president signed an anticrime bill that called for more prisons and increases in mandatory sentencing. Governors in about half the states signed "three strikes and you're out" legislation. Local officials who make most of the day-to-day decisions that affect incarceration, including police, prosecutors, judges and probation officers, were strongly influenced by the law-and-order rhetoric of governors and presidents. Increasingly, they opted for incarceration of lawbreakers in local jails or in state prisons.

As a result, the length of sentences, already severe by western European standards, became even more punitive. Consequently, the number of those locked up rose more than fivefold between 1972 and 1998, to more than 1.8 million. Most of those sentenced in recent years are perpetrators of nonviolent crimes, such as drug possession, that would not ordinarily be punished by long prison terms in other Western countries. The rise in the population behind bars happened while the rate of property crime victimization was falling steeply and while the rate of violent crime victimization was generally trending down.



Conclusive proof is lacking as to whether harsh sentences actually deter crime. The most obvious result of harsh sentencing is the disruption of the black community, particularly as it bears on young black men. A substantial minority of both white and black teenage boys engage in violent behavior. In their twenties, most whites give up violence as they take on the responsibility of jobs and families, but a disproportionate number of African-Americans do not have jobs, and they are most likely to contribute to crime and imprisonment rates. The system is biased against blacks in other ways, such as in sentencing for drug offenses: although 13 percent of drug users in the U.S. are black, blacks account for 74 percent of all those sentenced to prison for drug offenses. One in seven adult black males has lost his voting rights because of a felony conviction.

Two British criminologists, Leslie Wilkins (retired) and Ken Pease of the University of Huddersfield, have theorized that less egalitarian societies impose harsher penalties. Imprisonment thus becomes a negative reward, in contrast to the positive reward of wealth. The theory perhaps explains why the U.S. has higher incarceration rates than other Western countries, where income inequality is less extreme, and why rates began to rise in the early 1970s, shortly after income disparities began rising. If the theory is correct, high U.S. incarceration rates are unlikely to decline until there is greater equality of income.

—Rodger Doyle (rdoyle2@aol.com)

RODGER DOYLE

PROFILE

Of Survival and Science

From street waif in war-torn Italy to "knocking out" the genes of mice—Mario R. Capecchi shows how genius springs from the most unlikely beginnings

In 1996 Japan's Inamori Foundation asked Mario R. Capecchi to review his life and work in an acceptance speech for the prestigious Kyoto Prize. Capecchi dutifully described his pathbreaking research on a precision method for insertion or deletion of genes in mice. The most compelling part of the talk, however, had nothing to do with mouse chimeras or positive-negative selection. Rather Capecchi recounted memories of a childhood with the makings of a script Italian actor/director Roberto Benigni might use as an encore for his Academy Award–winning *Life Is Beautiful*.

Capecchi is living evidence that scientific creativity and genius can spring from the most improbable circumstances. Little more than 15 years before he began doctoral studies under Nobelist James D. Watson, an eight-year-old Capecchi was using the same intellect to avoid death on the streets of war-ravaged Italy.

Capecchi was born on October 6, 1937, in the northern city of Verona, the offspring of a brief liaison between an Italian airman and an American poet. In 1941 the Gestapo arrested and sent his mother to the Dachau concentration camp. Hitler believed that like Jews, gypsies and homosexuals, the Bohemians, a group of artists who opposed the Nazis and Fascists, should be extirpated from society. In anticipation of being deported, Lucy Ramberg sold her possessions and gave the proceeds to a Tyrolean peasant family to care for the three-and-a-half-year-old Mario.

For a while, things went as well as they could in the middle of a war. On the farm, the boy watched the wheat harvest and would help crush wine grapes with his bare feet. One of his first direct encounters with the war came one afternoon when American airplanes strafed peasants in the field with machine-gun fire. Capecchi took a bullet in the leg, although the wound healed quickly.

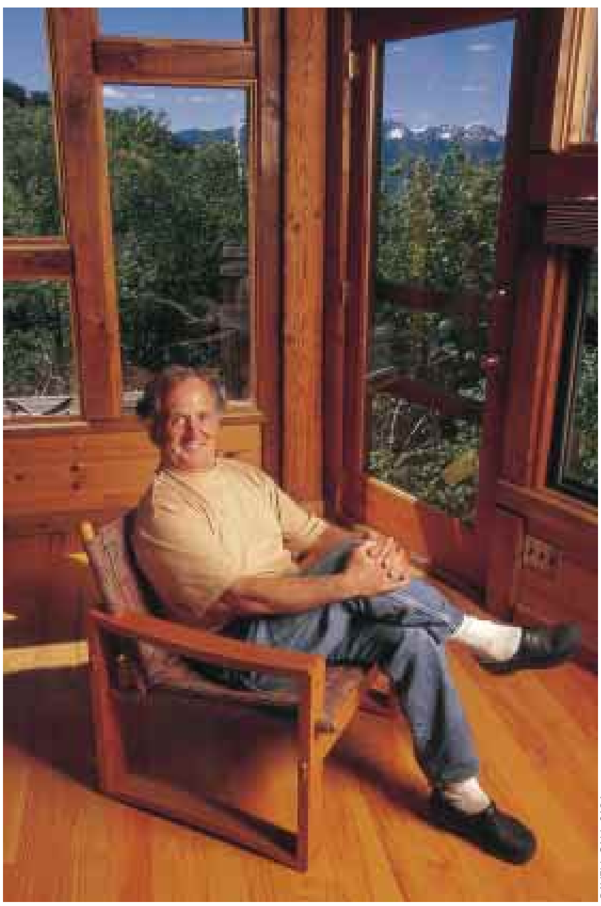
After a year, his mother's money unexpectedly ran out, and the boy was put out on the street—Capecchi suspects that his father, an Italian fighter pilot, may have wrangled the remainder of the cash from his caretakers. Thus began a life-defining odyssey for the young boy, the effects of which persist to this day. The man who greets a visitor in his University of Utah office looking out onto the distant Oquirrh Mountains is five feet, four inches tall, perhaps eight inches or so shorter than he would be had he had enough to eat during those formative years.

From 1942 to 1946, Capecchi was in and out of orphanages, a hospital and the Balilla, Mussolini's youth army. These places, usually bereft of food and run by Dickensian masters, proved worse than simply fending for oneself on the street. So he spent most of his time plotting escapes. On the outside, he would live in bombed-out buildings and conspire with companions to steal bread and fruit from open-air shops. It was the best existence possible, despite having to protect himself with his fists and to witness frequent atrocities or their aftermaths, such as discovering a pile of body parts. At times he would live with his father, Luciano Capecchi, who would put up with him for a while and then throw him out. "He was a very loose soul," as Capecchi remembers.

On his ninth birthday, a woman he did not recognize showed up at the hospital where he was confined in the northern Italian city of Reggio Emelia. He had been relegated there because he suffered from malnutrition, yet the hospital itself served only a bowl of chicory coffee and a crust of bread once a day. The woman looked much older than his vague memory of his mother, but Capecchi didn't care whether she was his mother or not. He only knew that she represented a ticket to freedom. Life in the hospital was marked by endless days of lying naked on a bed staring at the ceiling, wracked by famine-induced fevers. Three weeks later—a period that gave him the assurance that his orphanhood had ended—mother and son left on a boat for America.

In the course of just a few weeks, Capecchi went from a collapsed civilization to the highly moralistic environment of a Quaker commune, where he and his mother settled with his uncle and aunt, 20 miles north of Philadelphia. In contrast to the murderous rivalries that had fractured Europe, the commune harbored an ethnic melange that included Chinese, blacks and Jews.

His uncle, Edward Ramberg, a physicist who worked on electron optics during the day at the Princeton RCA Research Laboratory in New Jersey, was



RAVELL CALL SABA

FLEEING A HARVARD PROFESSORSHIP, Mario R. Capecchi sought out Utah's wide open vistas.

a conscientious objector who refused to fight in the war or labor on projects that would help the military effort. The childless couple virtually adopted the boy, taking over parenting responsibilities from his mother, who was still scarred from her time at Dachau. "Their mission was to make me into a social being, and it was a struggle," Capecchi notes, his voice retaining the slightest trace of an Italian accent.

The child entered the third grade at the local public school not knowing a word of English nor how to read or calculate. The one thing the adopted Quaker communard did know was how to fight. "Initially what I did was beat up everybody. That established my own turf and gave me a social status," Capecchi recounts, his blue-jeaned leg draped over the arm of his desk chair, revealing a foot in a black clog.

Gradually, he sublimated his aggression into sports, particularly wrestling, and caught up academically with his schoolmates. At Antioch College he dropped his dalliance with athletics and began to pursue the simple elegance of the physical sciences, which held a great appeal for someone whose life had been shaped by the chaos of war. On a work-study program he grew excited over the new field of molecular biology. Later, during an interview for a graduate program at Harvard University, he shyly asked Professor Watson where he should do his graduate studies. "You would be f—ing crazy to go anywhere else," he remembers Watson telling him. He received his doctorate for doing protein synthesis work in Watson's laboratory and went on to a four-year stint as a faculty member in the department of biochemistry at Harvard Medical School.

Then Capecchi did something that seemed an act of madness to his colleagues but made sense in the larger context of his earlier experiences of entrapment and self-reliance. In 1973 he abandoned the claustrophobic, politicized atmosphere of the Harvard-M.I.T. biomedical-research complex. There researchers seemed to be suffering from a herding instinct in which each group would pursue closely related problems. Capecchi accepted a position at the University of Utah. The West's wide open spaces afforded a sense of release and a place where he could follow Watson's entreaty to concentrate only on the biggest and most important biomedical research problems. "I think that by being isolated you have the opportunity to do things much more long range," he says.

That desire for freedom extends to his personal life as well. Capecchi lives in a refashioned wooden geodesic dome on 18 acres of land in the Wasatch Mountains that he bought from a hippie in the late 1970s. He and his wife, Laurie Fraser, waited until years after the birth of their daughter, Misha, in 1984 before trading the outhouse for central plumbing.

This independent streak helped Capecchi weather the biggest crisis of his professional career. In 1980 a panel of reviewers from the National Institutes of Health classified his studies on targeted gene replacement (inactivating or modifying a gene in mouse embryos) as "not worthy of pursuit." The reviewers judged that it would be unlikely that a segment of DNA introduced into a cell could line up and replace a matching sequence from among the cell's billions of nucleotides and that if it did it would be all but impossible to detect.

Capecchi made the decision to use funds from another project to pursue this line of research. By 1984 he had amassed enough evidence to prove to NIH scientists that the technique was effective. Gene targeting gets around the tendency of a newly introduced gene to insert itself randomly into a cell's nuclear DNA. It takes advantage of a natural cellular process called homologous recombination, in which strands of nucleotides from a gene home in on matching sequences in a cell. If the newly inserted gene finds its target, it will line up with it and replace it, even when carrying altered sequences that turn off a gene or modify its activity.

This process occurs in only a small fraction of embryo cells. What made the technique effective was that the investigators found a way to detect gene insertions by killing off those cells that did not contain the gene or had inserted it in the wrong place. That year a critique done by the reviewing scientists of a new submission for funding from Capecchi's laboratory began by saying, "We are glad you didn't follow our advice."

The basic gene-targeting technique—pursued on a parallel track by Oliver Smithies of the University of North Carolina—has become the fundamental technology for testing the functional role of a particular gene in mammals. Scientists have published thousands of papers in which a mouse gene has been "knocked out" to assess resulting genetic defects—the triggering of a process that leads to cancer, for instance.

In recent years Capecchi's main interest has focused on using the suite of knockout techniques to trace neurological development in mice. His group, part of the Howard Hughes Medical Institute, is investigating how the set of homeobox genes involved in programming embryonic development can produce the thousands of types of differentiated neurons from a single set of brain cells. "What we're asking is how an embryo makes a brain. If you understand how to take it apart, you'll understand how it works," he says.

COURTESY OF MARIO R. CAPECCHI

***CAPECCHI'S MOTHER AND UNCLE** rescued the boy from the horrors of his war experiences.*

Capecchi does not foresee retirement for another 15 years. "My wife says I'm going to die in the laboratory," he notes. Even if his career ended now, his life story would remain a testament to a message that Capecchi tried to convey to his Japanese audience. Genius should be nurtured in places both high and low. Society must find ways to recruit and nurture its outcasts, even malnourished, illiterate street urchins. "No matter how good you think you are," he remarks, "you don't have the capability to predict who are the people who are going to bloom." Unlikely beginnings can produce extraordinary lives.

—Gary Stix in Salt Lake City

AGRICULTURE

THE BUTTERFLY EFFECT

New research findings and European jitters could cloud the future for genetically modified crops

Will the conjectured absence of butterflies flapping their wings on Iowa farms provoke political firestorms among Washington policymakers? That is the question that environmentalists have earnestly posed after a recent study in *Nature* found that pollen from corn bioengineered to produce a natural pesticide can kill the caterpillars of *Danaus plexippus,* better known as the monarch butterfly. Bringing this icon of summer and elementary school science projects into the debate over genetically modified food may do more to energize the issue than a foot-high stack of policy papers and more prosaic scientific studies.

In the past, disturbing findings about possible hazards of bioengineered crops—studies, for instance, that have focused on the prospect of moth pests developing resistance to a *Bacillus thuringiensis* (*Bt*) toxin, the natural pesticide incorporated in many genetically engineered crops—have received relatively little notice. Yet photographs of the monarch's flaming colors accompanied prominent headlines in major newspapers about the killing potential of *Bt* corn and generated cautionary editorials. An entomologist interviewed by the *Washington Post* summed things up by calling the monarch the "Bambi of the insect world."

Worries about monarchs have yet to metamorphose into hard evidence. The Cornell researchers who conducted the study emphasized the preliminary nature of what was a laboratory-confined investigation. Results, of course, may differ between laboratory and farm. The Swiss Federal Research Station for Agroecology and Agriculture found that green lacewings, insects that help to protect crops by eating aphids and other insects, have elevated mortality when they were fed in a laboratory on European cornborers that had eaten *Bt* corn. But how much harm ensues in an actual cornfield is unclear, because the cornborer spends much of its life inside the plant stalks, protected from lacewings.

Monsanto, a major supplier of *Bt* corn, potato and cotton seeds, has pointed out that most of the milkweed plants that the monarch caterpillars feed on are not near cornfields. But entomologists are not so sure. "There are a lot of field edges where monarchs occur in close proximity to corn plants," says John J. Obrycki, professor of entomology at Iowa State University. "There's potentially a real effect on monarchs. We need more data and more studies." The Cornell investigators dusted milkweed leaves with corn pollen in the laboratory to visually match the amount encountered in a field. But one of Obrycki's students, Laura C. Hansen, is preparing a paper that demonstrates that 20 percent of monarch caterpillars died after munching on *Bt* corn pollen found on leaves of potted milkweed plants placed at the edge of cornfields. A milkweed census in and near cornfields is now under way.

KENT LOEFFLER *Cornell University*

***DEADLY FEAST OF POLLEN** from genetically modified corn dusted on laboratory milkweed leaves proved fatal to nearly half of the monarch butterfly caterpillars sampled.*

Whether the monarch issue galvanizes U.S. public opinion and leads to a regulatory response remains to be seen. But the headlines did bolster Europe's already stiff opposition to bioengineered foods. The European Commission decided to suspend further authorizations for genetically engineered crops after the monarch butterfly study hit the press. Europe has yet to approve the use of seven of the genetically engineered corn products that are planted in about 7 percent of the 78 million acres of U.S. field corn. In total, the 11 *Bt* and other bioengineered corn products on the market occupy 39 percent of total U.S. acreage. At about the time of the monarch study release, the British Medical Association recommended a moratorium on the planting of genetically engineered commercial crops. Two multinational companies, Nestlé and Unilever, have decided not to buy genetically modified ingredients.

These actions worry both farmers and Wall Street. The National Corn Growers Association (NCGA) frets that genetically modified crops may bring lower prices from food processors, negating the benefits of the higher crop yields from these premium-priced seeds. "If a two-tier pricing system develops where genetically modified grain is discounted, farmers will retreat away from the technology just as fast as they've adopted it," says Scott McFarland, NCGA's director of industry relations. One large grain processor, A. E. Staley, has refused to accept any corn that has not received European approval, and other major companies are not buying the genetically modified grain at plants that produce corn products targeted for export. A two-tier market has already begun to develop for soybeans. "What we're seeing broadly is that nongenetically modified soybeans sell at a premium," says Timothy S. Ramey, a securities analyst with Deutsche Banc Alex. Brown in New York City.

Finding the contaminated grain in a storage bin is getting easier. A company called Strategic Diagnostics has begun to sell a rapid test using monoclonal antibodies to determine whether a grain crop is bioengineered. Farmers who use genetically engineered crops could face lawsuits if pollen contaminates a neighbor's plantings. One company, Terra Prima, had to recall 80,000 bags of organic corn chips because the corn was found to be contaminated with residues of genetically modified corn that had blown into organic farmers' fields. With these disputes raging, industry's diehard opposition to identifying bioengineered foods may be weakening. A federal task force has begun to consider labeling of genetically modified food products. Giving consumers a choice, it is thought, might help gain acceptance.

On Wall Street, some analysts have soured on the technology. The research department of Deutsche Banc Alex. Brown produced a report recently on genetically modified organisms entitled "GMOs Are Dead," echoing the NCGA's concern about two-tier pricing. It recommended that investors sell their stock in seed company Pioneer Hi-Bred while asking: "Are GMOs safe, good for the environment, and necessary to support the inevitable growth in the world's population? Yes, but the same arguments can be made for advancing nuclear power."

Butterflies on the front page have not gone unnoticed by industry representatives, either. When the monarch story broke, McFarland pulled an e-mail message off the corn growers association's World Wide Web site from an elementary school class in central Illinois. "Stop Killing Butterflies, You Mean Farmers" was more or less the message that appeared on opening the electronic envelope. McFarland was taken aback. "Definitely the tenor of this issue has changed," he observes. "And I do not ever want to position farmers as being butterfly killers." *—Gary Stix*

CONSUMER FRAUD

TOO GOOD TO BE TRUE

Scams purported to treat sexual dysfunction prey on the unwary

Treatments for impotence are as old as the use of herbs as medicinals. Plying men with rejuvenating elixirs, however, has experienced a renaissance with the advent of Viagra. Remedies based on largely worthless plant-based concoctions can be ordered, no questions asked, from mail-order houses and the World Wide Web. A recent Federal Trade Commission (FTC) antifraud case illustrates the perils confronted by those seeking unorthodox potions.

In May the FTC reached a settlement with several companies headed by entrepreneur David A. Brady that had marketed purported anti-impotence cures with names like Väegra, Testosterone-21, Celldenaphil-*pc* and Alprostaglandin. Brady and the companies involved—the American Urological Corporation, the National Institute for Urological Health and others—agreed to give up more than $2 million in frozen assets to satisfy an

COURTESY OF THE FTC

***BUYER BEWARE:** this useless elixir of herbs, an amino acid, a vitamin and a mineral sold via mail order does nothing to cure a man's impotence.*

$18.5-million judgment against the defendants. And Brady must post a $6-million bond before promoting any new impotence product during the next 10 years. Last year Viagra maker Pfizer obtained an order to halt marketing of Brady's Väegra because of trademark infringement. Brady then began selling the same remedy under other names, according to the FTC.

"It would take a long time to describe each and every misrepresentation Brady made about these products," said then FTC attorney Sondra L. Mills at a conference on impotence held at the National Institutes of Health. Alprostaglandin, whose name bears a resemblance to that of a legitimate anti-impotence drug on the market, contained a mix of homeopathic and Chinese herbs. Expert witnesses—including Arnold Melman, chairman of the department of urology at Albert Einstein College of Medicine, and even a homeopathic and a Chinese herbal medicine practitioner—testified that this mix of substances was ineffective. Brady's National Institute for Urological Health had claimed, nonetheless, that it reversed impotence in up to 94 percent of men.

The FTC charged that Brady's assertions about double-blind, placebo-controlled trials were fabricated—and that none of the institutions existed "except on paper." A photograph of a high-rise building in a promotional brochure purported to show the Seattle-based headquarters of the National Institute for Urological Health. But the address turned out to be nothing more than a post office box. "Postal employees testified in the case that dozens of elder-

IN YOUR FACE

Calculating Pie

British supermarket giant Tesco works hard to tickle its customers' taste buds, so it was a bit of a blow when the calls started coming—reports that people were actually throwing Tesco products instead of eating them. To its credit, management took this news on the chin—and the nose and the forehead.

"Our checkout staff noticed it first," says Tesco spokesperson Melodie Schuster. "People were buying an extraordinary number of pies. Then the customer service lines lit up with callers asking which of our pies left a better impression." These urgent concerns over the impact of dessert service on dinner guests weren't coming from transatlantic Martha Stewart devotees but from fans of another American export, *The Simpsons*. It seems the bad behavior of Bart, Homer and, particularly, Krusty the Clown is rubbing off on the Brits.

Realizing that it did not know how well their cream cakes, tarts and open pies worked as projectiles, Tesco decided to do a little ballistics research this past May. The company rented a gym near its headquarters in Cheshunt and draped it with plastic. It marked off distances in feet and had employee volunteers comment on range, coverage and, if on the receiving end, feel. In half a day of testing, they decorated the place with nine kinds of pie. "It was quite fun, actually," Schuster says.

Fun, but also a serious inquiry. "Here in the U.K., we have a law called the Food Safety Act," Schuster explains. "While we certainly are in business to encourage people to eat our pies, if our customers were going to throw them, we had to look into the possibilites of people having an accident."

The tests found some clear winners and losers. For "maximum face-filling coverage," Schuster says, you can't go wrong with the egg custard tart. The lemon meringue holds up well in flight and nicely highlights a good aim with a sticky, yellow smear. Upper-crust pie slingers will appreciate the strawberry and raspberry fruit tarts. "They're a little more expensive, but you do get two to a pack. They fit neatly in the hand, so you can be sneakier," Schuster notes. Pies that will leave egg on the thrower's face include nut pies, which could cause eye injury, and partly frozen gâteaux, which would be like flinging a snowball with a rock in it—thoroughly bad form.

Tesco's results compare with earlier work by Buster Keaton et al. The vaudevillian and slapstick movie comedian was reported to be very particular about his pies, which created good visual effects for the big screen but would have been hard to swallow in real life. Keaton had studio bakers cook two crusts until they were brittle, then stick them together with a flour-and-water glue. He found that a double crust kept the pie from crumbling in his hand. (He never used a pie plate for fear of injuring a co-star.) Filling then depended on the target's complexion. Blondes could expect chocolate or blackberries in the mix. Brunettes were stuck with lemon meringue.

Building on Keaton's model, TV comedian Soupy Sales may have achieved the record for pies thrown: 19,000 chucked at last count. He says the crust is the critical point of contact: "You have to have a pie crust that explodes into about a thousand pieces." His show, which creamed the likes of Frank Sinatra, Sammy Davis, Jr., and Shirley MacLaine, ran from 1955 to 1962.

As for further research, Tesco's pie-throwing tests have generated tangential questions. Says Schuster: "We're thinking of putting out a pamphlet about how to get pie stains out of clothes."

—*Brenda DeKoker Goodman*

DENNIS KITCHEN *Tony Stone Images*

TAKE THAT! Research confirms what pie throwers—and those on the receiving end—already knew.

BRENDA DEKOKER GOODMAN, a journalist based in Albuquerque, N.M., does not recommend chicken pot pie.

ly men came into the post office looking for the institute," Mills remarked. Nevertheless, Brady sold his wares to 150,000 customers, from a mailing list of 250,000, garnering the $18.5 million in a little more than a year, the FTC claims. He also marketed some of the products on the Web.

To help alert the public, the FTC established for a time last year a "teaser sting" site on the Web that entices prospective customers with bogus impotence treatments. After clicking on a link to find out more, the Web surfer discovers a warning from the agency that the user could be victimized by fraud. "The FTC has taken lessons from the con artists themselves, who are so effective in reaching people," Mills noted. Let the self-medicator beware. —*Gary Stix*

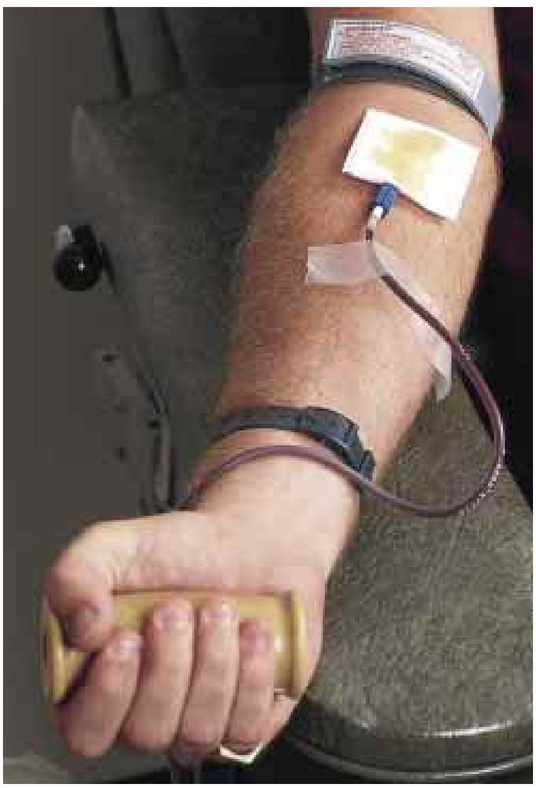
BLOOD SAFETY

VIRAL GENE SCREEN

U.S. blood banks turn to genetic testing to find HIV and hepatitis C viruses in donations

Thanks to serological tests and rigorous screening, the U.S. blood supply is safer than ever before. But that doesn't mean there isn't any bad blood in the nation: although there is only a one-in-676,000 chance that blood containing HIV will slip by standard tests, as many as 14 million units are donated every year. The liver-ravaging hepatitis C virus can elude standard tests with a frequency nearly seven times greater than that for HIV. The chances may be slim, but the public "demands zero risk for blood and plasma donations," says Edward Tabor, associate director for medical affairs at the Food and Drug Administration's Office of Blood Research and Review. To work toward that goal, blood centers around the country began evaluating a technique this past March that could cut the risks by half or more—by looking for the viral genes themselves.

Currently U.S. blood banks interview potential donors, rejecting those with even small risk factors, such as having traveled to certain countries. Technicians generally test donated blood by identifying viral antigens (distinctive proteins on the surface of a virus) or the antibodies mobilized by the body against an infection.



LARRY MULVEHILL *Photo Researchers, Inc.*

***DONATED BLOOD** in the U.S. is among the world's safest, thanks to screening and testing, but there is still a slight risk that viruses could slip by.*

An infected person could donate, however, during the window period—the time between contraction of the virus and an immune response, when the person may not even feel sick or show any symptoms. The tainted blood could then be divided into its several useful components and go on to infect recipients. For HIV, this window period is about 16 days; for the hepatitis C virus, about 70 to 80 days.

So blood collection facilities—including the major players, the American Red Cross and America's Blood Centers—began phasing in a complicated program to evaluate tests that could narrow that vital window period. They are gradually implementing nucleic-acid amplification testing, or NAT. Instead of detecting viral antigens or the body's reaction to a virus, NAT zeroes in on the genetic material of the viral particles—amplifying, or copying, them millions of times. NAT, which encompasses the familiar polymerase chain reaction and similar technologies, makes it possible to find as few as 100 viral particles per milliliter of blood. With it, HIV may be detectable 10 days after infection and hepatitis C virus within 10 to 30 days. Eventually, other viruses may be targeted for evaluation.

Of course, applying genetic testing to each donation would be impractical. "What we are dealing with is a tremendously important advance in technology," Tabor remarks, "but the real advance here" is minipooling. In this procedure, samples from donations are pooled together and tested at once. Pooling samples before testing them individually cuts the cost of NAT without markedly reducing sensitivity. NAT now adds $6 to $8 to the $75 average price tag for a unit of red blood cells, according to Jim MacPherson, executive director of America's Blood Centers.

For the past few months, the Red Cross has used master pools of 128 samples, which are made up of eight smaller primary pools of 16 samples each, explains Gary Griffin, CEO of the Red Cross's National Genome Testing Laboratory in San Diego. If a master pool tests positive, then each of the eight primary pools are tested, and so on until the infected blood sample is found. America's Blood Centers uses a simpler system, going directly from a master pool of 24 samples, each of which are tested individually if there is a reaction. (The Red Cross was planning in July to reduce its pooling size to just 16 samples.) Smaller pool sizes significantly reduce the time required to locate an infected donation, because each round of NAT takes up to eight hours.

NAT is being phased in gradually across the country as an investigational new drug (IND) through the FDA. At the end of May, Tabor estimated that more than 50 percent of all donated blood was being tested using minipools under the IND. It is unclear how long it will be before a judgment about approval is made. Whatever the outcome, the scope of this trial represents "one of the grandest scale INDs we've ever embarked on," notes Karen S. Lipton, chief executive officer of the American Association of Blood Banks. With NAT, the window period may eventually be eliminated entirely, so that no virus escapes detection and the risk is reduced to virtually zero. *—Jessa Netting*

CYBER VIEW

How to Steal Millions in Chump Change

It used to be a joke: a computer can make a mistake in a fraction of a second that would take an army of mathematicians working with pencil and paper 100 years to make. For 900,000 people whose credit cards apparently suffered fraudulent charges in a single computer-based scam, this old saw morphed into an unpleasant reality. The Federal Trade Commission (FTC) is trying to recover as much as $45 million from a handful of people who used modern technology to flood outdated security precautions. In late 1998 the group accounted for 4 percent of all the Visa chargebacks (in which a merchant's account is debited for the amount of a transaction) in the world. Victims did not have to use their cards on the Web to be hit with charges. They didn't even have to use their cards at all.

It would have taken about three years for a dishonest restaurant employee or store clerk working 24 hours a day just to fill out and submit the bogus transactions that FTC investigators ascribe to Kenneth H. Taves, his wife, Teresa, and their associates. The group, they say, set up a series of companies that processed Visa charges for adult Web sites and used the card numbers from those transactions plus others made up by a simple computer program to charge people for services that never existed. (At press time, Taves was in jail on contempt-of-court charges after disobeying an order to turn over records and to repatriate about $6 million from accounts in the Cayman Islands. His trial is scheduled for September 28.)

The essence of the scam was an updated version of the hoary computer-crime legend in which a clever programmer siphons fractional pennies from millions of bank accounts and ends up rich with no one the wiser. Here each fraudulent charge was typically $19.95, an amount unlikely to alarm a harried consumer who might not remember every last purchase on a statement. The transactions also clearly passed under the radar of Visa's fraud-detection algorithms. Although Visa and its member banks have been notably silent about the role of their security measures in the debacle, sources suggest that antifraud efforts have largely been geared to prevent smaller numbers of high-ticket thefts.

Indeed, the relatively small amount of each bill involved aggrieved customers in a financial catch-22: banks usually will go back only two months when reversing disputed charges, but $38.90 is comfortably less than the $50 limit above which U.S. financial institutions are required by law to compensate customers for fraudulent credit-card transactions. To make matters more difficult,


DAVID SUTER

Taves and his cohorts had an obvious excuse for disputed charges in the nature of the product they were selling: it was only natural, they reportedly faxed at least one bank, that people would want to disavow subscriptions to Web sites selling pornographic pictures.

Although it provided a convenient cover story, the porn connection may also have been Taves's undoing, says John G. Faughnan, a physician and software developer whose Web page is the best source of information on the scam (www.labmed.umn.edu/~john/ccfraud.html). Many of the more than 200 victims who contacted him found their jobs or their marriages in jeopardy, so they had much more incentive to track down the perpetrator than just recovering the $20 to $100 they were bilked out of. Faughnan acknowledges that his own attempts to navigate the financial bureaucracy and get a refund cost far more than the money lost.

Specific shortcomings in credit-card-processing procedures appear to have made this scam even more effective than it might otherwise have been. The tricksters apparently concentrated their charges outside the U.S., where most banks do not verify the billing address—or in some cases even the expiration date—of the card being charged. Because there was no shipping address involved, the recurring charges were generally treated like restaurant or store transactions, in which a merchant has the buyer's card in hand and a signature on a charge slip. All the thieves needed was a valid number—not even a name.

So what does this mean for the little slabs of plastic that make our lives so much more convenient? Although the wide availability of cheap processing power has made the system vulnerable to unscrupulous merchants for a decade or more, it may be the advent of a huge array of intangible products for sale, across an essentially untraceable network, that opens the floodgates of microfraud. A 20-seat restaurant or a tiny boutique that claimed $4 million a month in business would be an obvious target for investigation. A digital storefront, in contrast, could house a dozen fast PCs delivering millions of dollars' worth of products from a locked room the size of a journalist's office, or it could conceal a ring of high-tech bandits stealing just a little money from a lot of people. Telling the difference between the two would require more scrutiny of both digital buyers and sellers, perhaps to the point of making e-commerce less ravishingly attractive than it has lately become.

Furthermore, as long as a consumer's cost in time and money for reversing a fraudulent transaction exceeds the amount to be recovered, no one in the chain of electronic commerce has a significant incentive to adopt measures (such as the long-stalled Secure Electronic Transaction standard or various forms of digital cash) that would make such scams less likely. In fact, Faughnan points out, many sellers of digital content can profit from opening their Web sites to users of false credit cards—even in the unlikely event of a chargeback, the marginal cost of the extra bits that were delivered is negligible.

Ultimately, technologists will undoubtedly introduce security countermeasures—perhaps in the form of the cryptography software that governments still seem bent on keeping away from whoever hasn't gotten around to downloading it yet. In the meantime, the ability of individual victims (on the Internet, at least) to alert thousands or millions of their peers seems to be the only game in town. —*Paul Wallich*

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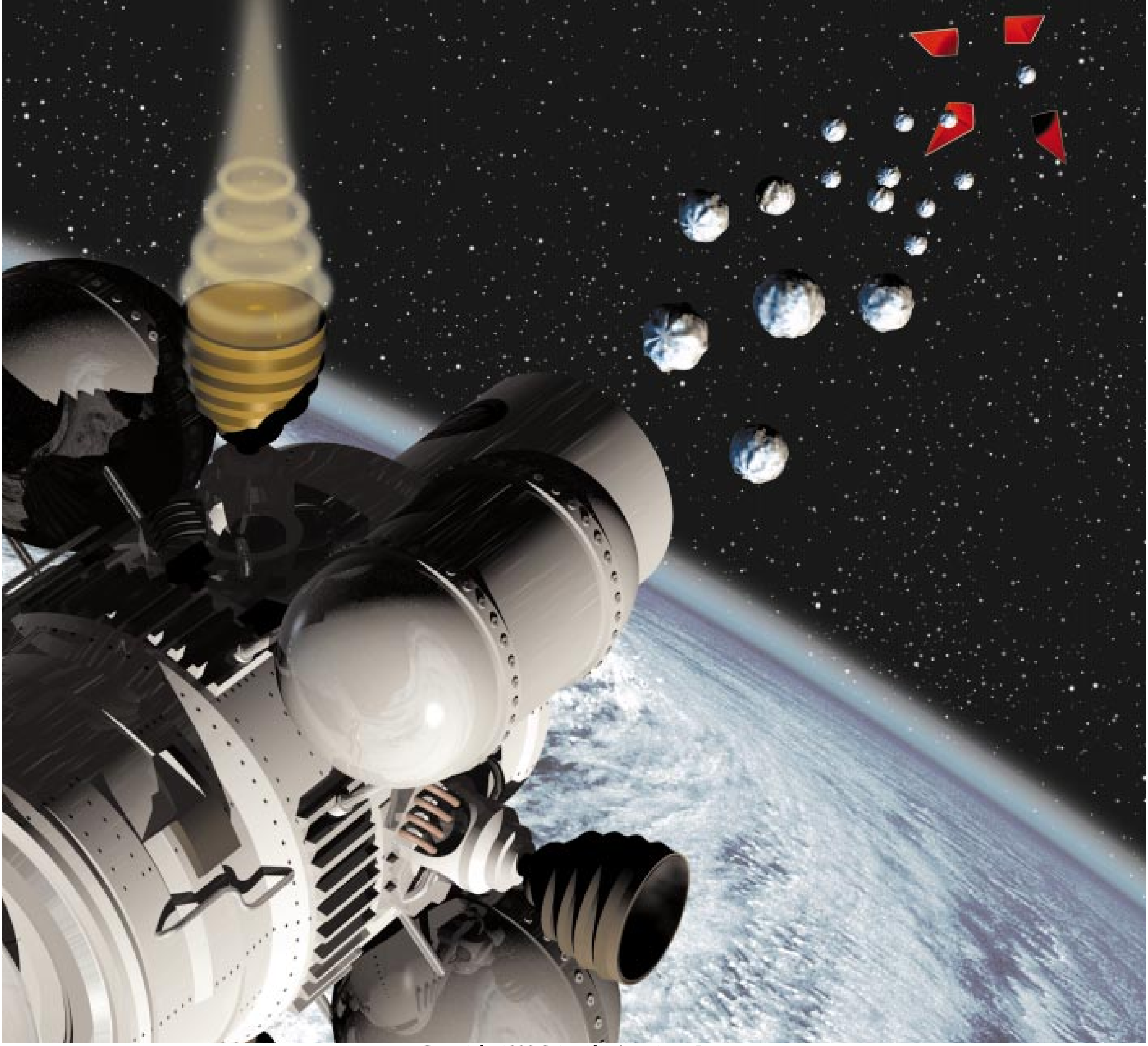
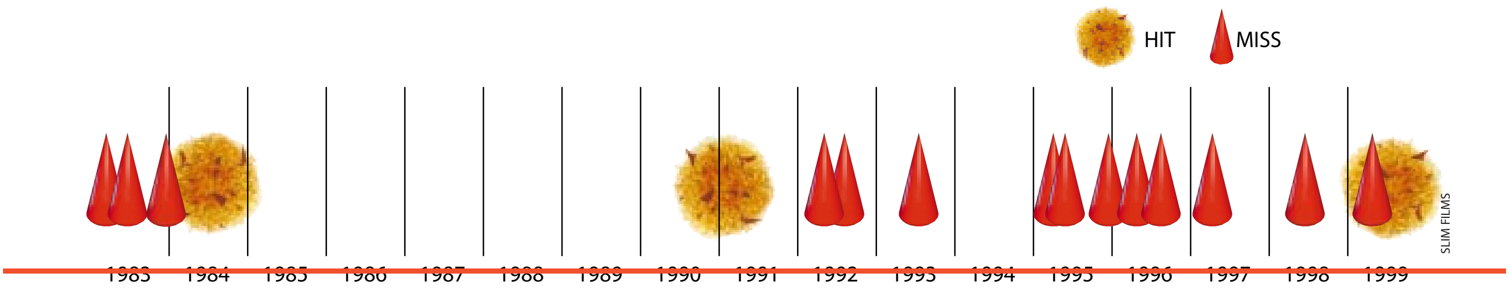
Why National Missile Defense WON'T WORK

The current plan for defending the U.S. against a ballistic-missile attack faces many of the problems that plagued a similar plan three decades ago

by George N. Lewis, Theodore A. Postol and John Pike





INTERCEPT FAILURES have plagued high-altitude, hit-to-kill technology since the first test in 1983. With less than a year until officials decide whether the national defense system is ready, only three of the first 17 intercept tests have hit their targets.

In 1968, with the threat of intercontinental ballistic-missile attacks driving the U.S. toward the development of a national missile defense system, a *Scientific American* article written by physicists Richard L. Garwin and Hans A. Bethe described how China or the Soviet Union could easily elude the "light" U.S. missile shield then under development [see "Anti-Ballistic-Missile Systems," March 1968]. This argument—that any national defense system would be technologically ineffective—was one reason the U.S. and the Soviet Union signed the Anti-Ballistic Missile (ABM) Treaty in 1972. The fear that such a system would provoke the Soviet Union and escalate the arms race also contributed to the U.S. decision to sign the treaty, considered a landmark of arms control. To this day, the treaty prohibits the U.S. and Russia from deploying nationwide defense systems.

More than 30 years later the U.S. remains without a national missile defense system. The cold war threat of massive Soviet missile strikes has abated, but ballistic-missile technology is rapidly proliferating. U.S. concerns now center on the possibility that a rogue developing state could eventually acquire the ability to threaten or strike the U.S. with long-range missiles. Accidental Russian launches and China's small but potent missile force are considered secondary threats.

Missile defense technology has also advanced. More powerful computers and improved radars and other sensors appear to have created an alternative to the nuclear-tipped interceptors envisioned in the 1960s. These advances offer the possibility that the U.S. could use more politically acceptable "hit-to-kill" missiles designed to destroy their targets by direct high-speed collisions.

Advocates of national missile defenses argue that this combination of missile threats and improved technology makes possible the deployment of an effective "homeland" missile shield, and their efforts to bring this about are bearing fruit. Since taking over the leadership of the U.S. Congress in 1994, Republican lawmakers have relentlessly pushed the White House to commit to deployment, and the administration in 1996 announced it would begin to develop a system capable of covering the entire U.S., although it did not name a deployment date.

Missile Threats

This fall the Pentagon plans to employ the key components of its national defense in the first test of the system's ability to intercept a long-range missile outside the earth's atmosphere. In June 2000, after only a handful of additional tests, the administration plans to decide whether the technology is ready; if so, a national defense system could be in place by 2003, although the administration says 2005 is a more realistic date.

Whatever the outcome of the June 2000 "deployment readiness review," the U.S. seems more likely than ever to commit to a national missile defense within the next few years. In 1998 then undersecretary of defense for acquisition and technology Jacques Gansler told Congress that the question is no longer whether the U.S. will deploy a national defense, but when. And since then, deployment has become more likely than ever: in January the Pentagon announced the addition of $6.6 billion to future defense budgets for building a national defense, and in March the administration withdrew its opposition to Senate legislation mandating deployment "as soon as technologically feasible." The bill soon passed by a wide margin.

Like the "Safeguard" system Garwin and Bethe analyzed in 1968, however, the national missile defense now under consideration could be readily defeated by simple offensive countermeasures. In fact, a system based on hit-to-kill interceptors is more vulnerable to countermeasures than one involving nuclear missiles. Moreover, as was feared more than 30 years ago, its deployment is likely to provoke other countries to take actions that lessen U.S. security.

Many more nations possess ballistic missiles today than in 1968. Most of these, however, are known as "theater" ballistic missiles because of their shorter range, and no theater missiles are positioned to strike the U.S. What is more, most of the countries possessing these missiles are not hostile to the U.S. Short-range missiles can be used primarily against allies' cities and U.S. forces overseas, and the U.S. is developing several theater defense systems to defeat them [*see box on next page*].

Theater ballistic missiles are a far cry from those that could strike the U.S. The latter are known as intercontinental ballistic missiles (ICBMs), and they have always carried nuclear weapons. The U.S. fears that they may one day be armed with other "weapons of mass destruction"—munitions containing deadly chemicals or biological agents. The U.S. national missile defense system is being developed to intercept such ICBMs.

Russia possesses the largest number of such missiles, but advocates of a limited national defense argue that a large Russian attack on the U.S. is highly improbable. The U.S. system is therefore being designed to combat only a handful of ICBMs at a time.

SLIM FILMS

HIT-TO-KILL INTERCEPTORS are the hallmark of the national missile defense system currently being developed to protect U.S. soil from intercontinental ballistic missiles. The duel between the warhead and the maneuverable kill vehicle (*foreground*), which is released from the tip of the interceptor missile, would occur high above the earth's atmosphere. The kill vehicle's success would rely on hitting the target dead-on, and critics argue that countermeasures, such as hiding the warhead inside one of a cluster of metal-coated balloons, would likely confuse the vehicle's homing sensors, making a direct hit nearly impossible.

Dangers Close at Hand

by Daniel G. Dupont

Debates over missile defenses usually center on national, or "homeland," systems designed to protect the U.S. from intercontinental ballistic missiles. The U.S. is also developing a handful of "theater" systems intended to safeguard troops and assets in other countries from missiles with shorter ranges of 30 to 3,000 kilometers (19 to 1,864 miles). Theater defense is generally considered easier to achieve than national defense because it requires protecting a smaller area from slower missiles. But even shorter-range systems are vulnerable to countermeasures similar to those that make homeland defense tricky. And the U.S. test record of theater defense systems shows that hitting one missile with another missile is far from easy.

The most prominent theater system is the army's Patriot, originally designed to shoot down aircraft and first used in the Persian Gulf War to battle Iraqi Scud missiles. The first-generation Patriot—the only theater defense system ever called on in combat—was intended to destroy or deflect incoming missiles by exploding an interceptor nearby.

COURTESY OF BALLISTIC MISSILE DEFENSE ORGANIZATION (*top*); COURTESY OF THEODORE A. POSTOL (*bottom*)

UNEXPECTED MANEUVERS and breakups of Iraqi Scud missiles in the Persian Gulf War (*above*) thwarted the U.S. Patriot missiles' ability to destroy them. Before the war, Patriot (*top*) was successful in all tests against ballistic-missile targets, which flew on stable, smooth trajectories.

The army claims a 60 percent success rate, but critics counter that the Patriot failed in all its Scud engagements even though the enemy warheads employed no obvious countermeasures. The Patriot system is now being upgraded with a new missile that uses the same "hit-to-kill" concept as the national defense system.

The army's Theater High Altitude Area Defense system, or THAAD, is projected to be the most versatile and sophisticated hit-to-kill system in use. Although it remains less developed than the Patriot, THAAD is intended to intercept the longest-range theater ballistic missiles, both inside and outside the atmosphere. Yet in its short history, THAAD has shown more than any other system the difficulties of developing effective missile defenses: in its first seven intercept tests, which started in 1995, THAAD hit only a single target missile.

Similar in design to THAAD is the navy's Theater Wide system. The navy plans to deploy ships with long-range missile interceptors near countries in which ballistic missiles threaten U.S. troops or allies' cities. The navy is also working on a shorter-range ship-based system known as Area Defense. Less developed programs include a theater defense system that will move with troops on the battlefield.

Beyond the controversial hit-to-kill interceptor technology are laser weapons. The air force's current missile defense plans include the Airborne Laser, which is mounted on a Boeing 747 and designed to intercept ballistic missiles early in flight. The air force is also developing a space-based laser that could one day intercept missiles as their booster rockets propel them into space.

DANIEL G. DUPONT edits the independent newsletter Inside the Pentagon *in Washington, D.C.*

The most commonly cited justification for national missile defense is that ICBMs might be built or obtained by a rogue state, which in the vernacular of the Defense Department could mean Iran, Iraq or North Korea. In July 1998 a commission of experts led by former secretary of defense Donald Rumsfeld concluded that North Korea or Iran could, with little warning, develop an ICBM within five years of deciding to do so. This finding gave a significant boost to national missile defense proponents and was a factor in the administration's decision to add billions of dollars to the Pentagon's budget for the first phases of deployment. Other factors included North Korea's August 1998 launch of a three-stage missile known as the Taepo-dong 1 and reports that a longer-range Taepo-dong 2 missile is being developed. If these reports prove correct, North Korea might one day be able to use the Taepo-dong 2 to strike Alaska or might be able to modify it to deliver small payloads to other parts of the U.S. [*see map on opposite page*].

A secondary justification for a limited national defense is the possibility of an accidental or unauthorized Russian missile launch, which might involve only one or a few warheads. Because of the way in which Russia's nuclear missile forces are organized, however, a break in Russia's chain of command would more likely involve all the warheads of a ballistic missile submarine—up to 200—or a large part of Russia's ICBM force. And proponents say that China, which possesses no more than two dozen ICBMs capable of reaching the U.S., also provides a justification for a limited national defense.

Designing a Defense

The particulars of the U.S. national missile defense system are not yet fully decided, but most key components are well along in development, and the general details of how it would operate are well known. An ICBM fired at the U.S. would be detected first by infrared early-warning satellites and then by one or more of the large phased-array early-warning radars, which are positioned in Massachusetts, California, Alaska, Britain and Greenland. These radars operate at relatively low frequencies, and although their range and angle resolution are poor, they can provide trajectory data on a small number of well-separated ballistic targets.

Data on the missile's path from satellites and early-warning radars would be used to cue the primary sensor of the national defense system, the ground-based radar, enabling it to increase its detection range by concentrating its search for the missile on a smaller area. This X-band phased-array radar is designed to provide long-range detection and tracking of ballistic-missile targets. A prototype is already in use at the U.S. Army's Kwajalein Atoll missile range in the Pacific.

The radar and sensor data would then be passed on to a battle management center, which would determine possible intercept points and issue launch and guidance commands to a ground-based interceptor missile. Each interceptor consists of a rocket booster and what is known as an exoatmospheric kill vehicle, which does the intercepting in space once it separates from the booster stack.

To maximize the defended area and the number of opportunities to strike the incoming missile, the interceptor would have to be launched soon after an attack was detected. Extremely fast, with a burnout speed in excess of seven kilometers per second (about four miles per second), the interceptor would receive guidance updates during flight based on data from various sensors. To increase the probability of destroying a target, several interceptors could be fired at a single missile. Current plans call for up to 100 interceptors at a single site.

The kill vehicle is designed to intercept incoming warheads well above the earth's atmosphere. (Enemy missiles are launched from too far away for this system to intercept them earlier.) Using its own infrared seeker and data from the ground-based radar and other sensors, the kill vehicle would attempt to discriminate between the attacking warhead and any missile debris or decoys employed to confuse it. It would then use thrusters to maneuver into a high-speed collision with the warhead. Ideally, an intercept would totally destroy both kill vehicle and target.

Several new or improved sensors would also play key roles in an expanded national defense. Existing early-warning radars will be enhanced so they can better track targets and guide interceptors. New X-band phased-array radars, similar to the main ground-based radar, will be installed, some of them alongside the early-warning radars. Finally, a space-based missile-tracking system known as SBIRS-Low (space-based infrared system–low earth orbit) is in the works. This satellite system, formerly called Brilliant Eyes, is designed to track missiles and their warheads from early in flight using short-, medium- and long-wavelength infrared sensors as well as visible-light sensors.

According to a recent U.S. General Accounting Office estimate, the deployment and operation of a limited national defense system would cost between $18 billion and $28 billion. But costs are likely to exceed these estimates, and con- that the program's schedule is optimistic when compared with those of past major weapon systems. The administration's planned defensive system is also designed to be expandable; once in place it is likely to be augmented with more interceptors or launch sites, which would increase the system's capability and cost.

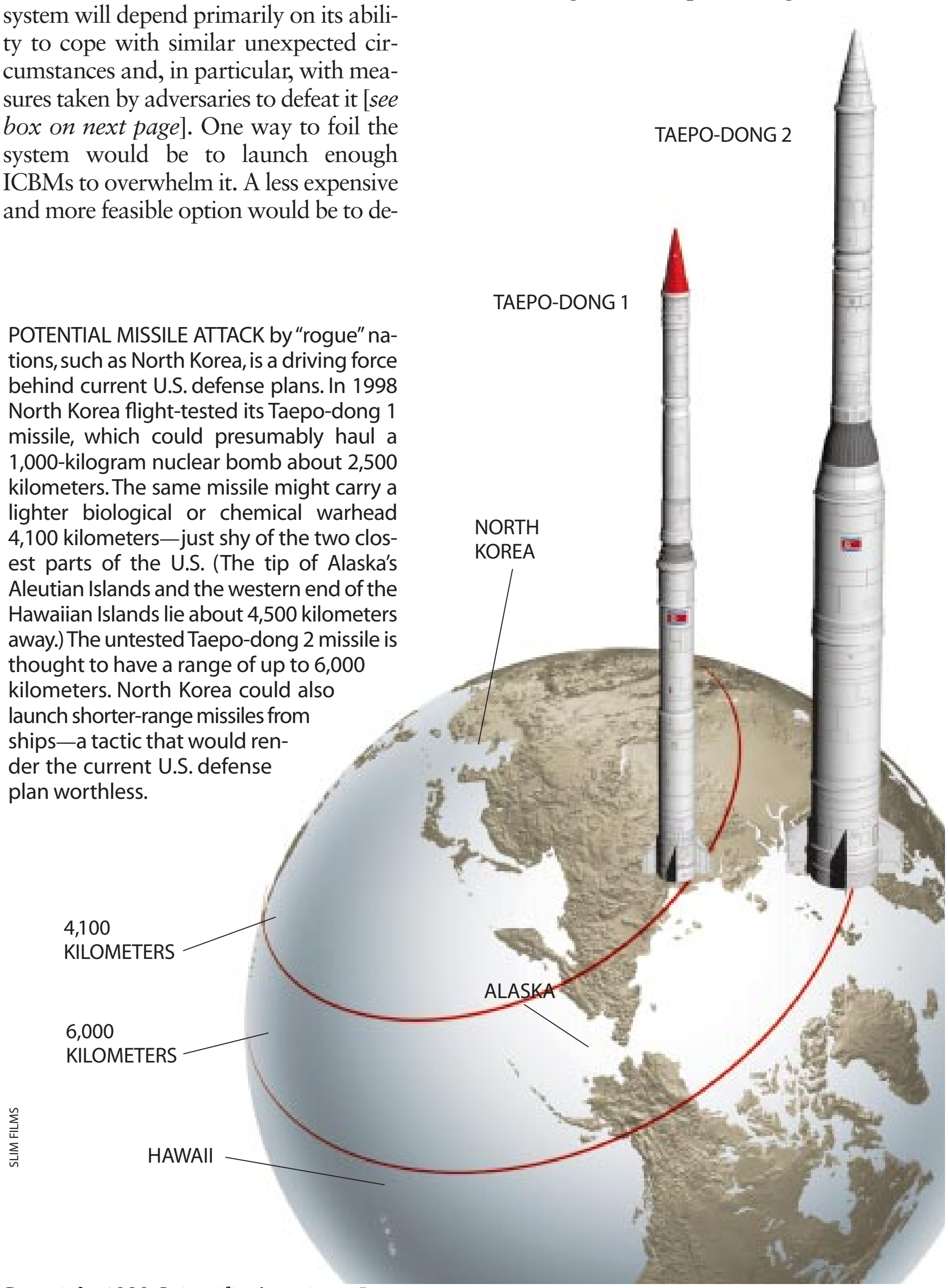
The U.S. success rate in tests of high-altitude hit-to-kill systems is dismal, with only three successes in the first 17 tries. This test record illustrates the challenge of hit-to-kill intercepts and suggests that the technology is not yet ready for use. Yet even if all the tests had been successful, they would not have established that the defense would work in the real world. Why? Consider the Patriot missile system, the only missile defense weapon ever used in combat. Patriot, a theater defense system, had a perfect test record before the Persian Gulf War in 1991, with 17 successes in 17 intercept tests. Yet contrary to most media reports, it failed in most or all 44 of its attempts to destroy Iraqi Scud missiles, which behaved differently from test-range targets.

Beating the System

Assuming its basic components can be made to work, the real-world effectiveness of the national missile defense system will depend primarily on its ability to cope with similar unexpected circumstances and, in particular, with measures taken by adversaries to defeat it [*see box on next page*]. One way to foil the system would be to launch enough ICBMs to overwhelm it. A less expensive and more feasible option would be to devote some of each missile's payload to lightweight countermeasures designed to confound defensive missile systems.

From the beginning, the U.S. has developed countermeasures that can be used with its strategic missiles, and any country capable of producing or obtaining both ICBMs and weapons of mass destruction would be able to produce or obtain effective countermeasures. Thus, if the U.S. deploys a national defense system, it must anticipate that any ICBM launched against the U.S. will be equipped with countermeasures.

In space, where the U.S. system is designed to intercept incoming missiles, many types of countermeasures could be used. Because objects travel on identical trajectories in space regardless of their weight, for example, an ICBM could be designed to disperse a light-



POTENTIAL MISSILE ATTACK by "rogue" nations, such as North Korea, is a driving force behind current U.S. defense plans. In 1998 North Korea flight-tested its Taepo-dong 1 missile, which could presumably haul a 1,000-kilogram nuclear bomb about 2,500 kilometers. The same missile might carry a lighter biological or chemical warhead 4,100 kilometers—just shy of the two closest parts of the U.S. (The tip of Alaska's Aleutian Islands and the western end of the Hawaiian Islands lie about 4,500 kilometers away.) The untested Taepo-dong 2 missile is thought to have a range of up to 6,000 kilometers. North Korea could also launch shorter-range missiles from ships—a tactic that would render the current U.S. defense plan worthless.

Potential Missile Defense Countermeasures

Overwhelm the defense

- Build more missiles than the defense can intercept
- Put multiple nuclear warheads on each missile
- Deploy chemical or biological agents in many small submunitions

Hinder warhead identification

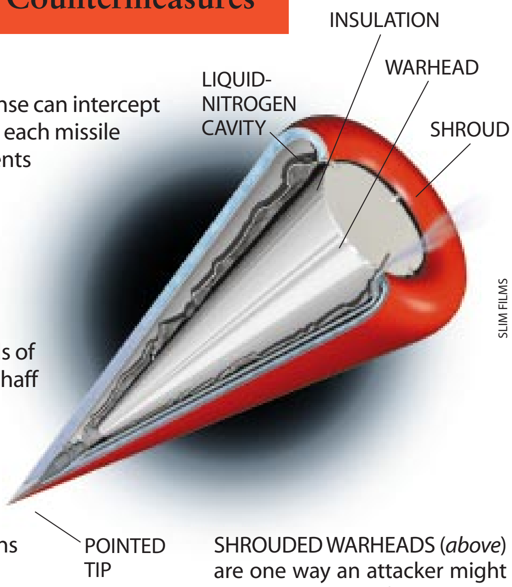
- Deploy replica or traffic decoys
- Hide warhead in one of many metal-coated balloons
- Surround warhead with thousands of tiny radar-reflecting wires called chaff
- Disguise warhead among debris from exploded booster rockets

Hinder warhead detection

- Jam radars
- Lead attack with nuclear explosions to blind infrared detectors
- Encase warhead in cooled shroud so it is invisible to infrared detectors
- Shape the warhead or the shroud so it reflects less radar energy
- Cover warhead with radar absorbing materials
- Attack missile-tracking satellites and coastal radars

Prevent the interceptor from hitting the warhead

- Hide warhead behind screens or large balloons
- Launch low-flying cruise missiles and shorter-range ballistic missiles from ships
- Add thrusters to warhead to enable maneuvers



SHROUDED WARHEADS (*above*) are one way an attacker might "blind" a missile defense system. Interceptors use an array of infrared sensors to target room-temperature warheads (300 kelvins; 80 degrees Fahrenheit) as far as a few hundred kilometers away. A warhead shrouded in cold liquid nitrogen (77 kelvins) would radiate an infrared signal less than one millionth as intense, making it invisible until it came within a few hundred meters of the interceptor.

weight decoy warhead alongside the real thing, and a U.S. kill vehicle would have to decide which to pursue. Once decoy and warhead hit the atmosphere, of course, the lighter of the two would travel more slowly, and sensors could discriminate between them, but by then it would be too late for an intercept.

Three types of simple countermeasures are especially worthy of note:

Submunitions. An attacker intent on reaching the U.S. with chemical or biological weapons could pack an ICBM with dozens or even hundreds of small submunitions containing deadly gases or biological agents. Each submunition would be designed to withstand reentry into the atmosphere, and combined they would thwart a U.S. defense simply by overwhelming it—there would be too many targets to intercept. This method is also more effective for dispersing chemical or biological agents than packing them in a single warhead.

Decoys. An attacking missile could be made to release dozens of lightweight decoys to overwhelm a U.S. defense. Replica decoys, which closely resemble actual warheads, could make discrimination by U.S. radars difficult if not impossible. Far easier and more effective, however, are antisimulation methods—making warheads look like decoys. Warheads wrapped in metal-coated Mylar balloons, for example, could be launched along with a large number of empty balloons. The thin metallic layer covering each balloon would reflect radar beams, preventing detection of the warheads, and each balloon could be equipped with a small heater to prevent discrimination by infrared sensors.

Alternatively, rather than making each balloon identical, the attacker could use different sizes and shapes and equip them with heaters of varying strengths. The U.S. defensive system would then face the daunting task of deciding which is the real thing among a large number of different targets—none of which would look like a warhead.

Cooled shrouds. An ICBM warhead with a shroud cooled by liquid nitrogen would be effectively invisible to an infrared homing interceptor. Such a shroud could be made of aluminum alloy and thermally isolated from the warhead by a multilayer insulator [*see illustration on this page*]. A shroud weighing 15 to 20 kilograms (33 to 44 pounds) would require a roughly equal weight of coolant to reach liquid-nitrogen temperature and about 300 grams of coolant per minute to maintain this temperature. The total weight of the shroud and coolant would be 40 to 50 kilograms, a small fraction of that of a 1,000-kilogram first-generation nuclear warhead. Assuming some care was taken in shaping and orienting the warhead to avoid reflecting light back to the interceptor, such a shroud would make the warhead invisible to the infrared sensor guiding the interceptor.

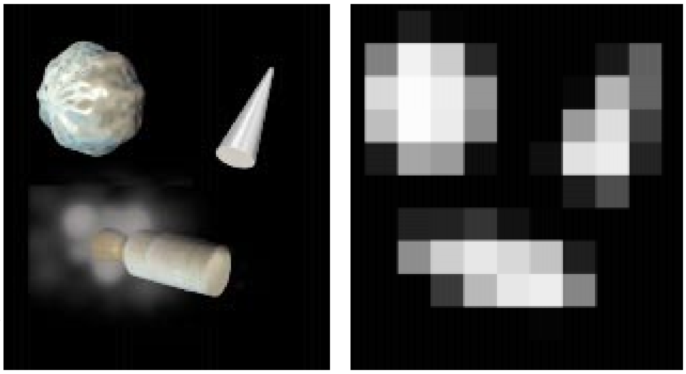
Any of these countermeasures could devastate a U.S. defense, and many more possibilities exist: radar jammers or other electronic countermeasures, warhead maneuvers, chaff or the use of shaping and radar-absorbing materials to reduce the visibility of the warhead to the defense's radars. Such countermeasures could be used singly or in many combinations.

Because of the open nature of the U.S. political system and the ongoing debate over national defenses, any adversary will know the general properties of a national missile defense system. Although only one effective countermeasure would be needed to defeat a U.S. defense, that defense must be able to defeat every plausible combination of countermeasures. Moreover, if it is to be effective in countering weapons of mass destruction, the U.S. system must work the first time it is used. The proposed system does not appear even close to capable of meeting these goals.

Arms-Control Concerns

Technology concerns aside, setting up a limited U.S. national missile defense system would give Russia and China something new to think about. The administration readily acknowledges the possibility of adding more interceptors and sites. And although the U.S. says the national missile defense system is needed only for accidental launches or rogue-state attacks, it would feature much of the infrastructure necessary for a more robust defense. In particular, once SBIRS-Low or the forward-based X-band radars are deployed, sensors that could support an expansion would be in place. Because of the time it takes to develop them, sensors are key to the rapid building or expansion of strategic defense systems, which is precisely why the ABM Treaty so sharply limits them.

Moreover, the U.S. is also currently developing two advanced, high-altitude theater missile defense systems whose interceptors are likely to have at least limited strategic capabilities if guided by sensors like SBIRS-Low. In short order, the U.S. could link these interceptors to the national missile defense system and have at its disposal 1,000 or more interceptors. Many Republican lawmakers, in fact, are campaigning to upgrade the navy's ship-based theater defense system and make it part of a homeland defense system; offensive force planners in Russia or China would have to take this possibility into account.



SLIM FILMS; SOURCE: THEODORE A. POSTOL

LIMITED RESOLUTION of the kill vehicle's homing sensors could make choosing the proper target difficult. A warhead, booster rocket and heated balloon decoy tumbling through space (*left*) could appear nearly indistinguishable to the kill vehicle about one second before impact (*right*).

How are Russia and China likely to respond to a U.S. decision to establish a national missile defense? Although technically informed Russians may understand that effective countermeasures are available, Russian political leaders may not. And the idea that the U.S. would spend many billions of dollars to set up a defense that can be easily countered may not strike Russian leaders as credible. In fact, Russian policymakers have said they oppose both a U.S. national defense and the suggestion that the ABM Treaty should be modified to permit such a system.

Should the U.S. move ahead with its plans, Russia might refuse to make negotiated reductions to its nuclear forces. Russia has linked its implementation of the START I and START II nuclear-reduction treaties to continued U.S. compliance with the ABM Treaty. Economic difficulties make it unlikely that the country will keep more than 2,000 intercontinental warheads in place anyway, but a U.S. national defense system may complicate efforts to reduce nuclear stockpiles further. In addition, Russia might keep more of its nuclear forces ready for rapid launch to increase the number that would survive an attack and could retaliate. This strategy, however, would also increase the risk of inadvertent launches against the U.S.—one of the key reasons behind the push for a national defense.

China's response to a U.S. national defense may also be problematic. To date, China has been content to maintain a very small deterrent force of ICBMs capable of reaching the U.S. China, however, could view even a very limited or ineffective U.S. defense system as a threat to its small ICBM force, so the country might feel motivated to improve its long-range missile capabilities. And any expansion of China's ICBM force would increase the threat to U.S. security.

So long as Russia and China seek to maintain relationships with the U.S. based on the concept of nuclear deterrence, a U.S. national missile defense system most likely will impede efforts to reduce nuclear forces. A U.S. deployment could also hinder U.S.-Russian cooperation on efforts to reduce the dangers of accidental launches—removing missiles from alert status and warheads from launchers, cooperation on early-warning and installing destruct-after-launch devices. Deployment will also make more difficult U.S. attempts to secure Russian and Chinese cooperation on other vital issues, such as limiting the transfer of weapons materials and technology to other countries and permitting enhanced controls on Russian fissile material.

Arms-control concerns, technological doubts, enormous price tags—these and other problems have dogged U.S. attempts to establish nationwide defenses for more than three decades. And today as much as ever, the problem of simple but effective countermeasures looms as the most daunting challenge. As Garwin and Bethe pointed out in 1968, a country that takes the time and risk to develop a costly capability to strike the U.S. with ICBMs armed with weapons of mass destruction cannot be expected to sit by and watch this capability be nullified by a national defense system if there are steps it can easily take to defeat it.

Although proponents continue to argue that the possibility of even one missile striking the U.S. is reason enough to push for a national missile defense system, a limited system with major technological shortcomings would do little to increase national security. In fact, it would have the opposite effect. Only a national defense that can reliably counter a real threat to U.S. security should be pursued: the system the U.S. is preparing to put in place will do neither.

The Authors

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Further Reading

FUTURE CHALLENGES TO BALLISTIC MISSILE DEFENSES. George N. Lewis and Theodore A. Postol in *IEEE Spectrum,* Vol. 34, No. 9, pages 60–68; September 1997.

More information is available on the World Wide Web:

The Ballistic Missile Defense Organization: www.acq.osd.mil/bmdo/bmdolink/html

The Carnegie Endowment for International Peace Non-Proliferation Project: www.ceip.org/programs/npp/missiledefense.htm

The Coalition to Reduce Nuclear Dangers: clw.org/coalition/libbmd.htm

Union of Concerned Scientists: www.ucsusa.org/arms

Federation of American Scientists: www.fas.org/spp/starwars

The Lurking Perils of *Pfiesteria*

This minute creature has been implicated in dramatic fish kills and has hurt people. But its most publicized actions may not be the most damaging. More subtle effects are raising new concerns

by JoAnn M. Burkholder

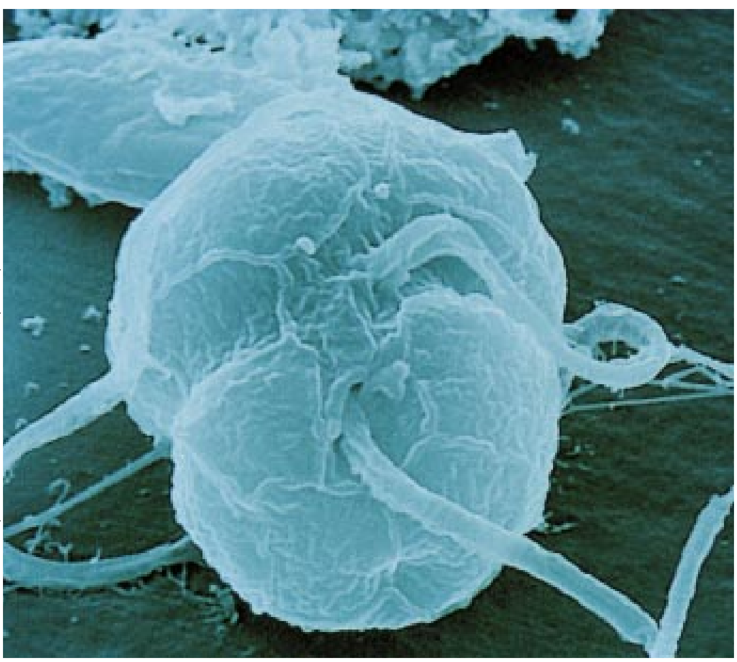
On a hot, humid October afternoon in 1995, I stood in a gently rocking boat, watching hundreds of thousands of bloody, dying fish break the mirrorlike surface of North Carolina's Neuse Estuary, where the Neuse River mixes with salty water from the Atlantic Ocean. Rising up out of the river, writhing, the fish gasped for air, then became still, floating on their sides. They were mostly Atlantic menhaden, small fish that serve as food for many larger species valued by commercial fishermen. An occasional flounder, croaker or eel also bobbed on the surface. Seagulls lined the shores of the nearly eight square miles of kill zone; a feast was in the making.

With my team from North Carolina State University (N.C.S.U.), I was collecting water samples from the area to try to determine the cause of the deaths. The bloody sores on the fish and their erratic behavior signaled a possible toxic outbreak of *Pfiesteria piscicida,* a single-celled microorganism that we had first seen in 1989 and had later linked to fish kills in several major estuaries. By the time this kill was over, 15 million silvery carcasses would carpet the water.

We quickly completed our sampling and pulled anchor, knowing it would be unwise to linger if *P. piscicida* was the culprit (as our test results later indicated was the case). People who have had contact with this creature in its toxic state have suffered from a range of symptoms, among them nausea, respiratory problems and memory loss so severe that it sometimes has been mistaken for Alzheimer's disease.

The scene on the river was all too familiar. In 1991 a billion fish died in the same way in this estuary. Since then, *P. piscicida,* occasionally with a closely related but unnamed toxic species, has been implicated almost yearly in massive fish kills in the estuaries of North Carolina (where it typically wipes out hundreds of thousands to millions of fish in a year) and in several smaller kills involving thousands of fish in Maryland waters of Chesapeake Bay.

These two species are the first members of the "toxic *Pfiesteria* complex," referred to hereafter as simply *Pfiesteria*. They (or still other toxic species that look the same but have not yet been identified definitively) have now been found as well in coastal waterways extending from Delaware to the Gulf Coast of Alabama, although they



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have not been linked to fish deaths outside North Carolina and Maryland.

Over the past 10 years, my colleagues and I have learned a great deal about *Pfiesteria*'s life cycle and about the reasons for its proliferation and toxic outbreaks. We have also found it to be an astonishing creature, displaying properties never before seen in dinoflagellates—the larger group of microorganisms to which it belongs. Dinoflagellates, encompassing thousands of species, gain their name from the whiplike appendages (flagella) that they use for swimming in certain of their life stages.

Other unexpected findings have prompted us to look beyond the floating dead fish to *Pfiesteria*'s additional untoward actions. Disturbingly, we have seen that aside from killing many fish at once, *Pfiesteria* can impair the health of finfish and shellfish in more subtle ways, such as by undermining their ability to reproduce and resist disease. These less obvious effects could potentially deplete fish populations more permanently than acute kills do.

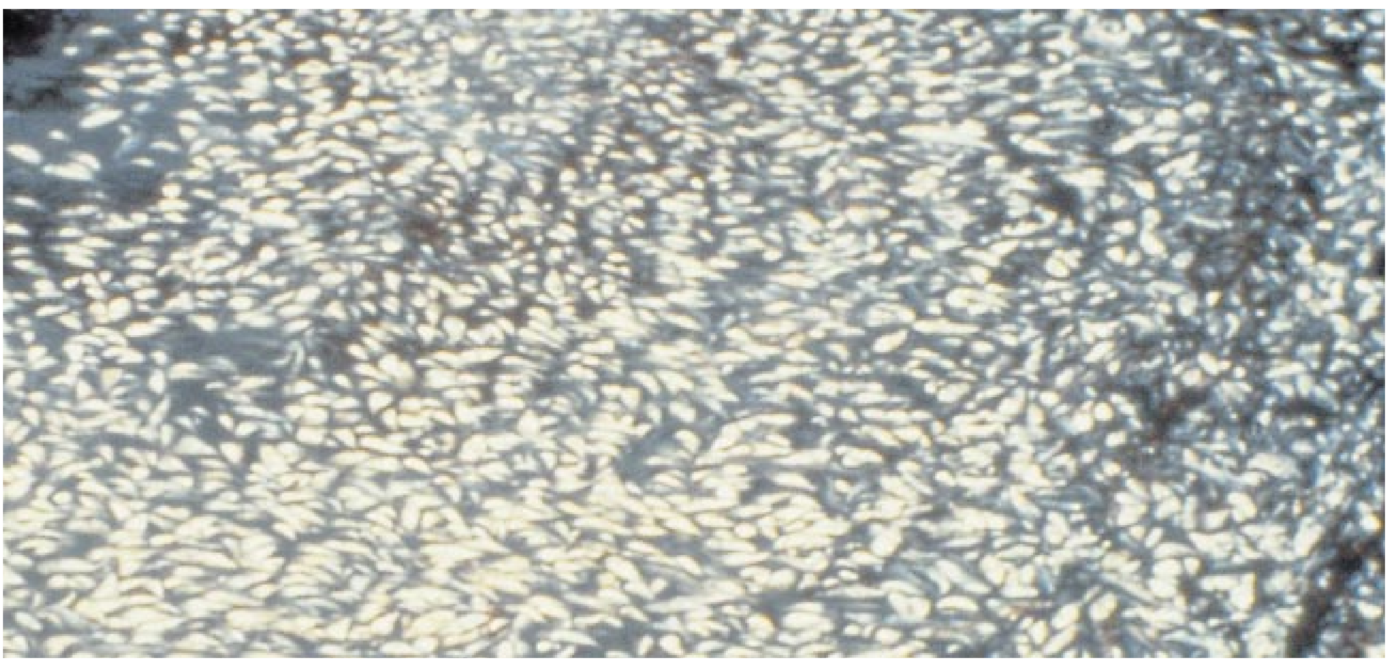
Pfiesteria is not alone in its quiet treachery. Work by many investigators has also turned up insidious activities of other "harmful algae." As the term implies, this eclectic category encompasses certain true algae—primitive plants that make chlorophyll and carry out photosynthesis to make their own food. But it also includes various (usually unicellular) creatures, such as *Pfiesteria,* that look like algae but are not plants at all. The members of this ragbag group can hurt fish when they bloom, or proliferate—doing damage by producing dangerous levels of toxins or by other means, such as by growing so extensively that they rob the water of oxygen and cause fish to suffocate.

Various harmful algae are infamous for causing huge fish kills and for acutely poisoning animals or people who ingest toxin-laden seafood or water. Indeed, some of *Pfiesteria*'s dinoflagellate cousins account for the extraordinary red tides that have discolored and poisoned coastal waters worldwide for thousands of years. Yet the less obvious effects of harmful algae also need to be clarified and addressed if other serious illnesses and death in fish—and possibly in humans and other organisms—are to be avoided.

Pfiesteria was first linked to the death of fish in 1988, when tank after tank of fish in brackish water at N.C.S.U.'s College of Veterinary Medicine began dying mysteriously. The veterinarians noticed a swimming microorganism in the water and deduced through microscopy that it was a dinoflagellate. They subsequently noted that it became abundant in the aquarium cultures just before the fish died and seemed to disappear soon after the fish perished. But it reappeared if live fish were added to the tanks.

Because fish from around the world are studied at this laboratory, no one

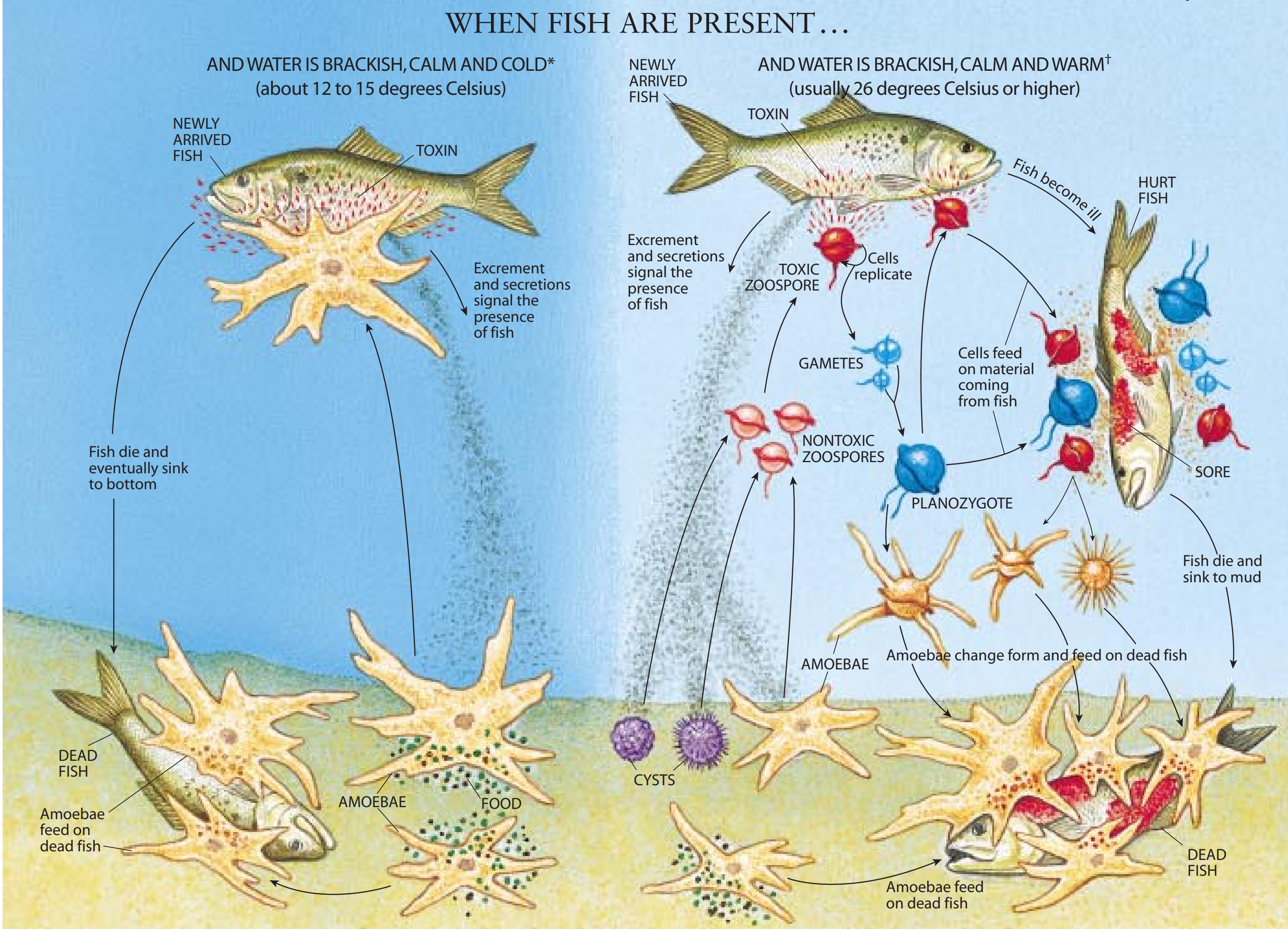
TOXIC *PFIESTERIA PISCICIDA* (*micrograph on opposite page*), sometimes along with a close, unnamed relative, has been implicated in fish kills in estuaries of North Carolina and Maryland (*larger map*). But these species, forming the "toxic *Pfiesteria* complex," range much farther. Members of the complex, or very similar but not yet identified toxic microorganisms, have been found from Delaware to Alabama's Gulf Coast (*smaller map*). The carnage below occurred in North Carolina's Pamlico Estuary in 1991 and was the first kill linked to *Pfiesteria.*



NORTH CAROLINA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES

The Extraordinary Life

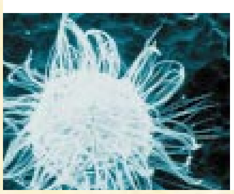
WHEN FISH ARE PRESENT…



*Findings for cold water are based on aquaculture tests.

†This is the typical condition during fish kills in nature.

LOBOSE AMOEBA

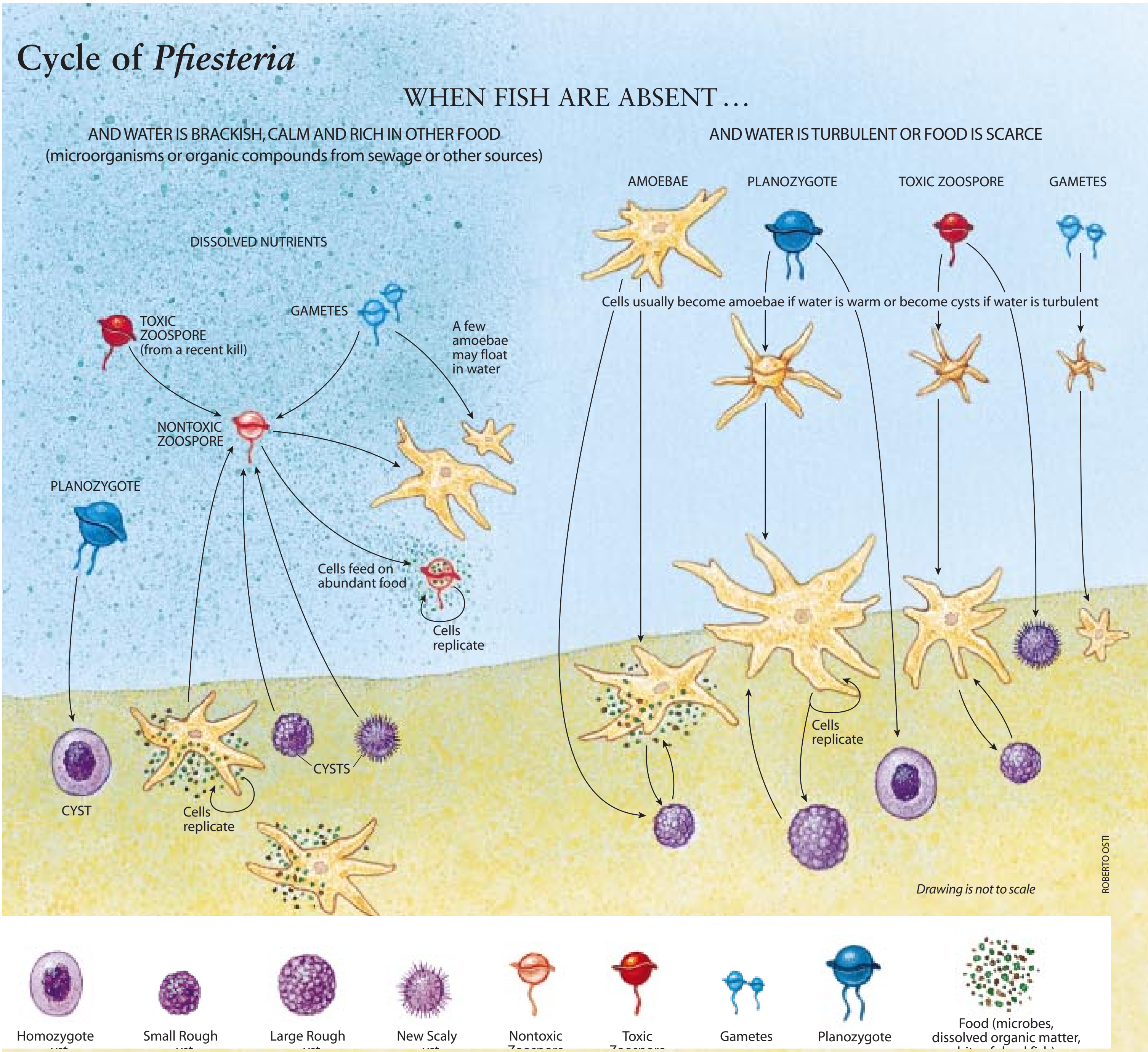


NEW SCALY CYST

Pfiesteria piscicida, a colorless single-celled organism, can change into at least 24 distinct forms—a rare feat. Only some are shown in the diagram (which is actually highly simplified) and micrographs here. The creature's shape and size depend on the type and amount of prey on the day's menu and on environmental conditions. That size can range from an invisible five microns (millionths of a meter) to a barely visible 750 microns.

The cells become toxic in nature when fish linger in their territory. Indeed, during the hotter seasons, the arrival of large schools of oily fish (*right panel above*) can trigger a "Jekyll and Hyde" personality transformation. Before fish enter the scene, the cells usually exist in any of three basic forms: various amorphous amoebae that quietly engulf algae and other prey in the bottom mud; encysted cells (also of many sizes) that hibernate, protected by a tough outer covering; or benign swimming cells known as nontoxic zoospores. When the fish arrive, the nontoxic zoospores become toxic (*unlabeled arrows indicate stage changes*). In addition, within minutes to hours, cysts and amoebae may give rise to nontoxic zoospores that soon become toxic as well. The altered zoospores send potent toxins into the water as they make a beeline for the fish.

The toxins drug the fish and destroy their skin, so that disease-causing bacteria and fungi can attack more easily as well. Meanwhile the toxic zoospores reproduce asexually and also produce gametes that fuse to form swimming, sexual products called planozygotes. As large sores develop on the fish, the toxic zoospores, planozygotes and gametes feed on substances that leak from the sores and on flecks of stripped skin, ingesting these materials by suction. When the fish



die, many of the cells may change into amoebae, attaching to the fish remains for a big meal.

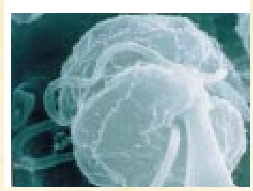
Laboratory tests and observations from aquaculture facilities suggest fish can face peril in cold water, too (*left panel on opposite page*). Large amoebae at the bottom of the tanks can quickly attack, kill and eat fish introduced into the system.

When dying fish disappear from the water but other nutrients, such as algal prey, are abundant, the toxic zoospores and gametes often revert to nontoxic zoospores (*left panel above*). Certain cells, meanwhile, may become amoebae or hypnozygotes (a kind of cyst). And amoebae and cysts in the bottom mud may produce more nontoxic zoospores. In the water the nontoxic zoospores feed well and multiply, but they will quickly become toxic attackers should another school of fish appear.

In more impoverished conditions (*right panel above*) the flagellated cells may opt to seek their fortune as scavenging amoebae in the mud. If the water is uncomfortably turbulent, though, swimming cells and amoebae may both turn into hibernating cysts, which are well suited for enduring adverse conditions. Twenty percent still survived even when we dried them for 35 days, immersed them in a concentrated acid or base for 30 minutes or held them in bleach for an hour.

The consummate opportunist, *P. piscicida* even resorts to thievery at times (*not shown*). It is unable to perform photosynthesis on its own. But in a process called kleptochloroplastidy, zoospores often steal chloroplasts, or photosynthetic organelles, from algae they have eaten and use them for days or weeks to help generate energy. *—J.M.B.*

FILLOSE AMOEBA



TOXIC ZOOSPORE

MICROGRAPHS COURTESY OF DEPARTMENT OF BOTANY, N.C.S.U.

knew where the organism had come from or if it was a species already known to science. In 1989 the veterinarians asked my research group in the N.C.S.U. department of botany to help identify the microbe and determine whether it was responsible for the fish deaths.

The Nature of the Adversary

We soon realized that the creature was unique among both toxic and nontoxic dinoflagellates in adopting some forms, or stages, that do not resemble those of other dinoflagellates at all; in those stages it looks like a group of microorganisms called chrysophytes. It also stood alone among the small subset of dinoflagellates that are toxic. Those species (totaling about 60) produce some of the most potent poisons ever discovered in nature, although they make them for no obvious purpose. But the newfound organism not only appeared to poison fish—it ate them as well!

My research team learned that the extraordinary microbe we eventually named *Pfiesteria piscicida* is nontoxic when fish are absent. When it senses fish excrement and secretions in the water, however, it both emits toxins and swims directly toward the fish materials. The toxins strip away the skin of the fish, damage their nervous system and vital organs and make them too lethargic to flee. Then the fish commonly sustain attacks by other destructive microbes, and bleeding sores develop where the skin has been destroyed. With the fish unable to escape, the dinoflagellate cells feed on sloughed skin, blood and other substances leaking from the sores. Later the lethal cells change from flagellated, swimming forms to more amorphous amoebae that dine on the victims' remains, sometimes becoming so engorged that they can no longer move.

Toxic *P. piscicida* can be a very effective killer. In laboratory tests, toxin-contaminated water or cultures of the cells have killed many finfish and shellfish species. My research associate, Howard B. Glasgow, Jr., has found that young animals, as well as adults of more sensitive species, can die minutes after exposure, and most victims die within hours.

We also discovered another trait that had never been found in other toxic dinoflagellates. Remarkably, *P. piscicida* can transform into at least 24 distinct stages over the course of its life cycle. It alters its shape and size according to available food sources, which include prey ranging from bacteria all the way up the food chain to mammalian tissue. Some of these stage changes can involve a more than 125-fold increase in size and can take place in less than 10 minutes.

We studied *Pfiesteria* for two years in aquarium tanks without knowing where it might have come from. But the information we gathered indoors prepared us for that search. We began by looking in our own "backyard." Every year since at least the mid-1980s, massive fish kills had plagued North Carolina's Albemarle-Pamlico Estuarine System, which contains the Neuse River. With help from state biologists, we obtained water samples in 1991 during a kill of about one million Atlantic menhaden in the Pamlico Estuary.

The Adversary in Nature

When we examined the samples with a scanning electron microscope, we saw small dinoflagellates that looked identical to those we had found in the contaminated vet-school aquariums. Moreover, just as had happened in our tanks, the cells seemed to disappear after the kill ended—they were absent from water samples collected among the floating remains of fish one day after the fish died. This work not only tracked the vet-school contaminant to its probable origin but also implicated *Pfiesteria* as an important cause of fish death in nature.

What triggers toxic outbreaks of *Pfiesteria*? Laboratory and field experiments by many researchers indicate that, among other factors, an overabundance of nutrients such as nitrogen and phosphorus in the water help to set the stage for these events. The shallow, slow-moving waters of many North Carolina estuaries are easily polluted by materials from the surrounding land. These include nutrient-rich human sewage, fertilizers, certain industrial by-products (including some rich in phosphates) and animal wastes (from many swine and poultry operations in the watershed). When the waters become overnutrified, algae proliferate, much as houseplants grow much better when their soil contains added fertilizer. The abundant algae provide a rich food source for *Pfiesteria,* which then reproduces rapidly, creating legions ready to attack schools of fish should they swim into *Pfiesteria*-infested waters.

The estuaries of North Carolina turn out to be a very troubling place for *Pfiesteria* to wreak havoc. The Albemarle-Pamlico is the second largest U.S. estuarine system outside Alaska, and it provides half the area used by fish from Maine to Florida as nursery grounds. Many young fish come to these waters to grow and develop before heading north or south. If such fish die in large numbers in this crucial area, populations of affected fish species up and down the coast could eventually shrink.

Early in our research, as we established that *Pfiesteria* is highly lethal to fish, we also learned that fish are not its only victims; people can also be affected. Other toxic dinoflagellates generally hurt people by poisoning seafood. But studies by David P. Green of N.C.S.U. and his co-workers have found little evidence that *Pfiesteria* toxins accumulate in fish, a sign that seafood harvested from *Pfiesteria*-contaminated waters probably does not serve as a "middleman" in harming human beings. Instead the exposure route is more direct: people can become dangerously ill after getting toxin-laden water on their skin

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FISH KILLED DURING AN OUTBREAK OF *PFIESTERIA* (a term that encompasses any member of the toxic *Pfiesteria* complex) often display bloody sores (*left*); many can also be seen to have had entire sections of their flesh eaten away (*right*).

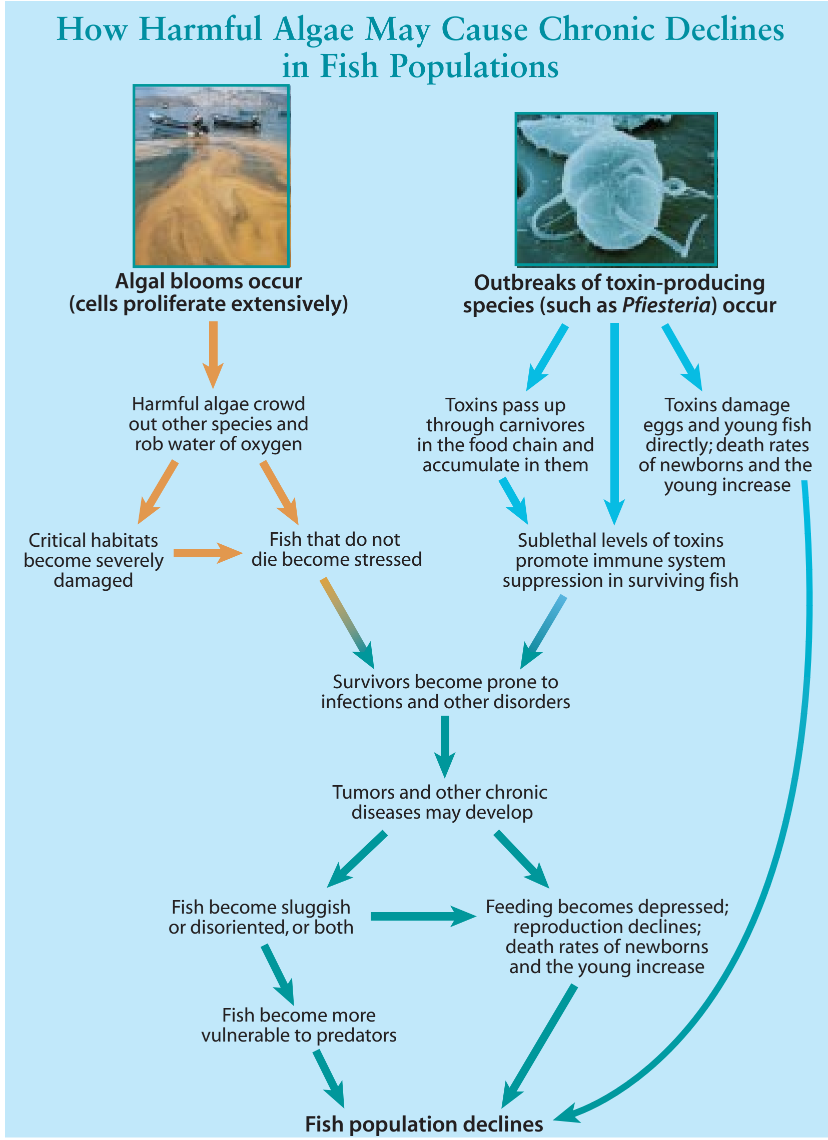
or after breathing the air over areas where fish are hurt or dying from their own encounters with toxic *Pfiesteria*.

An Unwelcome Surprise

We learned about this last effect on people the hard way. When we first began our investigations, we followed established safety procedures for working with toxic dinoflagellates. We had been informed by specialists on other toxic dinoflagellates that in the laboratory contact with contaminated water was the only danger. We did not know that *Pfiesteria* produces an aerosolized neurological toxin that can seriously hurt people—the first dinoflagellate known to do so—and that we were inhaling it.

The symptoms were so subtle at first that we attributed them to other causes: shortness of breath that we ascribed to asthma; problems akin to allergy attacks, such as itchy or mildly burning eyes or a "catching" in the throat; and headaches and forgetfulness that we attributed to stress. Then one evening in 1992 Howard Glasgow went to a small laboratory where we originally had worked with *Pfiesteria*. Another department controlled the lab and had not cleaned it for some time. He found the walls caked with evaporated, toxin-laced *Pfiesteria* culture. He began trying to wipe up the mess, but after several minutes his eyes began to burn and he gasped for breath. He lost coordination, his legs went numb and he began to vomit. He managed to crawl out of the laboratory. We thought the extreme condition of the room was at fault and that he would not have fallen ill in a well-maintained lab.

We refused to use that laboratory again and had new facilities constructed. These were supposed to have been carefully ventilated, but unknown to us, the contractors mistakenly vented the air from the toxic-culture lab directly into Howard's office. Over the next few months, this normally cheerful, detailed scientist became extremely moody and sometimes seemed disoriented and unable to focus on even simple tasks. This highly intelligent man, with a razor-sharp memory, suddenly could not recall conversations from earlier in the day. Finally, after a period of intensive lab work, even his long-term memory suffered. He could not find his way home, remember his phone number or even read, and he struggled to speak.



KEVIN SCHAFER *Peter Arnold, Inc. (left photograph)*; DEPARTMENT OF BOTANY, N.C.S.U. *(right photograph)*

BEYOND KILLING MANY FISH AT ONCE, harmful algae can hurt fish in other ways. In the long run, these less obvious effects might lead to more persistent declines in fish populations than are caused by dramatic fish kills. The term "harmful algae" is a loose, eclectic category encompassing noxious algae as well as several species, such as *Pfiesteria*, that are more animallike than plantlike.

After two months away, he recovered and returned to work. But over the next two years, strenuous exercise caused relapses of aching joints, burning muscles and bouts of disorientation.

Before we realized that *Pfiesteria* can produce aerosolized toxin, 12 people from four different labs were sickened from toxic cultures. Three of us, myself included, have sustained some persistent problems we did not have before we began to study toxic *Pfiesteria*. In the past six years I have had chronic bronchial infections and 16 bouts of pneumonia; to cope with the infections, I take antibiotics for about a third of each year.

We now conduct our research in a specially designed biohazard III facility, using more precautions than are needed for most research with the AIDS virus. The lab is fitted with air locks, decontamination chambers and other safety features, and researchers wear full hooded respirators supplied with purified air.

Chronic Effects in the Field

People exposed to toxic *Pfiesteria* outbreaks in nature have reported similar symptoms. Divers, fishermen and others working in contaminated waters while fish were showing signs of *Pfieste-*

ria poisoning have described respiratory problems, headaches, extreme mood swings, aching joints and muscles, disorientation, and memory loss. Such anecdotal reports have recently been bolstered by formal clinical assessments.

In 1997, for example, three small outbreaks of *Pfiesteria* led Maryland's governor to close the affected waters in Chesapeake Bay for several weeks. Reports of strange symptoms in people who had been in the affected areas prompted the Maryland Department of Health and Mental Hygiene to organize a medical team to investigate. Among those who complained were heavily exposed fishermen—who described getting lost on a bay they had worked their entire lives or losing their sense of balance and concentration. Through neuropsychological testing, a medical team led by J. Glenn Morris, Jr., of the University of Maryland School of Medicine documented "profound" learning disabilities in the patients. The severity of their cognitive dysfunction was directly related to their degree of exposure, and the patients recovered their faculties over the next few months.

Doctors have difficulty diagnosing this "*Pfiesteria* syndrome" conclusively, however, because the specific toxins at fault have not yet been identified (as is the case with many toxic algae). Without that information, investigators cannot examine how the chemical acts in the human body, nor can tests be designed that definitively identify it in the blood or tissues. Fortunately, progress is being made. Peter D. R. Moeller and John S. Ramsdell of the National Ocean Service in Charleston, S.C., have semipurified components of *Pfiesteria* toxins that destroy fish skin and affect the nervous system in rats (which are studied as a model for humans).

Our own lingering health problems have led us to devote much attention to the possibility that *Pfiesteria* might cause chronic effects in fish that sustain nonlethal exposures. In lab experiments, we subjected fish to low concentrations of toxic *Pfiesteria* and monitored the animals for up to three weeks. The fish appeared to be drugged, and they developed skin lesions and infections. Tests revealed that white blood cell counts were 20 to 40 percent below normal levels, suggesting that *Pfiesteria* toxins may compromise the functioning of the immune system and make fish more susceptible to disease. Autopsies of fish that were affected have revealed damage to the brain, liver, pancreas and kidneys.

Weakened immunity, increased disease and periodic fish kills can all contribute to a decline in fish stocks. But other problems could seriously affect the ability of fish populations to recover. Research has shown that when toxic *Pfiesteria* is in the water, the eggs of striped bass and other commercially valuable fish fail to hatch. Experiments by Sandra E. Shumway of Southampton College and my graduate research assistant Jeffrey J. Springer have established that *Pfiesteria* also kills shellfish larvae, sometimes within seconds of contact, and causes young bay scallops to lose their ability to close their shells. In that condition, they would be highly vulnerable to predators.

JEFFREY J. SPRINGER N.C.S.U.

RESPONSE OF BAY SCALLOPS to *Pfiesteria* in the laboratory is one of several indications that it can endanger the long-term health of fish it does not kill. When healthy scallops, such as the one on the left, were exposed to sublethal densities of toxic cells, they became unable to close their shells (*right*), a disability that would increase susceptibility to predation in the wild.

The Bigger Picture

As we became increasingly concerned that *Pfiesteria* could threaten the viability of fish populations, we began to wonder whether this phenomenon was part of a broader trend. Dogma had long held that most finfish and shellfish exposed to sublethal doses of toxins from harmful algae suffer no ill effects. But could many harmful algae cause trouble that had been overlooked—perhaps by interfering with reproduction, with the survival of sensitive young fish or with resistance to disease? We also wondered whether there was evidence that these organisms could produce sustained or subtle health problems in people.

Few researchers have explored these questions or looked intently at the long-range effects of harmful algal blooms on the ecosystem as a whole. Nevertheless, a cluster of findings indicates cause for concern. These findings become especially disturbing when we note that as a group harmful algae are thriving. Some experts have pointed out that within the past 15 years, outbreaks of certain harmful algae seem to have increased in frequency, geographic range and virulence in many parts of the world.

Consider these examples. When bay scallops were exposed to small amounts of toxin from the dinoflagellate *Alexandrium tamarense,* their gut lining was eaten away, and their heart rate and breathing slowed. Other dinoflagellates produce ciguatera toxins that can accumulate in reef fish without killing them outright. The fish can grow large enough to be harvested as food for people, who then become sick. In fact, more human illness is caused by ciguatera-laden barracuda, red snapper, grouper and other tropical fish than by any other seafood poisoning. The symptoms can relapse for years, often triggered by alcohol consumption. Ciguatera toxins can also interfere with the normal function of white blood cells called T lymphocytes and thereby compromise the immune system. Recent work suggests that these toxins may take a similar toll on fish, resulting in impaired equilibrium, fungal infections and hemorrhaging.

Two types of cancer, disseminated neoplasia (similar to leukemia) and germinomas (which attack the reproductive organs), affect such shellfish as blue mussels and soft-shell clams. Studies have linked these cancers to certain dinoflagellates that produce saxitoxins, the same toxins that can cause sometimes fatal poisoning in people who eat contaminated shellfish. People who recover from acute saxitoxin poisoning may relapse with malarialike symptoms for years afterward. Ingestion of shellfish tainted with okadaic acid from toxic dinoflagellates along European coasts normally causes people to have diarrhea, but smaller, chronic doses have caused tumors in lab rats and human tissues. Okadaic acid can also destroy cells in the hippocampus of the brain, an area important in memory, and can lead to suppression of the human immune system.

Chronic health problems from harmful algae are not restricted to marine environments. Blooms of blue-green algae (cyanobacteria) can take most of the oxygen from the water at night, so that fish become stressed and weakened and more vulnerable to disease. Moreover, toxins from these algae have caused liver, lung and abdominal tumors in mice, as well as mild to severe liver damage in humans.

Fish as Canaries

To combat the unwanted effects of harmful algae, scientists must first "know the enemy" more thoroughly. Many harmful algae are so poorly understood that even fundamental facts about their life cycles remain unknown. Scientists must also chemically characterize more of their toxins, so that improved warning systems can be developed for determining when waters are unsafe.

Armed with that information, investigators will be able to assess how the toxins are processed in the human body and whether they are stored in our tissues. We will also be able to make progress in answering other important questions, such as: What is the range of acute and chronic effects of the toxins on the human nervous and immune systems, and how long do these effects last? What are the overall consequences to fish health? How do the toxins interact with other microorganisms and with pollutants to hurt fish, wildlife and humans?

For many species of harmful algae, the factors that stimulate increased activity are as incompletely understood as the organisms' life cycles. Clearly, nutri-

JEFFREY J. SPRINGER N.C.S.U. *(left)*; HOWARD B. GLASGOW, JR. N.C.S.U. *(right)*

HIGHLY PROTECTIVE EQUIPMENT is now de rigueur for researchers studying *Pfiesteria* and its close relatives. People can be harmed not only by having contaminated water touch their skin but also by inhaling *Pfiesteria* toxins from the air.

ent pollution has stimulated the growth of *Pfiesteria* and certain other members of the group. Some ecologists believe that nutrient overenrichment and other types of pollution have contributed to a serious general imbalance in many aquatic ecosystems. Large algal blooms and toxic outbreaks, they assert, are symptomatic of this imbalance as well as participants in its perpetuation.

This ecological breakdown may have many causes. Continuing losses of the wetlands that act as the earth's kidneys hamper the ability of waterways to cleanse themselves. Some algal blooms have coincided with El Niño events, suggesting that warming trends in global climate may stimulate the growth of these species and extend their range. These climatic changes also create flooding that washes additional nutrients and other pollution into rivers and estuaries. Further, inadequate environmental regulations are providing too little protection for our waters at a time when nearly two thirds of Americans live within 50 miles of a coastline. There are more people on the earth than ever before. They are using relatively scarce freshwater supplies at an ever increasing rate, while they are also generating more and more wastes that degrade both fresh and marine waters.

As we pulled anchor during the October 1995 fish kill, many thoughts were in my mind. I was keenly aware that *Pfiesteria* is but one type of harmful microorganism that can disrupt both fish resources and human health. Ultimately, water quality, human health and fish health are strongly linked. All of us—scientists, politicians, resource managers, fishermen and other citizens—need to work together to learn much more about the chronic as well as the acute effects of harmful algae. We must also become more proactive in addressing the state of our waterways, instead of reacting to each fish kill as if it were a limited, isolated crisis. In protecting vulnerable fish, the health we spare may also be our own.

The Author

JOANN M. BURKHOLDER, the world's foremost authority on *Pfiesteria,* is professor of botany and a Pew Fellow at North Carolina State University. She has received many awards for her research and her contributions to environmental policy and education, including the Conservation Achievement Award in Science from the National Wildlife Federation, the Admiral of the Chesapeake Award, and the Scientific Freedom and Responsibility Award from the American Association for the Advancement of Science. She can be reached via e-mail at joann_burkholder@ncsu.edu

Further Reading

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The Aquatic Botany Laboratory at North Carolina State University site on the toxic *Pfiesteria* complex is available at www.pfiesteria.org on the World Wide Web.

The Future of Computing

M.I.T.'s Laboratory for Computer Science is developing a new infrastructure for information technologies—the Oxygen system—that promises to realize a vision long held by the lab's director: helping people do more by doing less

by Michael L. Dertouzos

Last year a few of us from the Laboratory for Computer Science at the Massachusetts Institute of Technology were flying to Taiwan. I had been trying for about three hours to make my new laptop work with one of those cards you plug in to download your calendar. But when the card software was happy, the operating system complained, and vice versa. Frustrated, I turned to Tim Berners-Lee sitting next to me, who graciously offered to assist. After an hour, though, the inventor of the Web admitted that the task was beyond his capabilities.

Next I asked Ronald Rivest, the co-inventor of RSA public-key cryptography, for his help. Exhibiting his wisdom, he politely declined. At this point, one of our youngest faculty members spoke up: "You guys are too old. Let me do it." But he also gave up after an hour and a half. So I went back to my "expert" approach of typing random entries into the various wizards and lizards that kept popping up on the screen until by sheer accident, I made it work . . . three hours later.

Such an ordeal is typical and raises an important issue: for the first 40 years of computer science, we have been preoccupied with catering our technology to what machines want. We design systems and subsystems individually and then throw them at the public, expecting people to make the different components work together. The image this approach evokes for me is that of designing a car in which the driver has to twist dozens of individual knobs to control the fuel mixture, spark advance and valve clearances, among other things—when all he wants to do is go from one place to another.

Doing More by Doing Less

We have done enough of this kind of design. It's time we change our machine-oriented mind-set and invent the steering wheel, gas pedal and brakes for people of the Information Age. This idea brings me squarely to the goal of my vision for the near future: people should be able to use the new information technologies to do more by doing less.

When I say "doing more by doing less," I mean three things. First, we must bring new technologies into our lives, not vice versa. We will not accomplish more if we leave our current lives, don goggles and bodysuits, and enter some metallic, gigabyte-infested cyberspace. When the industrial revolution came, we didn't go to motorspace. The motors came to us as refrigerators to store our food and cars to transport us. This kind of transition is exactly what I expect will happen with computers and communications: they will come into our lives, and their identities will become synonymous with the useful tasks they perform.

Second, new technologies must increase human productivity and ease of use. Imagine if I could pull out a handheld device and say, "Take us to Athens this weekend." My computer would connect to the EasySabre airline reservation system and begin interacting with it, using the same commands that travel agents use. The machine would know that "us" is two people and that we like business class, aisle seats and so forth. It would negotiate with the airline computer for maybe 10 minutes, until it found an acceptable flight and confirmed it. I would have spent three seconds giving my order, whereas my electronic bulldozer—the handheld's software—would have worked for 10 minutes, or 600 seconds. The human productivity improvement in this example is 600 divided by three, which is 200, or, in business terms, 20,000 percent.

Such huge gains will not be possible everywhere, of course. But during the 21st century, I expect that we will be able to increase human productivity by 300 percent as we automate routine office activities and offload brain and eyeball work onto our electronic bulldozers. This transformation will happen in the same way that we offloaded muscle work onto bulldozers during the industrial revolution. We have not yet begun to see these gains from the information revolution. Now we click away at our browsers or e-mail screens, squinting our eyeballs and squeezing our brains. In essence, we are still "shoveling," but we don't notice, because we are holding diamond-studded shovels, stamped "high-tech." So our expectations of what computers can do for us must also change if we are to have a true revolution.

To date, computer vendors have abused the phrase "ease of

A DAY IN THE LIFE of Oxygen users is imagined in this vignette. The five co-workers are able to make a fast decision, thanks to the system's ability to find them, to keep them connected and to do some of their research for them.

1 JANE IN PARIS, having just found an attractive site for her company's French office, uses her Handy 21 to track down her boss, Joe.

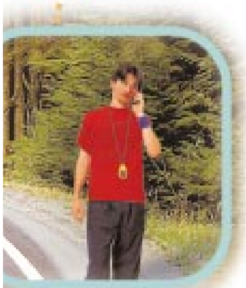
2 JANE'S HANDY "sniffs" the electromagnetic surround, finds the local cellular network and calls Joe in New York City.

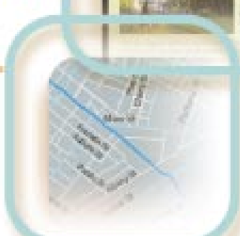
3 JOE'S ENVIRO 21 in the wall of his office answers the phone, to which it is connected. It recognizes Jane's voice and her urgency and forwards the call to Boston, where Joe is chatting with the local VP.

4 BOSTON'S OFFICE is also equipped with an Enviro 21, which fields the call. It senses that the VP's door is open and, based on an automation script, determines that it can interrupt.

5 JANE'S IMAGE appears on the wall in the Boston office and clears its throat. She explains about the site and that they have six hours to grab it. Joe understands and says, "Oxygen, get Juan, Michael and Mary."

6 OXYGEN finds Juan out jogging, Michael at home and Mary driving to Chicago, connected via her car-trunk Enviro 21 computer.





7 COLLABORATIVE REGION is created by Net 21 within seconds. As the five co-workers confer, they say things like, "Oxygen, get me the map from Lori's message" or "Find Web info on this new site."

8 "WE'LL DO IT," Joe concludes. He points his Handy at the printer and instructs, "Oxygen, send us copies of the documents we reviewed."

TOM DRAPER DESIGN; STEVE VIDLER *Leo de Wys, Inc. (Eiffel Tower)*; DEREK TRASK *Leo de Wys, Inc. (trees)*; LEO DE WYS, INC. *(car)*; DAN WAGNER *(people)* use." When they call a system user-friendly, it is tantamount to dressing a chimp in scrubs and earnestly parading it around as a surgeon. When I say "ease of use," I do not mean incorporating more colors and floating animals into our systems. I mean true ease of use, even if the interaction is only via text. It is inconceivable to me that the differences between browsers and operating systems will persist beyond a few more years. Both access information—one at a distance, one locally—and because people need to do the same things with information regardless of where it resides, ease of use demands that we have only one set of commands for both. The current state of affairs is as ridiculous as if your steering wheel turned your car on city streets but applied the brakes out in the country.

The final way in which new technologies can enable people to do more by doing less is by including everyone in the word "people." With some 100 million machines interconnected today, we feel pretty smug. Yet that figure represents only 1.6 percent of the world's population. We think the world is communicating widely, but we still cannot hear the voices of billions through anything other than television and government information feeds. Moreover, the information revolution, left to its own devices, will increase the gap between rich and poor, simply because the rich will use their machines to become more productive, hence richer, while the poor stand still.

We cannot let this happen—if not for the sake of altruism, then for self-preservation. Such disparities inevitably lead to bloody conflicts. And if we decide to help, the potential is immense: the rich could use the new world of information to buy services and products from the poor, as was done earlier with manufacturing. A Virtual Compassion Corps could for the first time in history match the people proffering human help to those who need it, worldwide. In fact, a small group of undergraduate students at the M.I.T. Laboratory for Computer Science have built a Web site (www.compassioncorps.org) to do precisely that. And help need not always travel from the developed to the developing world. Imagine a doctor in Sri Lanka who makes $20 a day administering health care to homeless people in Boston via a kiosk, equipped with a remote video and medical instrument connection and staffed by a nurse. The service might cost $5 a visit, and although not perfect, it would be superior to no health care at all.

This, then, is what I mean when I say that people should be able to do more by doing less: bring the technology into our lives, increase human productivity and ease of use, and offer these gains to all. Given this goal, let's take a look at the computing model over which this vision extends.

The Information Marketplace

My model of the information world in the near future is the same one I've talked about for the past 20 years—the Information Marketplace, the full capability of which is yet to be reached. In the coming decade, half a billion human-operated machines and countless computers—in the form of appliances, sensors, controllers and the like—will be interconnected. And these machines and their users will do three things: buy, sell and freely exchange information and information services. Some $50 billion changes hands over the Internet today. By 2030, I estimate that this flow will amount to four trillion of today's dollars, or one quarter of the world's industrial economy. It will come predominantly from the office sector, which accounts for half of that overall economy. Indeed, a large part of the information services of the future will involve a new type of activity—the purchase and sale of information work. Imagine 1,000 accountants from Beijing doing accounting services for General Motors at $1 per hour.

The "free exchange" part of the Information Marketplace will be just as important. It will affect our lives through its family messages; collaborative activities; knowledge-building and accessing capabilities; political, literary and social exchanges; and many new activities.

Given the goal of doing more by doing less and the model of the Information Marketplace, how do we get there in practice? To that end, at the Laboratory for Computer Science, we have just launched a major research project. We expect it to result in a radically new hardware and software system called Oxygen, which will be tailored to people and their applications and will become as pervasive—we hope—as the air we breathe. This multimillion-dollar, five-year project involves some 30 faculty members from the Laboratory for Computer Science, working in collaboration with the M.I.T. Artificial Intelligence Lab.

We still cannot hear the voices of billions through anything other than television and government information feeds.

Designing Oxygen

At the heart of the Oxygen system is the Handy 21, which is like a cellular phone but which has additionally a visual display, a camera, infrared detectors and a computer. The Handy 21 brings the help you need to where you are. Moreover, it is all-software-configurable in that it can change at the flip of a bit (in any country) from a cell phone to a two-way radio talking to other Handy 21s, to a network node near a high-speed wireless office network, or to a plain FM radio. The articles by Anant Agarwal on page 60 and John V. Guttag on page 58 address this aspect of Oxygen.

The second key technology of Oxygen is the Enviro 21. Unlike the Handy, which follows people, this device stays attached to the environments around people. It is built into the walls of your office and your house and into the trunk of your car. The Enviro 21 bears the same relation to the Handy 21 as does a power socket to a battery. It does everything the Handy 21 does but with greater capacity and speed. Enviro 21s may also be set up to regulate all kinds of devices and appliances, including sensors, controllers, phones, fax machines, and arrays of cameras or microphones.

Oxygen interacts with the inanimate physical world in two ways—through these controllable appliances and through the infrared detectors in the Handy 21s. If a door is of interest to your machines, you paste an infrared tag on it. Thereafter, when people point their Handy 21s to that door, the machines read the identity of the door and show what is supposed to be behind it. In other words, the system provides a kind of x-ray vision, helping people relate to the physical objects of interest in their environment.

The Handy 21s and Enviro 21s will be linked by way of a novel network, Net 21. Its principal function is to create a secure "collaborative" region among Oxygen users who wish to get together, wherever they may be. The Net 21 must do so on top of the noisy and huge Internet. It must be able to handle constant change as aggregates of participating nodes rise and collapse. It must find you wherever you are. It must connect to numerous appliances. And it must connect to the world's networks. This is no easy task. Oxygen will require a radically new approach to networking protocols that draws on self-organization and adaptation and that augments today's Internet.

Oxygen must also involve perceptual resources, especially speech understanding, and address people's inherent need to communicate naturally: we are not born with keyboard and mouse sockets but rather with mouths, ears and eyes. In Oxygen, speech understanding is built-in—and all parts of the system and all the applications will use speech. The systems built by Victor Zue and his group can handle narrow domains of inquiry, such as weather or airlines [see "Talking with Your Computer," on page 56]. We are stitching these narrow domains together—and incorporating vision and graphics where need be—to form a new quilt covering a broader front of human-machine communication.

Oxygen's fifth technology deals with people's need to find useful information. We are designing Oxygen so that you can first check your own knowledge stores in ways that are familiar to you. The system will allow you to say simply, "Get me the big red document that came a month ago," forgoing reference numbers and other clues. Oxygen will also check the stores of friends and associates who agree to share their knowledge with you, in the same sense that you might ask a friend or a co-worker a question if you don't know the answer yourself. Finally, Oxygen will search the vast information stores on the Web and "triangulate," relating what it finds there to your and your associates' stored knowledge bases.

Oxygen will also let people off-load routine and repetitive work onto their electronic bulldozers. It will help users write scripts for automating various jobs, as well as monitor and control the many appliances connected to the Enviro 21s. "Turn up the heat." "Print it there." "Every day at noon, give me the price of my portfolio and the weather in Athens." Oxygen will take care of such instructions using a reason and control loop, which allows a person to guide the machine gently as it carries out automated tasks.

The system's collaboration technology will help people keep track of what they do as they move forward. For instance, the system will keep a hyperlinked summary of a meeting, provided by a human secretary, with the help of speech-understanding annotations. When you ask what was decided about, say, a new building's glass roof, it will give you the secretary's three-word summary—"We eliminated it"—but if you desire will also let you probe deeper into the chain of spoken and video input that led up to that conclusion.

Last, Oxygen will include customization technology that tailors information to individual needs. There will be no shrink-wrapped software. All software will be downloaded onto the Handy 21s and Enviro 21s from the Net 21 network, triggered by user requests, errors or upgrades. The customization technology will also let people adapt the machines around them to their own needs and habits throughout their use of the other Oxygen technologies.

A Claim and a Wish

Oxygen, then, is an integrated collection of eight new technologies: handhelds, wall and trunk computers, a novel net, built-in speech understanding, knowledge access, collaboration, automation and customization. The power of Oxygen lies not in any one piece but in the totality of these human-oriented technologies together. They forge a new computing metaphor that we hope will mark an important shift from the desktop and icons of today, as those innovations did from text-only systems.

I will now stake a bigger claim: I believe that the five technologies of speech (and other perceptual capabilities), knowledge access, automation, collaboration and customization are the only new kids on the block. Out of the thousands of things that we can imagine doing in the new world of information, these five are the foundations on which any new activities that help us do more by doing less will be built. For the next few decades at least, they are the steering wheel, the gas pedal and the brakes we seek—as well as the forces leading to a full-fledged Information Marketplace.

If this claim is valid, it suggests that people who want to exploit the new world of information should explore the capabilities of the new Oxygen technologies. Every individual and organization will have access to them. The ones who will truly do more by doing less will be the ones who learn how to integrate these technologies and their people into a well-oiled, humming whole. And good Oxygen applications that exploit speech, knowledge access, automation, collaboration and customization will make it easier for people to reach their full potential. Imagine a health care application built on top of Oxygen: for knowledge access, it might use Medline (a searchable, on-line database of articles from medical journals, made available by the U.S. National Library of Medicine) and the patient records of hospitals, both available by speech. It could automate routine medical and administrative tasks, help doctors collaborate with one another and much more, taking its application "personality" from the capabilities of the underlying Oxygen system.

I hope that this vision, embodied in Oxygen and other systems like it, will help us break away from our 40-year machine preoccupation to a new era of people-oriented computing. And as we focus our technologies increasingly on human needs, perhaps we can make a bigger wish for the future. The first three socioeconomic revolutions were all based on things—the plow for the agrarian revolution, the motor for the industrial revolution and the computer for the information revolution. Perhaps the time has come for the world to consider a fourth revolution, aimed no longer at objects but at understanding the most precious resource on earth—ourselves.

MICHAEL L. DERTOUZOS is director of the M.I.T. Laboratory for Computer Science, a position he has held for the past 25 years.

TOM DRAPER DESIGN; PHOTOGRAPHS BY DAN WAGNER

Talking with Your Computer

Speech-based interfaces may soon allow computer users to retrieve data and issue instructions without lifting a finger

by Victor Zue

For decades, science-fiction writers have envisioned a world in which speech is the most commonly used interface between humans and machines. This is partly a result of our strong desire to make computers behave like human beings. But it is more than that. Speech is natural—we know how to speak before we know how to read and write. Speech is also efficient—most people can speak about five times faster than they can type and probably 10 times faster than they can write. And speech is flexible—we do not have to touch or see anything to carry on a conversation.

The first generation of speech-based interfaces is beginning to emerge, including high-performance systems that can recognize tens of thousands of words. In fact, you can now go to various computer stores and buy speech-recognition software for dictation. Products are offered by IBM, Dragon Systems, Lernout & Hauspie, and Philips. Other systems can accept extemporaneously generated speech over the telephone. AT&T Bell Labs pioneered the use of speech-recognition systems for telephone transactions, and now companies such as Nuance, Philips and SpeechWorks have also entered the field. The current technology is employed in virtual-assistant services, such as General Magic's Portico service, which allows users to request news and stock quotes and even listen to e-mail over the telephone. But the Oxygen project will need far more advanced speech-recognition systems.

I believe the next generation of speech-based interfaces will enable people to communicate with computers in much the same way that they communicate with other people. Therefore, the notion of conversation is very important. The traditional technology of speech recognition—which converts audible signals to digital symbols—must be augmented by language-understanding software so that the computer can grasp the meaning of spoken words.

On the output side, the machine must be able to verbalize; it has to take documents from the World Wide Web, find the appropriate information and turn it into well-formed sentences. Throughout this process the machine must be able to engage in a dialogue with the user so that it can clarify mistakes it might have made—for example, by asking questions such as "Did you say Boston, Massachusetts, or Austin, Texas?"

Galaxy Speaks

We at the M.I.T. Laboratory for Computer Science have spent the past decade working on systems with this kind of conversational interface. Unfortunately, the machines developed so far are not terribly intelligent; they can deal only with limited domains of knowledge, such as weather forecasts and flight schedules. But the information is up-to-date, and you can access it over the telephone. The machines are capable of communicating in several languages; the three to which we pay the most attention are American English, Spanish and Mandarin Chinese. These systems can answer queries almost in real-time—that is, just as quickly as in a normal conversation between two people—when the delays in downloading data from the Web are discounted.

The speech-based applications we have produced are founded on an architecture called Galaxy, which our group introduced five years ago. It is a distributed architecture, which means that all the computing takes place on remote servers.

A Conversation with Jupiter

The following is a transcript of a telephone conversation between Victor Zue and the Jupiter system for weather information. Jupiter's toll-free number is 1-888-573-8255.

[Phone ringing]

Jupiter: Hi. Welcome to Jupiter, the M.I.T. Lab for Computer Science Weather Information System. This call is being recorded for system development. You may hang up or ask for help at any time. How can I help you?

V.Z.: What is the forecast for Boston today?

[The theme song of the television show *Jeopardy* plays during a pause of seven seconds. Each of Zue's subsequent questions is followed by a pause of one to three seconds.]

Jupiter: In Boston this afternoon, partly sunny and windy. High around 50. Tonight, clear, lows around 35. What other information can I give you?

V.Z.: Will it rain tomorrow?

Jupiter: To my knowledge, the forecast calls for no rain in Boston tomorrow. Is there anything else?

V.Z.: How about Seattle?

Jupiter: To my knowledge, the forecast calls for no rain in Seattle tomorrow. Is there something else you would like to know?

V.Z.: Is it sunny anywhere in the Caribbean?

Jupiter: Sorry, I am not sure what you said.

V.Z.: Is it sunny anywhere in the Caribbean?

Jupiter: I am sorry, I may not know the city you are asking about. Try asking for the state or country. For example, what cities do you know about in Massachusetts?

V.Z.: What is the temperature in Montego Bay?

Jupiter: In Montego Bay today, high 86 and low 73. Is there something else?

V.Z.: Good-bye.

Galaxy can retrieve data from several different domains of knowledge to answer a user's query. The system can handle multiple users simultaneously, and last but not least, it is mobile. You can access Galaxy using only a phone, but if you also have an Internet connection, you can tell the machine to download data to your computer.

Galaxy has five main functions: speech recognition, language understanding, information retrieval, language generation and speech synthesis. When you ask Galaxy a question, a server called Summit matches your spoken words to a stored library of phonemes—the irreducible units of sound that make up words in all languages. Then Summit generates a ranked list of candidate sentences—the machine's guesses at what you actually said. To make sense of the best-guess sentence, the Galaxy system uses another server called Tina, which applies basic grammatical rules to parse the sentence into its parts: subject, verb, object and so forth. Tina then formats the question in a semantic frame, a series of commands that the system can understand. For example, if you asked, "Where is the M.I.T. Museum?" Tina would frame the question as the command "Locate the museum named M.I.T. Museum."

At this point, Galaxy is ready to search for answers. A third server called Genesis converts the semantic frame into a query formatted for the database where the requested information lies. The system determines which database to search by analyzing the user's question. Once the information is retrieved, Tina arranges the data into a new semantic frame. Genesis then converts the frame into a sentence in the user's language: "The M.I.T. Museum is located at 265 Massachusetts Avenue in Cambridge." Finally, a commercial speech synthesizer on yet another server turns the sentence into spoken words.

TOM DRAPER DESIGN; PHOTOGRAPHS BY P. BROZE *Leo de Wys, Inc.*

GALAXY ARCHITECTURE outlines the tasks carried out by speech-based applications such as the Voyager system. After a user poses a question, the system generates a list of guesses at what the user said, then translates the best-guess sentence into commands that are used to retrieve the information from a database. The retrieved data are incorporated into a response sentence, and a speech synthesizer turns the sentence into spoken words.

Our laboratory has so far created about half a dozen Galaxy-based applications that can be accessed by telephone. Jupiter offers weather information for 500 cities worldwide. Pegasus provides the schedules of 4,000 commercial airline flights in the U.S. every day, updated every two or three minutes. Voyager is a guide to navigation and traffic in the greater Boston area. To move from one application to another, the user simply says, "I want to talk to Jupiter" or "Connect me to Voyager." Since May 1997 Jupiter has fielded more than 30,000 calls, achieving correct understanding of about 80 percent of the queries from first-time users. The calls are recorded and evaluated to improve the system's performance [*see box on opposite page*].

Speech recognition would be an ideal interface for the handheld devices being developed as part of the Oxygen project. Using speech to give commands would allow much greater mobility—there would be no need to incorporate a bulky keyboard into the portable unit. And spoken language would enable users to communicate with their devices more efficiently. A traveling executive could say to his or her computer, "Let me know when Microsoft stock is above $160." The machine would act much like a human assistant, accomplishing a variety of tasks with minimum instruction.

Of course, several research problems still need to be addressed. We must create speech-recognition applications that can handle many complex domains of information. The systems must be able to draw data from different domains—the weather information domain, for example, and the flight information domain—without being specifically instructed to do so. We must also increase the number of languages that the machines can understand. And finally, to exploit the spoken-language interface fully, the systems must be able to do more than just what I *say*—they must do what I *mean*. Ideally, tomorrow's speech-based interfaces will allow machines to grasp their users' intentions and respond in context. Such advanced systems probably will not be available for at least a decade. But once they are perfected, they will become an integral part of the Oxygen infrastructure. SA

VICTOR ZUE is an associate director of the M.I.T. Laboratory for Computer Science and head of the lab's Spoken Language Systems Group. He is also a senior research scientist at M.I.T., where he received his Sc.D. in electrical engineering in 1976.

Communications Chameleons

Multipurpose communications systems will be the links of tomorrow's wireless computer networks

by John V. Guttag

A major goal of the Oxygen project is to replace the current plethora of communications gadgets with a single portable device. By analogy, consider how we use computers. I don't have one computer on which I run PowerPoint for slide presentations and another on which I run Eudora for e-mail and a third on which I run Photoshop for touching up images. I have one computer, and I switch from application to application with a click of a mouse. I want to do the same thing with communications devices. I want to switch from my cellular phone to my pager, then to my AM radio (so I can listen to the Boston Red Sox trounce the New York Yankees), then to my television, and then to my wireless Internet connection. All just by clicking a button.

The Handy 21 device now being developed by the M.I.T. Laboratory for Computer Science would allow me to do just that. As proposed, the Handy 21 will be a powerful handheld computer that combines the functions of a cellular phone, a wireless connection to the Internet, a pager, an AM/FM radio and a television set. At first glance, though, this proposal seems to face an intractable problem: How can you build all this functionality into the device without loading it up with so much hardware that it becomes impossible to carry? Solving this problem has become an important objective of the M.I.T. Lab's SpectrumWare project.

My colleagues and I in the project have been developing multipurpose communications systems that can be programmed to receive and transmit many different types of signals. We call these systems "communications chameleons" because they can change to suit the user's needs. If the user wants to call a friend, he or she can instruct the system to function as a cellular phone. But if the user then wants to surf the World Wide Web, he or she can use the same device to access the Internet and download data. The key to the system's adaptability is its software. A communications chameleon is a single piece of general-purpose hardware linked with a wide array of special-purpose applications. Such systems promise to usher in a whole new era of wireless networking.

To build a communications chameleon, one must replace physical things with software. For example, two of my graduate students, Vanu Bose and Matt Welborn, have designed a radio out of software, written in the C++ programming language. If you compile the code and run it on a personal computer that has been equipped with an antenna and a wide-band sampling device—essentially a tuner that returns a digitized swath of the spectrum—the machine will play Top 40 music and traffic updates just like a conventional radio. But if at some point you decide you are unhappy with the software radio you are using, you can transform it into an entirely new device simply by running a different application. Another student, John Ankcorn, built an all-software television that runs on the same hardware as the software radio constructed by Bose and Welborn.

Signaling with Software

In our software radio, we have moved the analog/digital and the hardware/software boundaries to the same point, which is as close to the antenna as we could make it. The hardware allows us to select any 10-megahertz region of the spectrum, convert it to intermediate frequency and then relay the signal to the RAM of an ordinary personal computer. All the signal processing is done on a general-purpose microprocessor, using a standard operating system. Processing the signal in the same memory used by applications allows the user to create a variety of communications devices—universal cell phones, wireless networking interfaces and so on—merely by running the appropriate applications on his or her computer. And because the system uses very little special-purpose hardware, it is dead simple to upgrade. To make our software radio faster—so that it can, for example, tune in to multiple stations and record all the signals—all we have to do is load it onto a faster PC.

Such a machine would allow people to connect communications devices that are now considered incompatible, such as digital and analog cellular phones. Users could configure the system to work like the patch panels that were once common in offices. Years ago you could pick up the telephone and say, "I would like to speak to so-and-so," and the switchboard operator would connect you to the desired party. The new wireless systems could provide the same kind of service, but they would not be limited to people who happen to be near telephones. You could access the network with a cheap walkie-talkie and say, "Connect me to my mother." The system would then patch you through to your mother's citizen-band radio in her 18-wheeler barreling down the highway.

Although we have emphasized voice-oriented communications devices in our current work, the same systems can also be used to transmit data. With some simple reprogramming, we could use the same hardware to build portable medical devices that could send and receive ultrasound readings or electrocardiograph signals. Doctors who carry these devices would have instant access to their patients' medical records and test results, even when they are far away from their offices.

Chameleons and Oxygen

We expect SpectrumWare–based communications chameleons to form the basis of the wireless communications infrastructure envisioned under the Oxygen project. In a wireless network with many mobile devices—such as the

TOM DRAPER DESIGN; MICHELLE TCHEREVKOFF *The Image Bank* (television)

"HANDY 21" DEVICE being developed by the M.I.T. Laboratory for Computer Science will incorporate the functions of a variety of communications gadgets, including (*left to right*) a television, a pager, an AM/FM radio, a cellular telephone and a wireless Internet connection. The device will be equipped with an antenna to transmit and receive communications signals, but all the signal processing will be done on a general-purpose microprocessor, allowing the user to run many applications.

network that would link the Handy 21 units—channel conditions tend to vary significantly over time and are difficult to predict. Furthermore, running a variety of applications over a network introduces considerable variability in desired bandwidth, error rate and security. For example, an electronic-commerce application may require a more thorough encryption of the communications signal than a radio or television application would require. Conventional network interfaces are fixed; they are designed to operate under the worst conditions that can be tolerated, rather than to adapt to the conditions that the system actually encounters. This often leads to inefficient use of resources such as spectrum and power.

A wireless network based on SpectrumWare technology would allow a much more dynamic organization of resources. Because the characteristics of all the communications layers are dictated by software, they can be changed at any time it seems useful to do so. For example, a base station might modify the wireless network's channels depending on the number of mobile units in the coverage area and their particular service requirements. Mobile units requiring real-time or high data-rate services might be assigned to a dedicated channel customized to their application, whereas units with lower data rates might be assigned to a shared channel.

The SpectrumWare project has already proved the usefulness of communications chameleons; now we are involved in creating practical applications that can be incorporated into future networks. Everything we do follows three basic tenets: First, whenever possible, we build general-purpose devices rather than special-purpose devices. Second, we design communications systems that can be dynamically optimized for the existing case, rather than for some hypothetical worst or even average case. Finally, whenever possible we design our systems in software, not hardware. And, fortunately for us, it is almost always possible to do it in software.

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Raw Computation

One of the main engines of the Oxygen project is the Raw microchip, which has wiring that can be automatically reprogrammed for different tasks

by Anant Agarwal

The Oxygen project is based on the premise that computation will eventually become as freely available as air. To achieve this goal, however, computer scientists, software designers and electrical engineers must rethink the basic architecture that underlies current computer systems. My colleagues and I in the Raw project at the M.I.T. Laboratory for Computer Science are developing an entirely new kind of microprocessor for the Oxygen project. Called the Raw chip, it will deliver unprecedented performance, energy efficiency and cost-effectiveness because of its flexible design: by exposing its wiring to the software system, the chip itself can be customized to suit the needs of whatever application is running on it.

The relentless miniaturization of microprocessors has paved the way for the Raw chip. In 1987 a microprocessor containing about 100,000 transistors and capable of performing 20 million instructions per second (MIPS) could fit on roughly one square centimeter (0.16 square inch) of silicon. But in 1997 a microprocessor with the same computing power could fit on a chip only one millimeter square. And in 2007 a 20-MIPS microprocessor will fit on a chip only one tenth of a millimeter square—one ten-thousandth the size of the 1987 microprocessor. We are entering an era in which each microchip will have billions of transistors. Clearly, we have an amazing opportunity before us.

We can, of course, fritter away this opportunity. One way to do so would be to continue advancing our chip architectures and technologies as just more of the same: building microprocessors that are simply more complicated versions of the kind built today. The problem is that the current architecture for microprocessors does not scale. Most personal computers use an interface called the Instruction Set Architecture, or ISA, between the hardware and the software. The instructions in the ISA move data from storage locations on the microprocessor to function units where the data are added, multiplied or otherwise processed. For example, an instruction might say: "ADD, Register 7, Memory Location 1,024, Register 8." This instruction directs the microprocessor to add the contents of Register 8 and Memory Location 1,024 and to store the resulting sum in Register 7. But most instruction sets do not tell the software where the memory locations or function units reside on the chip, so current microprocessors must use hardware—for example, sets of wires or buses—to connect every memory location with every function unit.

The ongoing reduction in transistor sizes will enable hardware designers to squeeze more storage locations and function units onto each chip. Smaller transistors will also lead to a decrease in the duration of the chip's clock cycle, which is the time required to perform a basic operation such as addition. But because the current architecture requires that the chip's wires connect every memory location with every function unit, the lengths of the wires will remain proportional to the diameter of the chip and will not decrease along with the clock cycle. Delays in moving data along the wires will become increasingly significant and will eventually set a limit on the chip's performance. The current architecture will also result in less energy-efficient microprocessors, because longer wires require more energy to switch signals.

Getting around the Problem

Some would argue that we have already hit a brick wall in terms of complexity, speed and energy efficiency in our existing architectures. Every personal computer has a microprocessor inside, but if you want to take full advantage of the machine you also have to buy several add-on cards, such as a modem card, a graphics card, a sound card, a math card, an FM radio card and a video card. You need to buy a big case for your personal computer simply to plug in all these specialized cards. Once the cards are installed, the system as a whole can deliver adequate performance for various multimedia applications.

But how do these special cards deliver the required performance? Some hardware designer has very carefully handcrafted the wiring on the cards' customized chips to match each specific application: video, radio and so on. The hardware experts have hand-fashioned the wires to fit the needs of the application, tailoring the circuits so that the wires are as short as possible and all the signals get from their origination point to the right place at exactly the right time. A huge amount of effort goes into this process.

So how can we get around this brick wall blocking the improvement of computer performance? We propose to solve the problem by throwing logic gates at it. A logic gate is an arrangement of transistors that controls the direction of electric current on a microchip and hence the flow of information. In about 10 years every chip will have billions of logic gates. Chip designers can take advantage of this surfeit by constructing a software compiler that uses the abundant logic gates to reroute the flow of information on the chip's wires. Instead of forcing chipmakers to spend so much time carefully laying out the wires for each application, we are going to build a processor and a compiler that permit us to

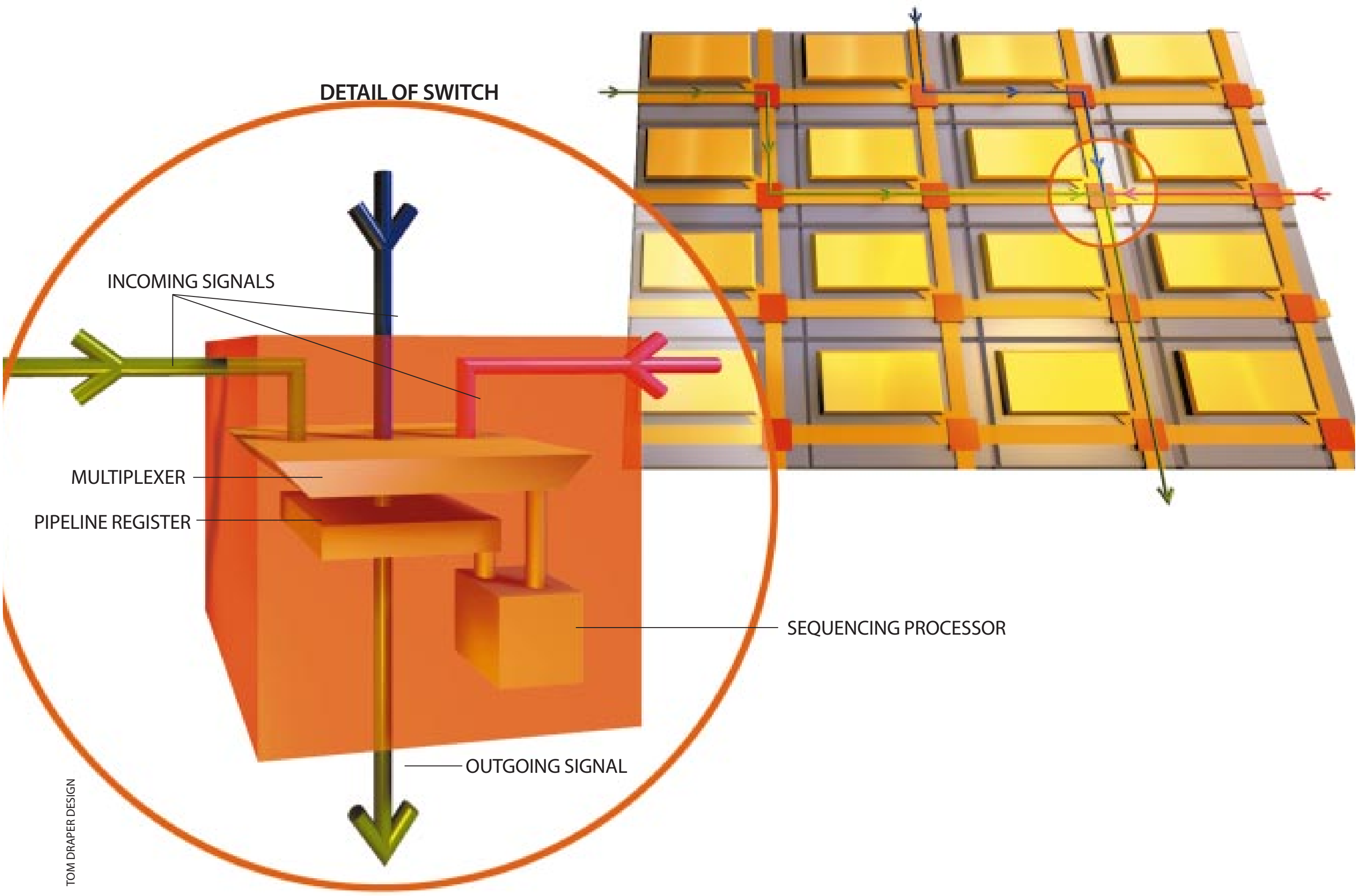
RAW MICROPROCESSOR is a rectangular array of many identical tiles. (Only a small portion of the microchip is shown above.) Each tile contains memory locations that store data and function units where the data are processed. Areas for data processing and storage are represented by the gold rectangles within the tiles. Signals flow through sets of wires that connect each tile to its neighbors. Switches at the wire junctions direct signals to data-processing areas or to adjacent tiles. The pathways of the signals are determined by a software compiler that programs the switches to meet the needs of whatever application is running on the microprocessor. The chip can run more than one application at a time; for example, it can direct a stream of video data (*blue*) along the optimal pathway for a video application, while simultaneously guiding an audio signal (*yellow*) along the path best suited for a radio application.

reconfigure the wires automatically. The software compiler will be able to take applications written in human-readable languages, such as C and Java, and map them directly into the chips.

This new model of computation is called Raw because it exposes the raw hardware on a chip—including the wires—to the software compiler. By using the free logic gates to direct and store the signals that run through the chip's wires, the compiler basically customizes the wiring for each application. This is a radical departure from existing architectures, in which software controls the chip's logic operations—basic functions such as "ADD" and "SUBTRACT"—but not the chip's wiring. In contrast, Raw allows the software to program the wires, the microchip's most valuable resource.

The layout of the Raw chip is very simple. The chip itself is an array of many tiles. Each tile is identical to all the others and contains memory units, which are collections of memory locations, and function units. More important, each tile has a switch that controls the wires connecting the tile with adjacent ones.

The excess logic gates are devoted to this switch. The compiler programs the switches on all the tiles to issue a sequence of commands that determine exactly which set of wires to connect at every cycle in the chip's operation. Thus, the compiler and the software system choreograph how data move around the entire chip by programming each of the



MULTIPLEXING improves the performance of the Raw microprocessor by routing several signals along a single wire segment. The software compiler programs the chip so that the signals converge at one switch in the array of tiles (*right*). The switch contains a multiplexer and a sequencing processor, which are also programmed by the compiler (*left*). Depending on the needs of the application running on the chip, the multiplexer selects one of the incoming signals (*green*) and transmits it along a wire segment leading to an adjacent tile. During the next clock cycle, the multiplexer transmits another signal. (The wire segment can carry only one signal during a given clock cycle.) The pipeline register in the switch stores the data until the signals can be transmitted. Multiplexing increases the carrying capacity of the chip's wires and thus reduces delays in moving data across the chip.

switching blocks. The customized signal routing effectively rewires the chip for each application.

As a first step, the compiler "pipelines" the chip's wiring so that long wires do not incur long delays. It does this by introducing registers for storing data along the wires, essentially breaking them up into multiple segments. When a wire is pipelined, a signal does not have to traverse the entire length of the wire during a clock cycle; it traverses only one segment and is then stored in a register. Because the duration of the clock cycle can be much shorter, the Raw architecture can greatly improve clock frequency, or the number of cycles that a chip can complete in a second. Raw chips will be able to achieve clock frequencies on the order of 10 to 15 gigahertz by 2010, compared with frequencies of about 500 megahertz for today's microprocessors. Although communicating a signal along a pipelined wire will take multiple clock cycles, many signal values—one for each segment—will be able to travel down the wire simultaneously. After the first signal value arrives at its destination, subsequent signal values will arrive at the end of every clock cycle, thereby increasing the signal throughput, or carrying capacity, of the wire.

The compiler also attempts to place signal values in memory locations close to the function units that will process the data. This minimizes the number of cycles that the signal values spend traveling from one location to another.

The next step comes from the realization that because the chip's wires are such a critical resource, using a wire to connect only two locations on a chip is wasteful. Rather we would like to "multiplex" each wire segment so that it can connect a large number of storage locations and function units. Multiplexing is similar to merging the feeder roads from several cities into a superhighway. Signals from the feeder connections arrive at one end of the wire segment, and a multiplexer constructed from logic gates ensures that only one signal is transmitted along the segment during a given clock cycle. The compiler programs the multiplexers to select the appropriate signals at the right times for each application. Just as a superhighway carries more traffic than a feeder road, a multiplexed wire carries many more signals than an ordinary wire.

Finally, the compiler routes the signals along the optimal pathways by precisely scheduling the signals to meet the demands of the application. Because the chip's wires are programmed by the software, we like to call them "soft wires."

A major advantage of this design is that it can bring massive streams of data—for instance, video or sensor information—directly to the parts of the chip where computation takes place. The faster data input will yield far better performance and energy efficiency than is currently possible. The Raw chip we are building will have more than 1,000 input-output pins that can be dedicated to data streams—10 times more than the number of such pins in today's microprocessors.

By exposing its wiring to the software system, the chip itself can be customized to suit the needs of whatever application is running on it.

One Chip Fits All

The Raw chip could be incorporated into a single device that could perform a wide variety of applications: encryption or speech recognition, games or communications. We have dubbed this proposed 21st-century tool the Handy 21. A user would be able to tell the Handy 21, "Hey, turn yourself into a cell phone." The device would then locate the appropriate configuration software, download it and configure the wires of the Raw chip inside to give it the characteristics of a cell phone.

Today I carry a beeper. I also carry a cell phone and a Palm Pilot. But in the near future I'll be able to throw away all these specialized gadgets. Instead I'll carry just the Handy 21, which will be able to download the appropriate configuration software and take on the functions of pretty much any device I want. The Handy 21 will contain a single Raw chip and several perceptual interfaces: cameras, small video displays and speech-based interfaces, including both speakers and microphones. It will use an antenna for communications and an analog-to-digital converter. The converter will be integrated on the same Raw chip, so that virtually all the functions for which we now buy special hardware will be accomplished by customizing applications directly into the chip's wires.

Our team has already built a compiler that can program applications directly into a simulator of the Raw chip. For example, we compiled a software radio application—which gives a personal computer the ability to function as an FM radio—to a 128-tile Raw chip [see "Communications Chameleons," on page 58]. Our results indicate that the application will run on the order of 10 times faster on the Raw chip than on any conventional microprocessor. Some of our students obtained a further 10-fold improvement by painstakingly translating the application without the aid of a compiler. But the real challenge is to develop a compiler that can approach the 100-fold improvement achieved by hand-customizing a chip's wiring to match the application.

If we are successful, the Raw chip could become a universal logic chip, a replacement for both general-purpose microprocessors and special-purpose microchips. We can say, with perhaps a bit of overstatement, that within a couple of decades there will be only three kinds of chips in the world: Raw chips, memory chips and, of course, potato chips.

ANANT AGARWAL co-directs the Raw project at the M.I.T. Laboratory for Computer Science. He is an associate director of the lab and professor of electrical engineering and computer science at M.I.T., where his research interests include computer architecture, compilation and software systems. He earned his Ph.D. in electrical engineering from Stanford University in 1987. The other members of the Raw project team are Michael Zhang, Michael Taylor, Mark Stephenson, Andras Moritz, Jason Miller, Albert Ma, Walter Lee, Sam Larsen, Jason Kim, Benjamin Greenwald, Matthew Frank, Rajeev Barua, Jonathan Babb and Saman Amarasinghe.

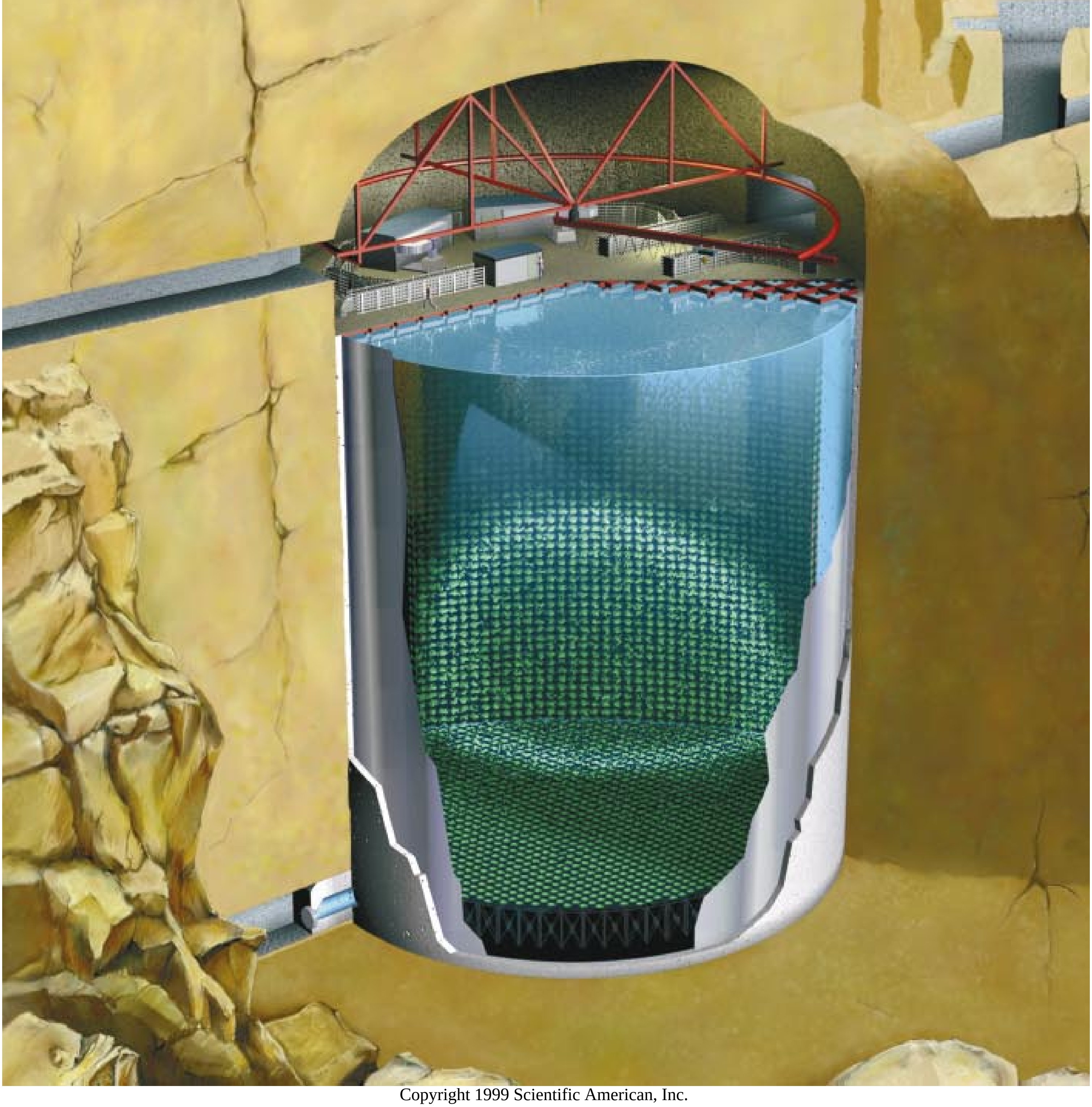
Further Reading

The M.I.T. Laboratory for Computer Science's home page (www.lcs.mit.edu) summarizes the work of the many research groups involved in the Oxygen project. The home page of the Spoken Language Systems group (www.sls.lcs.mit.edu/sls/) offers details on conversational interfaces and the speech-based applications that the group has developed. Information on software communications devices and wireless networking can be found at the SpectrumWare project's home page (www.sds.lcs.mit.edu/SpectrumWare/home.html). The Raw project's site (www.cag.lcs.mit.edu/raw/) includes a description of the Raw microprocessor as well as a list of publications by the project's team members. Contact information for the researchers is also available at the laboratory's Web site (www.lcs.mit.edu/contact/). For an overview of the future of information technology, a good source is *What Will Be,* by Michael L. Dertouzos (HarperCollins, 1997).

Detecting Massive Neutrinos

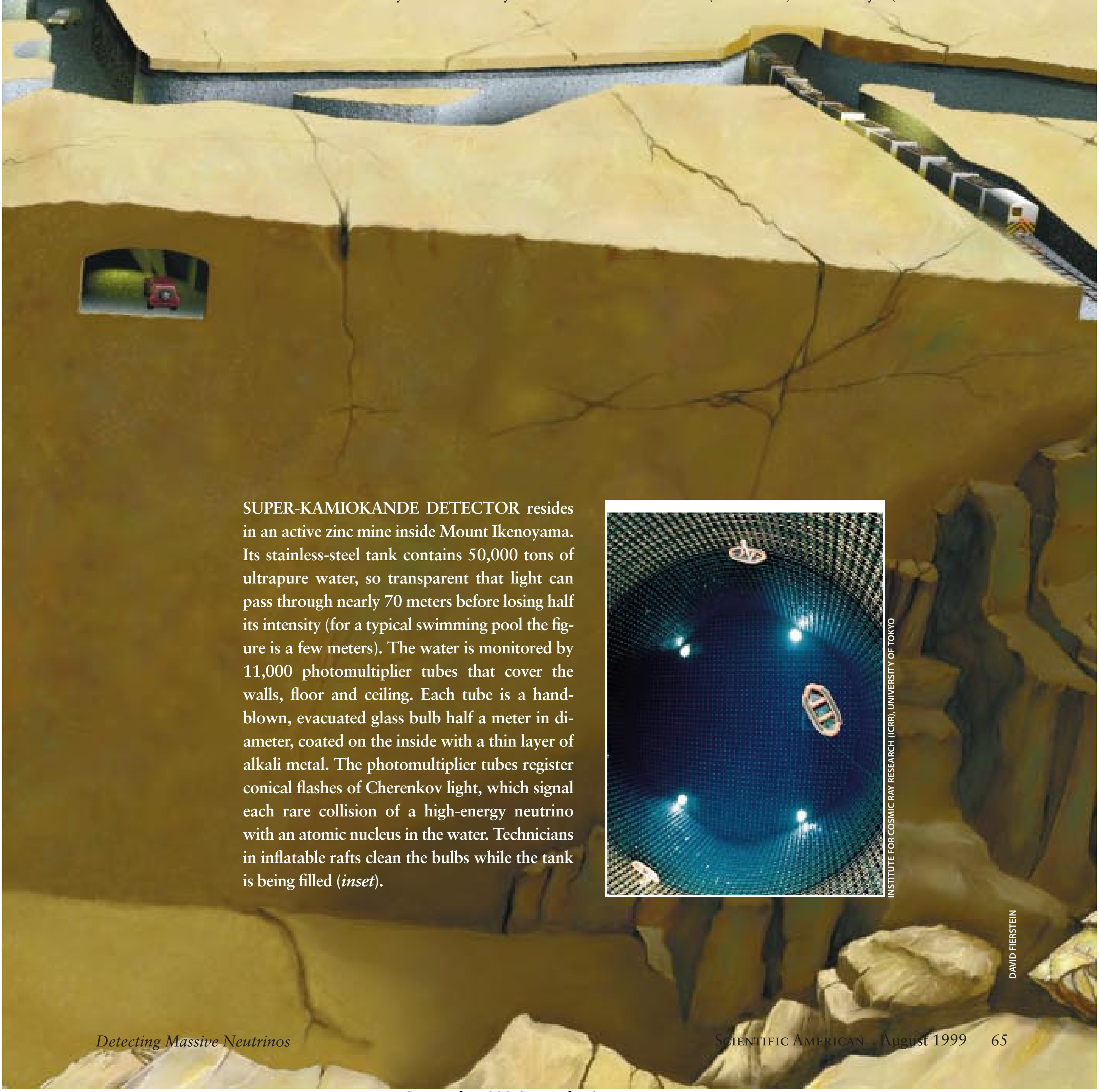
A giant detector in the heart of Mount Ikenoyama in Japan has demonstrated that the neutrino metamorphoses in flight, strongly suggesting that these ghostly particles have mass

by Edward Kearns, Takaaki Kajita and Yoji Totsuka



One man's trash is another man's treasure. For a physicist, the trash is "background"—some unwanted reaction, probably from a mundane and well-understood process. The treasure is "signal"—a reaction that we hope reveals new knowledge about the way the universe works. Case in point: over the past two decades, several groups have been hunting for the radioactive decay of the proton, an exceedingly rare signal (if it occurs at all) buried in a background of reactions caused by elusive particles called neutrinos. The proton, one of the main constituents of atoms, seems to be immortal. Its decay would be a strong indication of processes described by Grand Unified Theories that many believe lie beyond the extremely successful Standard Model of particle physics. Huge proton-decay detectors were placed deep underground, in mines or tunnels around the world, to escape the constant rain of particles called cosmic rays. But no matter how deep they went, these devices were still exposed to penetrating neutrinos produced by the cosmic rays.

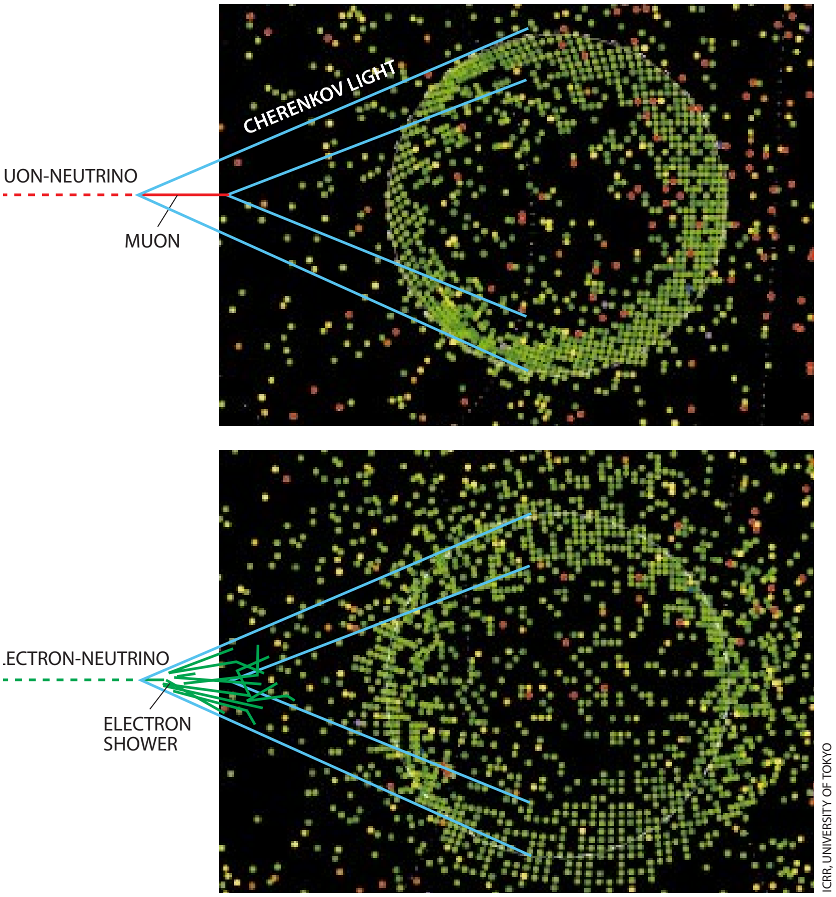
The first generation of proton-decay detectors, operating from 1980 to 1995, saw no signal, no signs of proton decay—but along the way the researchers found that the supposedly mundane neutrino background was not so easy to understand. One such experiment, Kamiokande, was located in Kamioka, Japan, a mining town about 250 kilometers (155 miles) from Tokyo (as the neutrino



INSTITUTE FOR COSMIC RAY RESEARCH (ICRR), UNIVERSITY OF TOKYO

DAVID FIERSTEIN

SUPER-KAMIOKANDE DETECTOR resides in an active zinc mine inside Mount Ikenoyama. Its stainless-steel tank contains 50,000 tons of ultrapure water, so transparent that light can pass through nearly 70 meters before losing half its intensity (for a typical swimming pool the figure is a few meters). The water is monitored by 11,000 photomultiplier tubes that cover the walls, floor and ceiling. Each tube is a handblown, evacuated glass bulb half a meter in diameter, coated on the inside with a thin layer of alkali metal. The photomultiplier tubes register conical flashes of Cherenkov light, which signal each rare collision of a high-energy neutrino with an atomic nucleus in the water. Technicians in inflatable rafts clean the bulbs while the tank is being filled (*inset*).



CONES OF CHERENKOV LIGHT are emitted when high-energy neutrinos hit a nucleus and produce a charged particle. A muon-neutrino (*top*) creates a muon, which travels perhaps one meter and projects a sharp ring of light onto the detectors. An electron, produced by an electron-neutrino (*bottom*), generates a small shower of electrons and positrons, each with its own Cherenkov cone, resulting in a fuzzy ring of light. Green dots indicate light detected in the same narrow time interval.

flies). The name stood for "Kamioka Nucleon Decay Experiment." Scientists there and at the IMB experiment, located in a salt mine near Cleveland, Ohio, used sensitive detectors to peer into ultrapure water, waiting for the telltale flash of a proton decaying.

Such an event would have been hidden, like a needle in a small haystack, among about 1,000 similar flashes caused by neutrinos interacting with the water's atomic nuclei. Although no proton decay was seen, the analysis of those 1,000 reactions uncovered a real treasure—tantalizing evidence that the neutrinos were unexpectedly fickle, changing from one species to another in midflight. If true, that phenomenon was just as exciting and theory-bending as proton decay.

Neutrinos are amazing, ghostly particles. Every second, 60 billion of them, mostly from the sun, pass through each square centimeter of your body (and of everything else). But because they seldom interact with other particles, generally all 60 billion go through you without so much as nudging a single atom. In fact, you could send a beam of such neutrinos through a light-year of lead, and most of them would emerge totally unscathed at the far end. A detector as large as Kamiokande catches only a tiny fraction of the neutrinos that pass through it every year.

Neutrinos come in three flavors, corresponding to their three charged partners in the Standard Model: the electron and its heavier relatives, the muon and the tau particle. An electron-neutrino interacting with an atomic nucleus can produce an electron; a muon-neutrino makes a muon; a tau-neutrino, a tau. For most of the seven decades since neutrinos were first posited, physicists have assumed that they are massless. But if they can change from one flavor to another, quantum theory indicates that they most likely have mass. And in that case, these ethereal particles could collectively outweigh all the stars in the universe.

Building a Bigger Neutrino Trap

As is so often the case in particle physics, the way to make progress is to build a bigger machine. Super-Kamiokande, or Super-K for short, took the basic design of Kamiokande and scaled it up by about a factor of 10 [*see illustration on page 64*]. An array of light-sensitive detectors looks in toward the center of 50,000 tons of water whose protons may decay or get struck by a neutrino. In either case, the reaction creates particles that are spotted by means of a flash of blue light known as Cherenkov light, an optical analogue of a sonic boom, discovered by Pavel A. Cherenkov in 1934. Much as an aircraft flying faster than the speed of sound produces a shock wave of sound, an electrically charged particle (such as an electron or muon) emits Cherenkov light when it exceeds the speed of light in the medium in which it is moving. This motion does not violate Einstein's theory of relativity, for which the crucial velocity is *c*, the speed of light in a vacuum. In water, light propagates 25 percent slower than *c*, but other highly energetic particles can still travel almost as fast as *c* itself. Cherenkov light is emitted in a cone along the flight path of such particles.

In Super-K, the charged particle generally travels just a few meters and the Cherenkov cone projects a ring of light onto the wall of photon detectors [*see illustration on this page*]. The size, shape and intensity of this ring reveal the properties of the charged particle, which in turn tell us about the neutrino that produced it. We can easily distinguish the Cherenkov patterns of electrons from those of muons: the electrons generate a shower of particles, leading to a fuzzy ring quite unlike the crisper circle from a muon. From the Cherenkov light we also measure the energy and direction of the electron or muon, which are decent approximations to those of the neutrino.

Super-K cannot easily identify the third type of neutrino, the tau-neutrino. Such a neutrino can only interact with a nucleus and make a tau particle if it has enough energy. A muon is about 200 times as heavy as an electron; the tau about 3,500 times. The muon mass is well within the range of atmospheric neutrinos, but only a tiny fraction are at tau energies, so most tau-neutrinos in the mix will pass through Super-K undetected.

One of the most basic questions experimenters ask is, “How many?” We have built a beautiful detector to study neutrinos, and the first task is simply to count how many we see. Hand in hand with this measurement is the question, “How many did we expect?” To answer that, we must analyze how the neutrinos are produced.

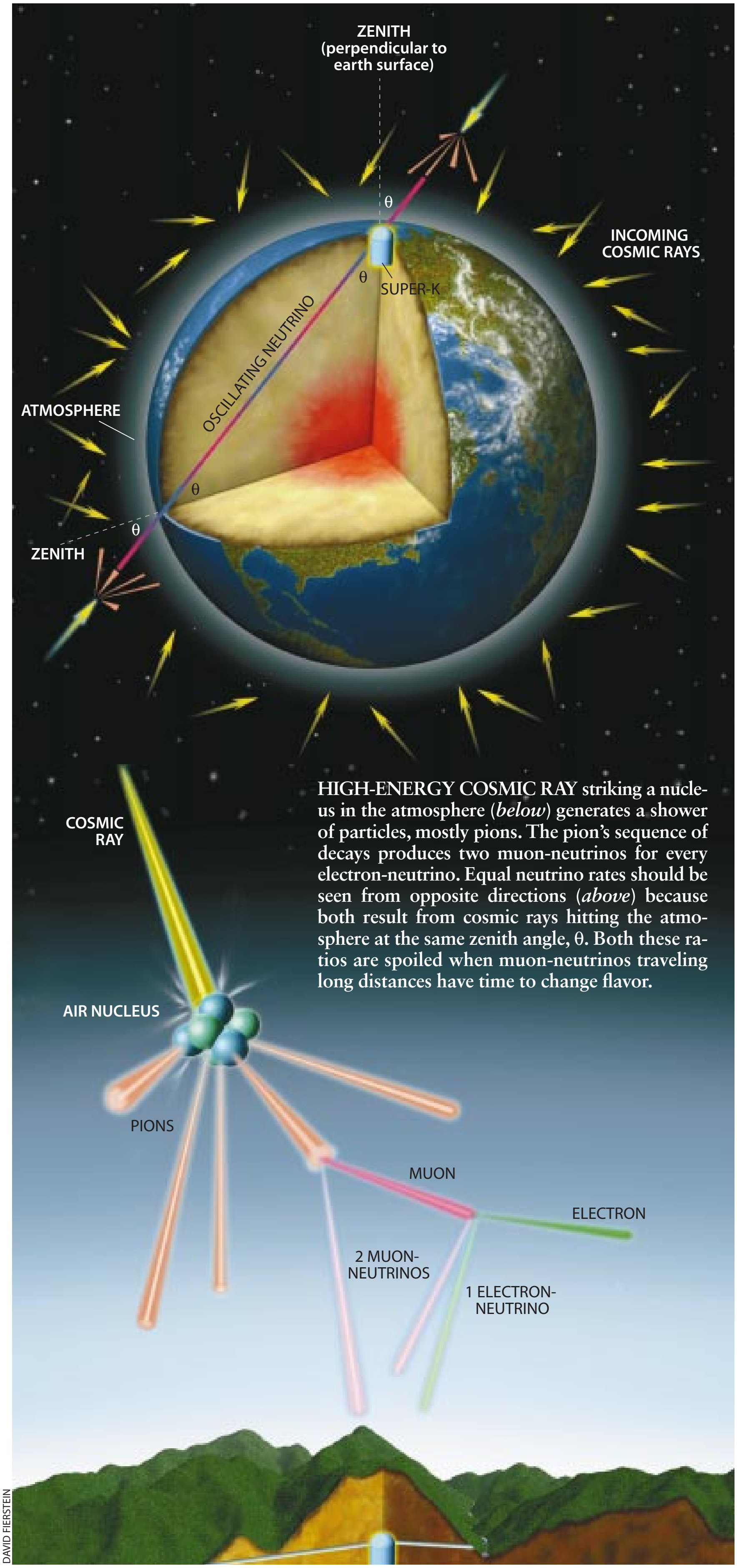
Super-K monitors atmospheric neutrinos, which are born in the spray of particles when a cosmic ray strikes the top of our atmosphere. The incoming projectiles (called primary cosmic rays) are mostly protons, with a sprinkling of heavier nuclei such as helium or iron. Each collision generates a shower of secondary particles, mostly pions and muons, which decay during their short flight through the air, creating neutrinos [*see illustration at right*]. We know roughly how many cosmic rays hit the atmosphere each second and roughly how many pions and muons are made in each collision, so we can predict how many neutrinos to expect.

Tricks with Ratios

Unfortunately, this estimate is only accurate to 25 percent, so we take advantage of a common trick: often the ratio of two quantities can be better determined than either quantity alone. For Super-K, the key is the sequential decay of a pion to a muon and a muon-neutrino, followed by the muon’s decay to an electron, an electron-neutrino and another muon-neutrino. No matter how many cosmic rays are falling on the earth’s atmosphere, or how many pions they produce, there should be about two muon-neutrinos for every electron-neutrino. The calculation is more complicated than that and involves computer simulations of the cosmic ray showers, but the final predicted ratio is accurate to 5 percent, providing a much better benchmark than the individual numbers of particles do.

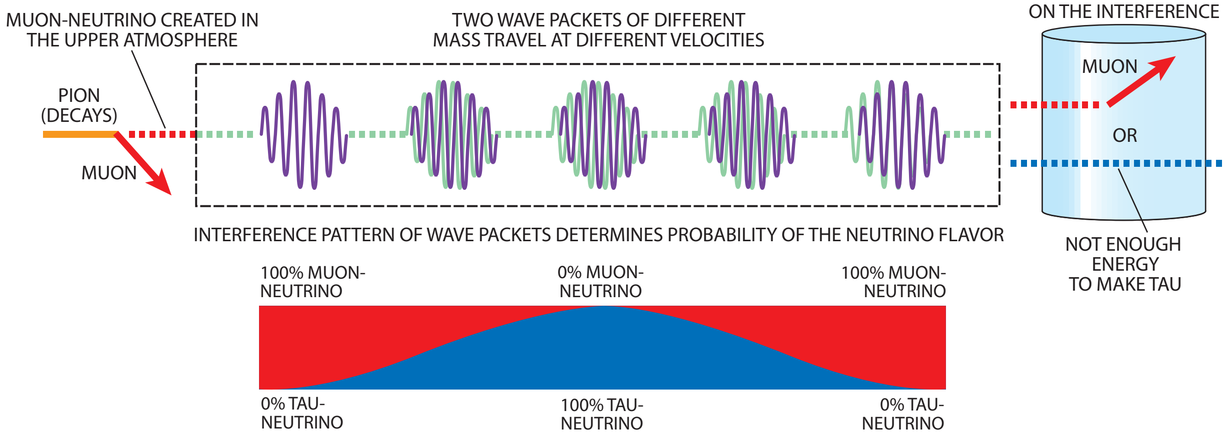
After counting neutrinos for almost two years, the Super-K team has found that the ratio of muon-neutrinos to electron-neutrinos is about 1.3 to 1 instead of the expected 2 to 1. Even if we stretch our assumptions about the flux of neutrinos, how they interact with the nuclei and how our detector responds to these events, we cannot explain such a low ratio—unless neutrinos are changing from one type into another.

We can play the ratio trick again to



HIGH-ENERGY COSMIC RAY striking a nucleus in the atmosphere (*below*) generates a shower of particles, mostly pions. The pion’s sequence of decays produces two muon-neutrinos for every electron-neutrino. Equal neutrino rates should be seen from opposite directions (*above*) because both result from cosmic rays hitting the atmosphere at the same zenith angle, θ. Both these ratios are spoiled when muon-neutrinos traveling long distances have time to change flavor.

How Quantum Waves Make a Neutrino Oscillate



When a pion decays (*top left*), it produces a neutrino. Described quantum-mechanically, the neutrino is apparently a superposition of two wave packets of different mass (*purple* and *green; top middle*). The wave packets propagate at different speeds, with the lighter wave packet getting ahead of the heavier one. As this proceeds, the waves interfere, and the interference pattern controls what flavor neutrino—muon (*red*) or tau (*blue*)—one is most likely to detect at any point along the flight path (*bottom*). Like all quantum effects, this is a game of chance, with the chances heavily favoring a muon-neutrino close to where it was produced. But the probabilities oscillate back and forth, favoring the tau-neutrino at just the right distance and returning to favor the muon-neutrino farther on. When the neutrino finally interacts in the detector (*top right*), the quantum dice are rolled. If the outcome is muon-neutrino, a muon is produced. If chance favors the tau-neutrino, and the neutrino does not have enough energy to create a tau particle, Super-K detects nothing. —*E.K., T.K. and Y.T.*

LAURIE GRACE

test this surprising conclusion. The clue to our second ratio is to ask how many neutrinos should arrive from each possible direction. Primary cosmic rays fall on the earth's atmosphere almost equally from all directions, with only two effects spoiling the uniformity. First, the earth's magnetic field deflects some cosmic rays, especially the low-energy ones, skewing the pattern of arrival directions. Second, cosmic rays that skim the earth at a tangent make showers that do not descend deep into the atmosphere, and these can develop differently from those that plunge straight in from above.

But geometry saves us: if we "look" up into the sky at some angle from the vertical and then down into the ground at the same angle, we should "see" the same number of neutrinos coming from each direction. Both sets of neutrinos are produced by cosmic rays hitting the atmosphere at the same angle; it is just that in one case the collisions happen overhead and in the other they are partway around the world [*see illustration on preceding page*]. To use this fact, we select neutrino events of sufficiently high energy (so their parent cosmic ray was not deflected by the earth's magnetic field) and then divide the number of neutrinos going up by the number going down. This ratio should be exactly 1 if no neutrinos are changing flavor.

We saw essentially equal numbers of high-energy electron-neutrinos going up and down, as expected, but only half as many upward muon-neutrinos as downward ones. This finding is the second indication that neutrinos are changing identity. Moreover, it provides a clue to the nature of the metamorphosis. The upward muon-neutrinos cannot be turning into electron-neutrinos, because there is no excess of upward electron-neutrinos. That leaves the tau-neutrino. The muon-neutrinos that become tau-neutrinos pass through Super-K without interaction, without detection.

Fickle Flavor

The above two ratios are good evidence that muon-neutrinos are transforming into tau-neutrinos, but why should neutrinos switch flavor at all? Quantum physics describes a particle moving through space by a wave: in addition to properties such as mass and charge, the particle has a wavelength, it

1930

Wolfgang Pauli rescues conservation of energy by hypothesizing an unseen particle

1933

Enrico Fermi formulates the theory of beta-decay incorporating Pauli's particle,

1956

Frederick Reines (*center*) and Clyde Cowen first detect the neutrino using the Savannah

1962

At Brookhaven, the first accelerator beam of neutrinos proves the distinction

1969

Raymond Davis, Jr., first measures neutrinos from the sun, using 600 tons of can diffract, and so on. Furthermore, a particle can be the superposition of two waves. Now suppose that the two waves correspond to slightly different masses. Then, as the waves travel along, the lighter wave gets ahead of the heavier one, and the waves interfere in a way that fluctuates along the particle's trajectory [*see box on opposite page*]. This interference has a musical analogue: the beats that occur when two notes are almost but not exactly the same.

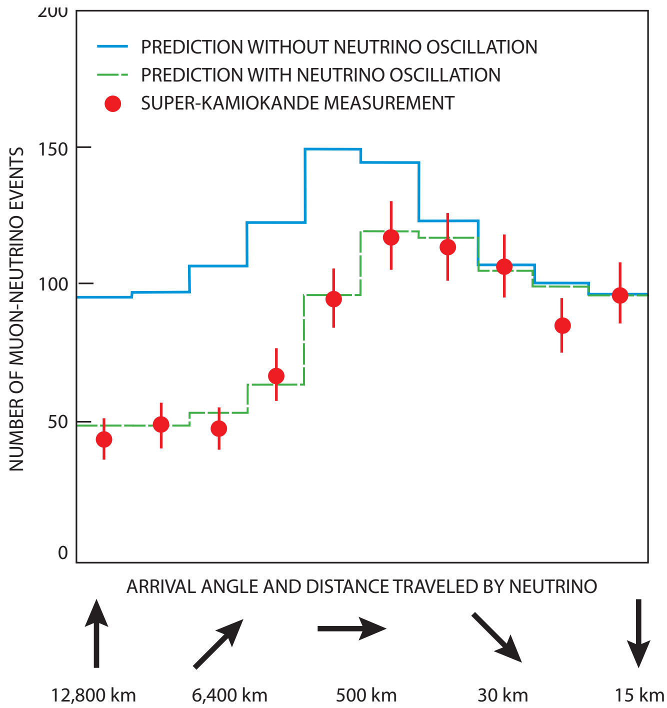
In music this effect makes the volume oscillate; in quantum physics it is the probability of detecting one type of neutrino or another that oscillates. At the outset the neutrino appears as a muon-neutrino with a probability of 100 percent. After traveling a certain distance, it looks like a tau-neutrino with 100 percent probability. At other positions, it could be either a muon-neutrino or a tau-neutrino, depending on the roll of the dice.

This oscillation sounds like bizarre behavior for a particle, but another familiar particle performs similar contortions: the photon, the particle of light. Light can occur in a variety of polarizations, including vertical, horizontal, left circular and right circular. These do not have different masses (all photons are massless), but in certain optically active materials, light with left circular polarization moves faster than right circular light. A photon with vertical polarization is actually a superposition of these two alternatives, and when it is traversing an optically active material its polarization will rotate (that is, oscillate) from vertical to horizontal and so on, as its two circular components go in and out of sync.

For neutrino oscillations of the type we see at Super-K, no "optically active" material is needed; a sufficient mass difference between the two neutrino components will cause flavor oscillations whether the neutrino is passing through air, solid rock or pure vacuum. When a neutrino arrives at Super-K, the amount it has oscillated depends on its energy and the distance it has traveled since it was created. For downward muon-neutrinos, which have traveled at most a few dozen kilometers, only a small fraction of an oscillation cycle has taken place, so the neutrinos' flavor is only slightly shifted, and we are nearly certain to detect their original muon-neutrino flavor [*see illustration on page 67*]. The upward muon-neutrinos, produced thousands of kilometers away, have gone through so many oscillations that on average only half of them can be detected as muon-neutrinos. The other half pass through Super-K as undetectable tau-neutrinos.

This description is just a rough picture, but the arguments based on the ratio of flavors and the up/down event rate are so compelling that neutrino oscillation is now widely accepted as the most likely explanation for our data. We also have done more detailed studies of how the number of muon-neutrinos varies according to the neutrino energy and the arrival angle. We compare the measured number against what is expected for a wide array of possible oscillation scenarios (including no oscillations). The data look quite unlike the no-oscillation expectation but match well with neutrino oscillation for certain values of the mass difference and other physical parameters [*see illustration above*].

With about 5,000 events from our first two years of running the experi-

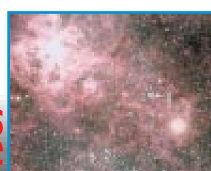


LAURIE GRACE

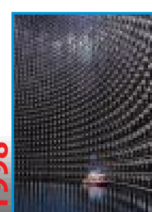
NUMBER OF HIGH-ENERGY MUON-NEUTRINOS seen arriving on different trajectories at Super-K clearly matches a prediction incorporating neutrino oscillations (*green*) and does not match the no-oscillation prediction (*blue*). Upward-going neutrinos (*plotted toward left of graph*) have traveled far enough for half of them to change flavor and escape detection.

1975–1977
The tau lepton and b quark are discovered, revealing a third generation of quarks

1983
W and Z^0 bosons are discovered at CERN: they are the carriers of the weak force, which

1987

Neutrino astronomy: the IMB and Kamiokande proton decay experiments detect 19 neutrinos

1989
The Z^0 decay rate is precisely measured at SLAC and CERN, showing

1998

Super-K assembles evidence of neutrino oscillation using

TIMELINE BY HEIDI NOLAND; AIP EMILIO SEGRÈ VISUAL ARCHIVES (*Pauli and Reines*); COURTESY OF THE INSTITUTE FOR ADVANCED STUDY, PRINCETON (*Davis*); DAVID MALIN *Anglo-Australian Observatory (SN1987A)*; ICRR (*Super-Kamiokande*) ment, we have eliminated any speculation that the anomalous numbers of atmospheric neutrinos could be just a statistical fluke. But it is still important to confirm the effect by looking for the same muon-neutrino oscillation with other experiments or techniques. Different detectors in Minnesota and Italy have provided some verification, but with fewer events measured they do not have the same statistical certainty.

Corroborating Evidence

Further corroboration comes from studies of a different variety of atmospheric neutrino interaction: their collisions with nuclei in the rock around our detector. Electron-neutrinos again produce electrons and subsequent showers of particles, but these are absorbed in the rock and never reach Super-K's cavern. High-energy muon-neutrinos make high-energy muons, which can travel through many meters of rock and enter our detector. We count such muons from upward-traveling neutrinos—downward muons are masked by the background of cosmic-ray muons that penetrate Mount Ikenoyama from above.

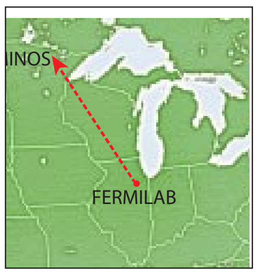
We can count upward-traveling muons arriving on trajectories that range from directly up to nearly horizontal. These paths correspond to neutrino travel distances (from production in the atmosphere to the creation of a muon near Super-K) as short as 500 kilometers (the distance to the edge of the atmosphere when looking horizontally) and as long as 13,000 kilometers (the diameter of the earth, looking straight down). We find that the numbers of muon-neutrinos of lower energy that travel a long distance are more depleted than higher-energy muon-neutrinos that travel a short distance. This behavior is just what we expect from oscillations, and careful analysis produces neutrino parameters similar to those from our first study.

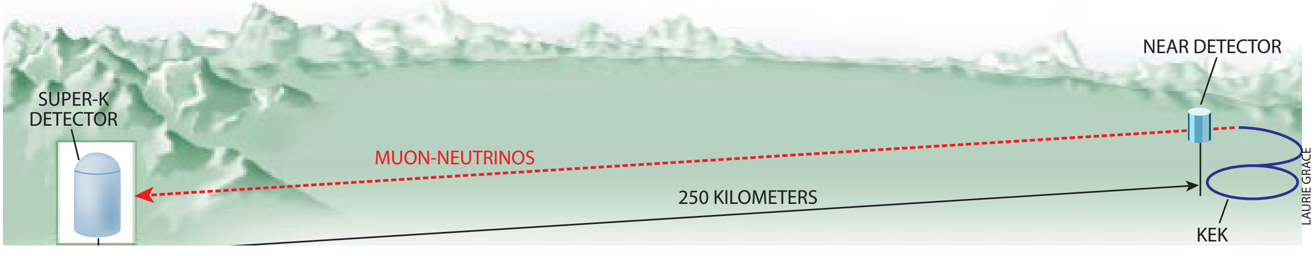
If we consider just the three known neutrinos, our data tell us that muon-neutrinos are changing into tau-neutrinos. Quantum theory says that the underlying cause of the oscillation is almost certainly that these neutrinos have mass—although it has been assumed for 70 years that they do not. (The box on the opposite page mentions some other scenarios.)

Unfortunately, quantum theory also limits our experiment to measuring only the difference in mass-squared between the two neutrino components, because that is what determines the oscillation wavelength. It is not sensitive to the mass of either one alone. Super-K's data give a mass-squared difference somewhere between 0.001 and 0.01 electron volt (eV) squared. Given the pattern of masses of other known particles, it is likely that one neutrino is much lighter than the other, which would mean that the mass of the heavier neutrino is in the range of 0.03 to 0.1 eV. What are the implications of this result?

First, giving neutrinos a mass does not wreck the Standard Model. The mismatch between the mass states that make up each neutrino requires the introduction of a set of so-called mixing parameters. A small amount of such mixing has long been observed among quarks, but our data imply that neutrinos need a much greater degree of mixing—an important piece of information that any successful new theory must accommodate.

Second, 0.05 eV is still very close to zero, compared with the masses of the other particles of matter. (The lightest of those is the electron, with a mass of 511,000 eV.) So the long-held belief that neutrinos had exactly zero mass is understandable. But theoreticians who wish to build a Grand Unified Theory, which would elegantly combine all the forces except gravity at enormously high energies, also take note of this relative lightness of neutrinos. They often employ a mathematical device called the seesaw mechanism that actually predicts that such a small but nonzero neutrino mass is very natural. Here the mass of some very heavy particle, perhaps at the Grand Unified mass scale, provides the leverage to separate the very light neutrinos from the quarks and leptons that are a billion to a trillion times heavier.





LONG-BASELINE neutrino oscillation experiments are planned in Japan and the U.S. Beams of neutrinos from accelerators will be detected hundreds of kilometers away. The experiments should confirm the oscillation phenomenon and precisely measure the constants of nature that control it.

Another implication is that the neutrino mass should now be considered in the bookkeeping of the mass of the universe. For some time, astronomers have been trying to tabulate how much mass is found in luminous matter, such as stars, and in ordinary matter that is difficult to see, such as brown dwarfs or diffuse gas. The total mass can also be measured indirectly from the orbital motion of galaxies and the rate of expansion of the universe. The direct accounting falls short of these indirect measures by about a factor of 20. The neutrino mass suggested by our result is too small to resolve this mystery by itself. Nevertheless, neutrinos created during the big bang permeate space and could account for a mass nearly equal to the combined mass of all the stars. They could have affected the formation of large astronomical structures, such as galaxy clusters.

Finally, our data have an immediate implication for two experiments that are soon to commence. Based on the earlier hints from smaller detectors, many physicists have decided to stop relying on the free but uncontrollable neutrinos from cosmic rays and instead are creating them with high-energy accelerators. Even so, the neutrinos must travel a long distance for the oscillation effect to be observed. So the neutrino beams are aimed at a detector hundreds of kilometers away. One such detector is being built in a mine in Soudan, Minn., optimized to study neutrinos sent from the Fermilab accelerator near Batavia, Ill., 730 kilometers away on the outskirts of Chicago.

Of course, a good atmospheric neutrino detector is also a good accelerator neutrino detector, so in Japan we are using Super-K to monitor a beam of neutrinos created at the KEK accelerator laboratory 250 kilometers away. Unlike atmospheric neutrinos, the beam can be turned on and off and has a well-defined energy and direction. Most important, we have placed a detector similar to Super-K near the origin of the beam to characterize the muon-neutrinos before they oscillate. Effectively, we are using the ratio (again) of the counts near the source to those far away to cancel uncertainty and verify the effect. As this article is being printed, neutrinos in the first long-distance artificial neutrino beam are passing under the mountains of Japan, with 50,000 tons of Super-K capturing a small handful. Exactly how many it captures will be the next chapter in this story.

Other Puzzles, Other Possibilities

There are other indications of neutrino mass that particle physicists are trying to sort out. For more than 30 years, scientists have been capturing some of the electron-neutrinos that are generated by nuclear fusion processes in the sun. These experiments have always counted fewer neutrinos than the best models of the sun predict [see "The Solar-Neutrino Problem," by John N. Bahcall; SCIENTIFIC AMERICAN, May 1990].

Super-K has also counted these solar neutrinos, finding only about 50 percent of what is expected. We are studying these data, hoping to find a clear signature of neutrino oscillations. In May the Sudbury Neutrino Observatory in Ontario detected its first neutrinos. It uses 1,000 tons of heavy water, which greatly enhances solar neutrino detection. Other new detectors will start up soon.

An experiment performed at Los Alamos National Laboratory provides a further hint of neutrino oscillation: it detects electron-neutrinos from a source that should produce only muon-neutrinos. The signal is mixed, however, with background processes. The result has not yet been independently confirmed, but some experiments will check it in the next few years.

Mass-induced oscillations between muon- and tau-neutrinos seem the most natural explanation for the Super-K neutrino data, but there are other possibilities. First, the most general scenario has mixing between all three neutrino flavors, and Super-K's data can accommodate some oscillations between electron- and muon-neutrinos at the energies it covers. Yet results from an experiment at the Chooz nuclear power station in Ardennes, France, greatly limit how much electron-muon oscillation could be occurring at Super-K.

Another possibility is that the muon-neutrinos are oscillating to a previously unseen flavor of neutrino. Still, studies of the so-called Z^0 particle at CERN, the European laboratory for particle physics near Geneva, clearly show that there are only three active flavors of neutrino. ("Active" means that the flavor participates in the weak nuclear interaction.) A new flavor would therefore have to be "sterile," a species of neutrino that interacts only through gravity. Some physicists favor this idea, because current evidence for three distinct effects (solar neutrinos, atmospheric neutrinos and the Los Alamos data) cannot be accounted for by one consistent set of masses for the electron-, muon- and tau-neutrinos.

Other oscillation mechanisms, relying on more esoteric effects than neutrino mass, have also been proposed. *—E.K., T.K. and Y.T.*

The Authors

EDWARD KEARNS, TAKAAKI KAJITA and YOJI TOTSUKA are members of the Super-Kamiokande Collaboration. Kearns, a professor of physics at Boston University, and Kajita, a professor of physics at the University of Tokyo, lead the analysis team that studies proton decay and atmospheric neutrinos in the Super-K data. Totsuka is spokesman for the Super-K Collaboration and is director of the Institute for Cosmic Ray Research at the University of Tokyo, the host institution for the experiment.

Further Reading

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The Official Super-Kamiokande Web site is available at www-sk.icrr.u-tokyo.ac.jp/doc/sk/

The K2K Long Baseline Neutrino Oscillation Experiment Web site is available at neutrino.kek.jp/

The Super-Kamiokande at Boston University Web site is available at hep.bu.edu/~superk/index.html

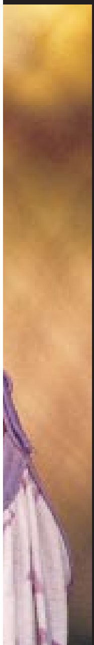
MIKE GREENLAR *The Image Works*

The Moral Developme

It is not enough for kids to tell right from wrong. They must develop a commitment to acting on their ideals. Enlightened parenting can help

NANCY RICHMOND *The Image Works*

LIGHTING UP, COOLING OFF, helping out, fighting over—children from a very young age lead a richer moral life than adults often assume. The trick for scientists is to make enough simplifications to say something useful about children's behavior but not so many that they lose sight of the psychological complexity.



JIM NOELKER *The Image Works*

nt of Children

by William Damon

With unsettling regularity, news reports tell us of children wreaking havoc on their schools and communities: attacking teachers and classmates, murdering parents, persecuting others out of viciousness, avarice or spite. We hear about feral gangs of children running drugs or numbers, about teenage date rape, about youthful vandalism, about epidemics of cheating even in academically elite schools. Not long ago a middle-class gang of youths terrorized an affluent California suburb through menacing threats and extortion, proudly awarding themselves points for each antisocial act. Such stories make *Lord of the Flies* seem eerily prophetic.

What many people forget in the face of this grim news is that most children most of the time do follow the rules of their society, act fairly, treat friends kindly, tell the truth and respect their elders. Many youngsters do even more. A large portion of young Americans volunteer in community service—according to one survey, between 22 and 45 percent, depending on the location. Young people have also been leaders in social causes. Harvard University psychiatrist Robert Coles has written about children such as Ruby, an African-American girl who broke the color barrier in her school during the 1960s. Ruby's daily walk into the all-white school demonstrated a brave sense of moral purpose. When taunted by classmates, Ruby prayed for their redemption rather than cursing them. "Ruby," Coles observed, "had a will and used it to make an ethical choice; she demonstrated moral stamina; she possessed honor, courage."

All children are born with a running start on the path to moral development. A number of inborn responses predispose them to act in ethical ways. For example, empathy—the capacity to experience another person's pleasure or pain vicariously—is part of our native endowment as humans. Newborns cry when they hear others cry and show signs of pleasure at happy sounds such as cooing and laughter. By the second year of life, children commonly console peers or parents in distress.

Sometimes, of course, they do not quite know what comfort to provide. Psychologist Martin L. Hoffman of New York University once saw a toddler offering his mother his security blanket when he perceived she was upset. Although the emotional disposition to help is present, the means of helping others effectively must be learned and refined through social experience. Moreover, in many people the capacity for empathy stagnates or even diminishes. People can act cruelly to those they refuse to empathize with. A New York police officer once asked a teenage thug how he could have crippled an 83-year-old woman during a mugging. The boy replied, "What do I care? I'm not her."

ELIZABETH CREWS *The Image Works*

A scientific account of moral growth must explain both the good and the bad. Why do most children act in reasonably—sometimes exceptionally—moral ways, even when it flies in the face of their immediate self-interest? Why do some children depart from accepted standards, often to the great harm of themselves and others? How does a child acquire mores and develop a lifelong commitment to moral behavior, or not?

Psychologists do not have definitive answers to these questions, and often their studies seem merely to confirm parents' observations and intuition. But parents, like all people, can be led astray by subjective biases, incomplete information and media sensationalism. They may blame a relatively trivial event—say, a music concert—for a deep-seated problem such as drug dependency. They may incorrectly attribute their own problems to a strict upbringing and then try to compensate by raising their children in an overly permissive way. In such a hotly contested area as children's moral values, a systematic, scientific approach is the only way to avoid wild swings of emotional reaction that end up repeating the same mistakes.

The Genealogy of Morals

The study of moral development has become a lively growth industry within the social sciences. Journals are full of new findings and competing models. Some theories focus on natural biological forces; others stress social influence and experience; still others, the judgment that results from children's intellectual development. Although each theory has a different emphasis, all recognize that no single cause can account for either moral or immoral behavior.

The Six Stages of Moral Judgment

Growing up, children and young adults come to rely less on external discipline and more on deeply held beliefs. They go through as many as six stages (grouped into three levels) of moral reasoning, as first argued by psychologist Lawrence Kohlberg in the late 1950s (*below*). The evidence includes a long-term study of 58 young men interviewed periodically over two decades. Their moral maturity was judged by how they analyzed hypothetical dilemmas, such as whether a husband should steal a drug for his dying wife. Either yes or no was a valid answer; what mattered was how the men justified it. As they grew up, they passed through the stages in succession, albeit at different rates (*bar graph*). The sixth stage remained elusive. Despite the general success of this model for describing intellectual growth, it does not explain people's actual behavior. Two people at the same stage may act differently. —*W.D.*

EVEL 1: SELF-INTEREST

STAGE 1 PUNISHMENT "I won't do it, because I don't want to get punished."

STAGE 2 REWARD "I won't do it, because I want the reward."

EVEL 2: SOCIAL APPROVAL

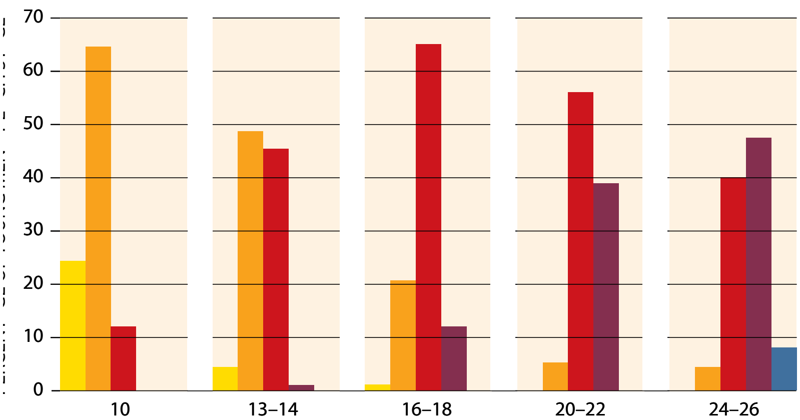
STAGE 3 INTERPERSONAL RELATIONS "I won't do it, because I want people to like me."

STAGE 4 SOCIAL ORDER "I won't do it, because it would break the law."

EVEL 3: ABSTRACT IDEALS

STAGE 5 SOCIAL CONTRACT "I won't do it, because I'm obliged not to."

STAGE 6 UNIVERSAL RIGHTS "I won't do it, because it's not right, no matter what others say."



EDWARD BELL; SOURCE: ANNE COLBY *Carnegie Foundation for the Advancement of Teaching*

Watching violent videos or playing shoot-'em-up computer games may push some children over the edge and leave others unaffected. Conventional wisdom dwells on lone silver bullets, but scientific understanding must be built on an appreciation of the complexity and variety of children's lives.

Biologically oriented, or "nativist," theories maintain that human morality springs from emotional dispositions that are hardwired into our species. Hoffman, Colwyn Trevarthen of the University of Edinburgh and Nancy Eisenberg of Arizona State University have established that babies can feel empathy as soon as they recognize the existence of others—sometimes in the first week after birth. Other moral emotions that make an early appearance include shame, guilt and indignation. As Harvard child psychologist Jerome S. Kagan has described, young children can be outraged by the violation of social expectations, such as a breach in the rules of a favorite game or rearranged buttons on a piece of familiar clothing.

Nearly everybody, in every culture, inherits these dispositions. Mary D. Ainsworth of the University of Virginia reported empathy among Ugandan and American infants; Norma Feshbach of the University of California at Los Angeles conducted a similar comparison of newborns in Europe, Israel and the U.S.; Millard C. Madsen of U.C.L.A. studied sharing by preschool children in nine cultures. As far as psychologists know, children everywhere start life with caring feelings toward those close to them and adverse reactions to inhumane or unjust behavior. Differences in how these reactions are triggered and expressed emerge only later, once children have been exposed to the particular value systems of their cultures.

In contrast, the learning theories concentrate on children's acquisition of behavioral norms and values through observation, imitation and reward. Research in this tradition has concluded that moral behavior is context-bound, varying from situation to situation almost independently of stated beliefs. Landmark studies in the 1920s, still frequently cited, include Hugh Hartshorne and Mark May's survey of how children reacted when given the chance to cheat. The children's behavior depended largely on whether they thought they would be caught. It could be predicted neither from their conduct in previous situations nor from their knowledge of common moral rules, such as the Ten Commandments and the Boy Scout's code.

Later reanalyses of Hartshorne and May's data, performed by Roger Burton of the State University of New York at Buffalo, discovered at least one general trend: younger children were more likely to cheat than adolescents. Perhaps socialization or mental growth can restrain dishonest behavior after all. But the effect was not a large one.

The third basic theory of moral development puts the emphasis on intellectual growth, arguing that virtue and vice are ultimately a matter of conscious choice. The best-known cognitive theories are those of psychologists Jean Piaget and Lawrence Kohlberg. Both described children's early moral beliefs as oriented toward power and authority. For young children, might makes right, literally. Over time they come to understand that social rules are made by people and thus can be renegotiated and that reciprocity in relationships is more fair than unilateral obedience. Kohlberg identified a six-stage sequence in the maturation of moral judgment [*see illustration on this page*]. Several thousand studies have used it as a measure of how advanced a person's moral reasoning is.

Conscience versus Chocolate

Although the main parts of Kohlberg's sequence have been confirmed, notable exceptions stand out. Few if any people reach the sixth and most advanced stage, in which their moral view is based purely on abstract principles. As for the early stages in the sequence, many studies (including ones from my own laboratory) have found that young children have a far richer sense of positive morality than the model indicates. In other words, they do not act simply out of fear of punishment. When a playmate hogs a plate of cookies or refuses to relinquish a swing, the protest "That's not fair!" is common. At the same time, young children realize that they have an obligation to share with others—even when their parents say not to. Preschool children generally believe in an equal distribution of goods and back up their beliefs with reasons such as empathy ("I want my friend to feel nice"), reciprocity ("She shares her toys with me") and egalitarianism ("We should all get the same"). All this they figure out through confrontation with peers at play. Without fairness, they learn, there will be trouble.

In fact, none of the three traditional theories is sufficient to explain children's moral growth and behavior. None captures the most essential dimensions of moral life: character and commitment. Regardless of how children develop their initial system of values, the key question is: What makes them live up to their ideals or not? This issue is the focus of recent scientific thinking.

Like adults, children struggle with temptation. To see how this tug of war plays itself out in the world of small children, my colleagues and I (then at Clark University) devised the following experiment. We brought groups, each of four children, into our lab, gave them string and beads, and asked them to make bracelets and necklaces for us. We then thanked them profusely for their splendid work and rewarded them, as a group, with 10 candy bars. Then the real experiment began: we told each group that it would need to decide the best way to divide up the reward. We left the room and watched through a one-way mirror.

Before the experiment, we had interviewed participants about the concept of fairness. We were curious, of course, to find out whether the prospect of gobbling up real chocolate would overwhelm their abstract sense of right and wrong. To test this thoroughly, we gave one unfortunate control group an almost identical conundrum, using cardboard rectangles rather than real chocolate—a not so subtle way of defusing their self-interest. We observed groups of four-, six-, eight- and 10-year-old children to see whether the relationship between situational and hypothetical morality changed with age.

The children's ideals did make a difference but within limits circumscribed by narrow self-interest. Children given cardboard acted almost three times more generously toward one another than did children given chocolate. Yet moral beliefs still held some sway. For example, children who had earlier expressed a belief in merit-based solutions ("The one who did the best job should get more of the candy") were the ones most likely to advocate for merit in the real situation. But they did so most avidly when they themselves could claim to have done more than their peers. Without such a claim, they were easily persuaded to drop meritocracy for an equal division.

Even so, these children seldom abandoned fairness entirely. They may have switched from one idea of justice to another—say, from merit to equality—but they did not resort to egoistic justifications such as "I should get more because I'm big" or "Boys like candy more than girls, and I'm a boy." Such rationales generally came from children who had declared no belief in either equality or meritocracy. Older children were more likely to believe in fairness and to act accordingly, even when such action favored others. This finding was evidence for the reassuring proposition that ideals can have an increasing influence on conduct as a child matures.

Do the Right Thing

But this process is not automatic. A person must adopt those beliefs as a central part of his or her personal identity. When a person moves from saying "People should be honest" to "I want to

"Could You Live with Yourself?"

In a distressed neighborhood in Camden, N.J., social psychologist Daniel Hart of Rutgers University interviewed an African-American teenager who was active in community service:

How would you describe yourself?

I am the kind of person who wants to get involved, who believes in getting involved. I just had this complex, I call it, where people think of Camden as being a bad place, which bothered me. Every city has its own bad places, you know. I just want to work with people, work to change that image that people have of Camden. You can't start with adults, because they don't change. But if you can get into the minds of young children, show them what's wrong and let them know that you don't want them to be this way, then it could work, because they're more persuadable.

Is there really one correct solution to moral problems like this one?

Basically, it's like I said before. You're supposed to try to help save a life.

How do you know?

Well, it's just—how could you live with yourself? Say that I could help save this person's life—could I just let that person die? I mean, I couldn't live with myself if that happened. A few years ago my sister was killed, and … the night she was killed I was over at her house, earlier that day. Maybe if I had spent the night at her house that day, maybe this wouldn't have happened.

You said that you're not a bad influence on others. Why is that important?

Well, I try not to be a bad role model. All of us have bad qualities, of course; still, you have to be a role model even if you're a person walking down the street. You know, we have a society today where there are criminals and crooks. There are drug users. Kids look to those people. If they see a drug dealer with a lot of money, they want money, too, and then they're going to do drugs. So it's important that you try not to be a bad influence, because that can go a long way. Even if you say, oh, wow, you tell your little sister or brother to be quiet so Mom and Dad won't wake so you won't have to go to school. And they get in the habit of being quiet [*laughs*], your not going to school, things like that. So when you're a bad influence, it always travels very far.

Why don't you want that to happen?

Because in today's society there's just really too much crime, too much violence. I mean everywhere. And I've even experienced violence, because my sister was murdered. You know, we need not to have that in future years, so we need to teach our children otherwise.

be honest," he or she becomes more likely to tell the truth in everyday interactions. A person's use of moral principles to define the self is called the person's moral identity. Moral identity determines not merely what the person considers to be the right course of action but also why he or she would decide: "I myself must take this course." This distinction is crucial to understanding the variety of moral behavior. The same basic ideals are widely shared by even the youngest members of society; the difference is the resolve to act on those ideals.

Most children and adults will express the belief that it is wrong to allow others to suffer, but only a subset of them will conclude that they themselves must do something about, say, ethnic cleansing in Kosovo. Those are the ones who are most likely to donate money or fly to the Balkans to help. Their concerns about human suffering are central to the way they think about themselves and their life goals, and so they feel a responsibility to take action, even at great personal cost.

In a study of moral exemplars—people with long, publicly documented histories of charity and civil-rights work—psychologist Anne Colby of the Carnegie Foundation and I encountered a high level of integration between self-identity and moral concerns. "People who define themselves in terms of their moral goals are likely to see moral problems in everyday events, and they are also likely to see themselves as necessarily implicated in these problems," we wrote. Yet the exemplars showed no signs of more insightful moral reasoning. Their ideals and Kohlberg levels were much the same as everyone else's.

Conversely, many people are equally aware of moral problems, but to them the issues seem remote from their own lives and their senses of self. Kosovo and Rwanda sound far away and insignifi-

How Universal Are Values?

The observed importance of shared values in children's moral development raises some of the most hotly debated questions in philosophy and the social sciences today. Do values vary from place to place, or is there a set of universal values that guides moral development everywhere? Do children growing up in different cultures or at different times acquire fundamentally different mores?

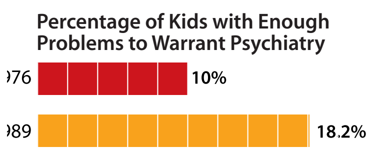
Some light was shed on the cultural issue by Richard A. Shweder of the University of Chicago and his colleagues in a study of Hindu-Brahmin children in India and children from Judeo-Christian backgrounds in the U.S. The study revealed striking contrasts between the two groups. From an early age, the Indian children learned to maintain tradition, to respect defined rules of interpersonal relationships and to help people in need. American children, in comparison, were oriented toward autonomy, liberty and personal rights. The Indian children said that breaches of tradition, such as eating beef or addressing one's father by his first name, were particularly reprehensible. They saw nothing wrong with a man caning his errant son or a husband beating his wife when she went to the movies without his permission. The American children were appalled by all physically punitive behavior but indifferent to infractions such as eating forbidden foods or using improper forms of address.

Moreover, the Indians and Americans moved in opposite directions as they matured. Whereas Indian children restricted value judgments to situations with which they were directly familiar, Indian adults generalized their values to a broad range of social conditions. American children said that moral standards should apply to everyone always; American adults modified values in the face of changing circumstances. In short, the Indians began life as relativists and ended up as universalists, whereas the Americans went precisely the other way.

It would be overstating matters, however, to say that children from different cultures adopt completely different moral codes. In Shweder's study, both groups of children thought that deceitful acts (a father breaking a promise to a child) and uncharitable acts (ignoring a beggar with a sick child) were wrong. They also shared a repugnance toward theft, vandalism and harming innocent victims, although there was some disagreement on what constitutes innocence. Among these judgments may be found a universal moral sense, based on common human aversions. It reflects core values—benevolence, fairness, honesty—that may be necessary for sustaining human relationships in all but the most dysfunctional societies.

A parallel line of research has studied gender differences, arguing that girls learn to emphasize caring, whereas boys incline toward rules and justice. Unlike the predictions made by culture theory, however, these gender claims have not held up. The original research that claimed to find gender differences lacked proper control groups. Well-designed studies of American children—for example, those by Lawrence Walker of the University of British Columbia—rarely detect differences between boys' and girls' ideals. Even for adults, when educational or occupational levels are controlled, the differences disappear. Female lawyers have almost the same moral orientations as their male counterparts; the same can be said for male and female nurses, homemakers, scientists, high school dropouts and so on. As cultural theorists point out, there is far more similarity between male and female moral orientations within any given culture than between male and female orientations across cultures.

Generational differences are also of interest, especially to people who bemoan what they see as declining morality. Such complaints, of course, are nothing new [see "Teenage Attitudes," by H. H. Remmers and D. H. Radler; SCIENTIFIC AMERICAN, June 1958; and "The Origins of Alienation," by Urie Bronfenbrenner; SCIENTIFIC AMERICAN, August 1974]. Nevertheless, there is some evidence that young people today are more likely to engage in antisocial behavior than those a generation ago were. According to a survey by Thomas M. Achenbach and Catherine T. Howell of the University of Vermont, parents and teachers reported more behavioral problems (lying, cheating) and other threats to healthy development (depression, withdrawal) in 1989 than in 1976 (*above*). (The researchers are now updating their survey.) But in the long sweep of human history, 13 years is merely an eye blink. The changes could reflect a passing problem, such as overly permissive fashions in child rearing, rather than a permanent trend. —*W.D.*



KIDS THESE DAYS are likelier to need mental health services, judging from parents' reports of behavioral and emotional problems.

EDWARD BELL; SOURCE: THOMAS M. ACHENBACH AND CATHERINE T. HOWELL cant; they are easily put out of mind. Even issues closer to home—say, a maniacal clique of peers who threaten a classmate—may seem like someone else's problem. For people who feel this way, inaction does not strike at their self-conception. Therefore, despite commonplace assumptions to the contrary, their moral knowledge will not be enough to impel moral action.

The development of a moral identity follows a general pattern. It normally takes shape in late childhood, when children acquire the capacity to analyze people—including themselves—in terms of stable character traits. In childhood, self-identifying traits usually consist of action-related skills and interests ("I'm smart" or "I love music"). With age, children start to use moral terms to define themselves. By the onset of puberty, they typically invoke adjectives such as "fair-minded," "generous" and "honest."

Some adolescents go so far as to describe themselves primarily in terms of moral goals. They speak of noble purposes, such as caring for others or improving their communities, as missions that give meaning to their lives. Working in Camden, N.J., Daniel Hart and his colleagues at Rutgers University found that a high proportion of so-called care exemplars—teenagers identified by teachers and peers as highly committed to volunteering—had self-identities that were based on moral belief systems. Yet they scored no higher than their peers on the standard psychological tests of moral judgment. The study is noteworthy because it was conducted in an economically deprived urban setting among an adolescent population often stereotyped as high risk and criminally inclined [*see box on page 75*].

At the other end of the moral spectrum, further evidence indicates that moral identity drives behavior. Social psychologists Hazel Markus of Stanford University and Daphne Oyserman of the University of Michigan have observed that delinquent youths have immature senses of self, especially when talking about their future selves (a critical part of adolescent identity). These troubled teenagers do not imagine themselves as doctors, husbands, voting citizens, church members—any social role that embodies a positive value commitment.

How does a young person acquire, or not acquire, a moral identity? It is an incremental process, occurring gradually in thousands of small ways: feedback from others; observations of actions by

BOB DAEMMRICH *The Image Works*

PACKING A PUNCH on a Texas playground: most children learn that being fair can often (though not always) forestall fights, a lesson that helps them grow morally.

others that either inspire or appall; reflections on one's own experience; cultural influences such as family, school, religious institutions and the mass media. The relative importance of these factors varies from child to child.

Teach Your Children Well

For most children, parents are the original source of moral guidance. Psychologists such as Diana Baumrind of the University of California at Berkeley have shown that "authoritative" parenting facilitates children's moral growth more surely than either "permissive" or "authoritarian" parenting. The authoritative mode establishes consistent family rules and firm limits but also encourages open discussion and clear communication to explain and, when justified, revise the rules. In contrast, the permissive mode avoids rules entirely; the authoritarian mode irregularly enforces rules at the parent's whim—the "because I said so" approach.

Although permissive and authoritarian parenting seem like opposites, they actually tend to produce similar patterns of poor self-control and low social responsibility in children. Neither mode presents children with the realistic expectations and structured guidance that challenge them to expand their moral horizons. Both can foster habits—such as feeling that mores come from the outside—that could inhibit the development of a moral identity. In this way, moral or immoral conduct during adulthood often has roots in childhood experience.

As children grow, they are increasingly exposed to influences beyond the family. In most families, however, the parent-child relationship remains primary as long as the child lives at home. A parent's comment on a raunchy music lyric or a blood-drenched video usually will stick with a child long after the media experience has faded. In fact, if salacious or violent media programming opens the door to responsible parental feedback, the benefits can far outweigh the harm.

One of the most influential things parents can do is to encourage the right kinds of peer relations. Interactions with peers can spur moral growth by showing children the conflict between their preconceptions and social reality. During the debates about dividing the chocolate, some of our subjects seemed to pick up new—and more informed—ideas about justice. In a follow-up study, we confirmed that the peer debate had heightened their awareness of the rights of others. Children who participated actively in the debate, both expressing their opinions and listening to the viewpoints of others, were especially likely to benefit.

In adolescence, peer interactions are crucial in forging a self-identity. To be sure, this process often plays out in cliquish social behavior: as a means of defining and shoring up the sense of self, kids will seek out like-minded peers and spurn others who seem foreign. But when kept within reasonable bounds,

JEFF GREENBERG *The Image Works*

PACKING A LUNCH for a New Jersey food bank: parents can set their kids up with peer experiences that foster moral learning, such as collaborative community service projects.

the in-group clustering generally evolves into a more mature friendship pattern. What can parents do in the meantime to fortify a teenager who is bearing the brunt of isolation or persecution? The most important message they can give is that cruel behavior reveals something about the perpetrator rather than about the victim. If this advice helps the youngster resist taking the treatment personally, the period of persecution will pass without leaving any psychological scars.

Some psychologists, taking a sociological approach, are examining community-level variables, such as whether various moral influences—parents, teachers, mass media and so on—are consistent with one another. In a study of 311 adolescents from 10 American towns and cities, Francis A. J. Ianni of the Columbia University Teachers College noticed high degrees of altruistic behavior and low degrees of antisocial behavior among youngsters from communities where there was consensus in expectations for young people.

Everyone in these places agreed that honesty, for instance, is a fundamental value. Teachers did not tolerate cheating on exams, parents did not let their children lie and get away with it, sports coaches did not encourage teams to bend the rules for the sake of a win, and people of all ages expected openness from their friends. But many communities were divided along such lines. Coaches espoused winning above all else, and parents protested when teachers reprimanded their children for cheating or shoddy schoolwork. Under such circumstances, children learned not to take moral messages seriously.

Ianni named the set of shared standards in harmonious communities a "youth charter." Ethnicity, cultural diversity, socioeconomic status, geographic location and population size had nothing to do with whether a town offered its young people a steady moral compass. The notion of a youth charter is being explored in social interventions that foster communication among children, parents, teachers and other influential adults. Meanwhile other researchers have sought to understand whether the specific values depend on cultural, gender or generational background [*see box on page 76*].

Unfortunately, the concepts embodied in youth charters seem ever rarer in American society. Even when adults spot trouble, they may fail to step in. Parents are busy and often out of touch with the peer life of their children; they give kids more autonomy than ever before, and kids expect it—indeed, demand it. Teachers, for their part, feel that a child's nonacademic life is none of their business and that they could be censured, even sued, if they intervened in a student's personal or moral problem. And neighbors feel the same way: that they have no business interfering with another family's business, even if they see a child headed for trouble.

Everything that psychologists know from the study of children's moral development indicates that moral identity—the key source of moral commitment throughout life—is fostered by multiple social influences that guide a child in the same general direction. Children must hear the message enough for it to stick. The challenge for pluralistic societies will be to find enough common ground to communicate the shared standards that the young need.

The Author

WILLIAM DAMON remembers being in an eighth-grade clique that tormented an unpopular kid. After describing his acts in the school newspaper, he was told by his English teacher, "I give you an A for the writing, but what you're doing is really shameful." That moral feedback has stayed with him. Damon is now director of the Center on Adolescence at Stanford University, an interdisciplinary program that specializes in what he has called "the least understood, the least trusted, the most feared and most neglected period of development." A developmental psychologist, he has studied intellectual and moral growth, educational methods, and peer and cultural influences on children. He is the author of numerous books and the father of three children, the youngest now in high school.

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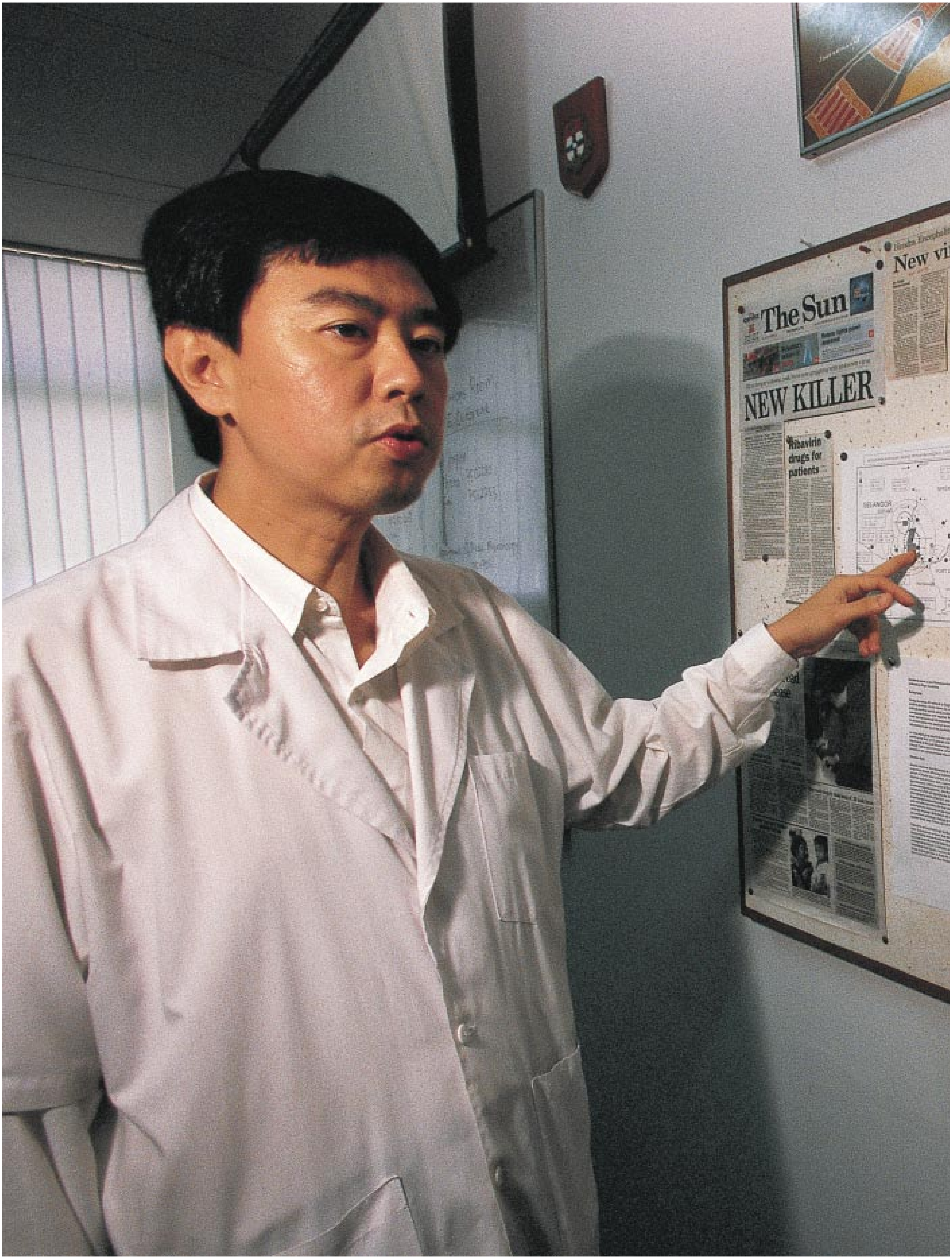
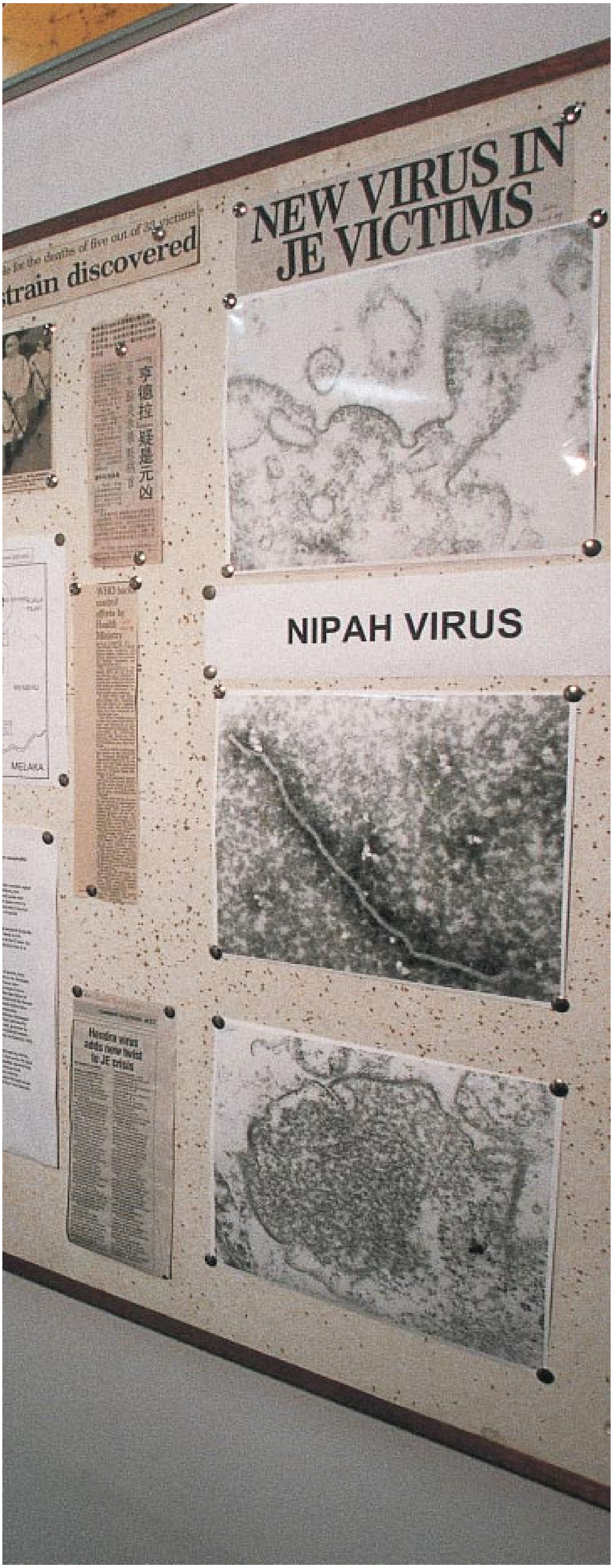

The Sun
NEW KILLER
Ribavirin drugs for patients



by W. Wayt Gibbs, *senior writer*
Photographs by Chris Brown *SABA*

Trailing a Virus

As a virus never seen before swept through rural Malaysia, killing more than 110 and forcing the destruction of a million swine, it revealed the world's vulnerability to new diseases. Even the best efforts of top scientists are sometimes not enough to thwart them

Chua Kaw Bing endured the 18-hour plane ride from Kuala Lumpur to Los Angeles uneasily. He hated long flights. Since he had given up his private practice to study viral outbreaks with Lam Sai Kit, a world-renowned expert on the subject and head of the University of Malaya's department of medical microbiology, the young doctor always seemed to be flying somewhere. "There is no individualism in our fight against emerging diseases—only internationalism" was the motto Lam had tacked to his whiteboard. He put the words to work in February when he dispatched Chua to Perth to get Australian help in confirming the cause of an outbreak that

Chua Kaw Bing (*left*) put his finger on the new virus that eats through blood vessel walls (*above*).

Neurologists (*right*) confront the new form of encephalitis, all too aware of the agonies it causes patients (*above*).

had painfully swelled the joints of 27 feverish people in Port Klang. Now, hardly a month later, Chua had set out on the track of a new epidemic—this time to the Centers for Disease Control and Prevention (CDC) laboratories in Fort Collins, Colo. He was counting on their high-tech equipment to identify what he could not: a mysterious and deadly virus packed carefully inside the carry-on bag at his feet.

As Chua's plane had climbed away from Kuala Lumpur's new airport toward Taipei, passengers on the left side of the jet might have just spotted the horse and swine stables near Ipoh where this strange disease had started last September. Even before it spread, it had seemed frightening enough—with 26 victims, it was the biggest outbreak of Japanese encephalitis in Malaysia in more than 25 years, they said.

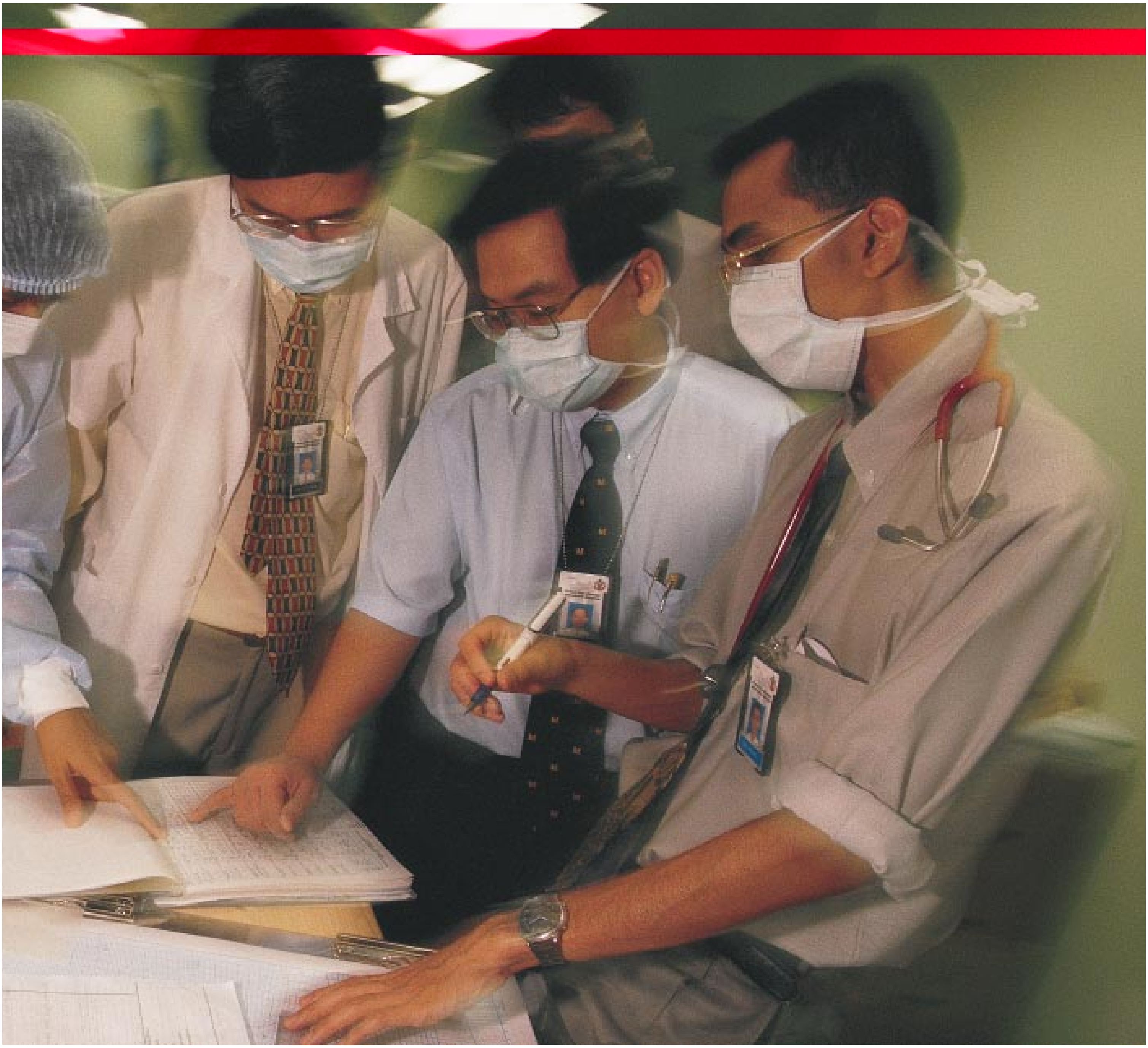
And then the virus had jumped. There, to the palm-covered state of Negri Sembilan, now off the right side of the plane, the heart of Malaysian pig country. No doubt some desperate farmer, under the cover of darkness, had found a hole in the quarantine and sent his pigs south from Ipoh for sale or for slaughter. How could a simple farmer have known the biological and economic firestorm it would ignite? How could he have foreseen hundreds of people—strong men, mostly—burning with fever, slipping into delirium, coma and beyond; entire villages emptied in a panic as one household in three is touched by the disease; gas-masked soldiers opening fire on herds of swine, decimating a huge export industry farm by farm; and other farmers like him smuggling pigs through other roadblocks into other states, a chain reaction with no clear end?

The government scientists were saying the disease was Japanese encephalitis, after all, and JE is easily stopped with a vaccine. Besides, pigs may provide a host in which the JE virus can multiply, but hogs do not transmit it directly to humans: mosquitoes do. Antimosquito fogging and mass JE vaccination had always quenched JE outbreaks before, and the government had already started this.

But if there is a lesson for the world to learn from the affliction visited on Malaysia's pig farmers this past spring, perhaps it is that a new disease can look, even to the best doctors, like a familiar one. When it does, the pathogen gains time to spread. And if the malady is transmitted by a valuable commodity such as the pig rather than by a pest such as the mosquito, the best efforts of a government to wipe out the viral carriers can never achieve complete success.

Chua, as he listened to the drone of the engines and sat with little to do but reflect on the two frenetic weeks just past, was now, in mid-March, all but convinced that this was not an epidemic of Japanese encephalitis. He had grown the virus that was in the blood and spinal fluid of three recent patients. He had captured the culprit, and it was definitely nothing that he or Lam had ever seen before.

On March 1, Chua's lab at the University Hospital in Kuala Lumpur received those first three samples of bodily fluids and brain tissue—one from a truck driver in Sungai Nipah and two from victims in Bukit Pelanduk—just as inhabitants of those towns began collapsing in its emergency room. It was the doctors' first confirmation that the disease had gained a foothold in Negri Sembilan. "This rash of new patients was alarming," remembers Goh Khean Jin, a neurologist at the hospital.



The clinicians were disturbed by more than just the size of the outbreak. The symptoms fit the profile of Japanese encephalitis, but the victims did not. Because it is spread by insects, Goh explains, "JE usually affects the very young and the very old, and it strikes in somewhat random fashion. But we were seeing mostly adult males falling ill, and no children. In some families four people would get sick, whereas the fifth would not. Plus about three quarters of the patients had been vaccinated against JE at least once. So we started asking more questions, and we learned that almost all the patients either owned a pig farm or worked on one."

It began to look less and less like an insect-borne illness. So far everyone who caught it had touched a pig at some point—many while caring for animals that were coughing and wheezing with some strange sickness. That, too, was odd, because the JE virus does not harm a hog, its natural host.

Chua and Lam had been asked only to confirm that their specimens did indeed contain antibodies to JE, signaling that those patients had either been infected with the JE virus or vaccinated against it. But the two men decided to go a step further. If they could grow enough of the virus, they might get a look at it. "We thought it might be a mutant strain, one that the vaccine did not protect against," Lam says.

Chua dismissed his technicians, locked himself and one assistant in the biohazard lab, and began placing droplets of infected fluid onto cultures of kidney cells from pigs and monkeys. "He even injected them into mosquito larvae and suckling mice," Lam says. "We didn't really know what we were looking for. We just tried to cover the field."

Two or three times every day Chua checked the cells in the incubator for signs of infection. Many pathogens will grow only at a certain temperature or pH. Two years before, when

Chua had isolated an enterovirus that sickened thousands in Malaysia, "it took 10 days to find the right conditions for growth," he recalls.

This agent was decidedly more aggressive. "It practically grew by itself—and very quickly," Chua says. Within three days the monkey cells began dying. By the fifth day many of those that were left had merged like water droplets into giant cellular blobs with multiple nuclei. The insect larvae—the host most susceptible to the JE virus—remained healthy.

For a week, Chua ran battery after battery of antibody tests on the viral isolate. The test for JE came up negative; measles also. Herpes simplex, dengue virus, panenterovirus, cytomegalovirus, respiratory syncytial virus—they tested for anything that might cause encephalitis. "All came up negative," he says. "Under the electron microscope," Lam recounts, "the viral particles looked very large. That was a clue that it might be a paramyxovirus," perhaps a cousin of the pathogens behind measles, mumps and some other highly contagious diseases.

"I remember going down to Chua's lab that day," Goh says. "He said, 'Look, we've got a new virus!' I was very frightened. We had been touching these patients, cleaning them. And Dr. Chua and others in the lab were growing quite large quantities with no protection. But scientifically it was extremely exciting."

If it was indeed a paramyxovirus causing the encephalitis, then Lam knew that it could not be carried by insects: fogging and JE vaccination would not work. But he lacked the equipment to be certain, and he was pressed for time as new patients continued to pour in. Lam decided to accept an offer of assistance from an old friend at the CDC in Fort Collins. "When we tried to ship the virus to the U.S., one courier company after another turned us down," Lam says. So the day after making his discovery, Chua gingerly packed the infected blood, spinal fluid and bits of human brain into an airtight

Among the razed pig farms in Bukit Pelanduk (*left*), Mike Bunning of the CDC hunts for infected rats he can later dissect (*above*).

metal capsule, placed it in dry ice and headed for the airport.

Seventy-two hours later CDC scientists, guided by Chua, reproduced his results but also failed to identify the virus. "We had anticipated that and had forwarded samples on to CDC headquarters in Atlanta," Lam says. After another long, uneasy flight, Chua arrived in Atlanta to learn that the virologists there already had some disturbing news. The virus, which Lam and Chua named Nipah after the village of the man from whom the isolate was grown, was completely new to medicine. But it shared about 82 percent of its DNA sequence with a virus called Hendra, which had killed 14 racehorses and their trainer in 1994 in Queensland, Australia. Hendra is spread by fruit bats. It so happens that fruit bats live in almost every part of Malaysia, and they are not known for halting their flight at national boundaries.

Brian Mahy, head of the CDC's division of viral diseases, sent Lam an e-mail with the news and with an offer to send a team of 10 experts, including two Australian veterinarians, to help with the investigation. "I took the message to the director general at the ministry of health," Lam remembers, "and he approved the idea on the spot."

By the second week of March, the wards were filling up with encephalitis patients," recalls Patrick Tan, who was helping to run the university hospital's intensive care unit. "It was a steady stream: one per day on average. That indicated a big pool of illness out there, but we could not imagine how big. Our worst estimates were being exceeded almost daily."

As the encephalitis patients grew sicker and larger in number, Tan scrambled to find more ventilators and nurses. Elective surgeries were postponed. "At the peak, we were operating very close to our bare minimum standards for medical care," he admits in a soft English accent, his lips drawn tight above a neat bow tie. Families, having abandoned their homes, crowded the corridors. Morale plummeted. "The mortality was very high: sometimes three deaths a day," Tan explains. "You would see a son die at seven in the morning and his father pass away at noon. We were clearly dealing with something unknown and very threatening."

The threat was more than medical. The demand for pork, consumed almost exclusively by the ethnic Chinese minority, had fallen by 90 percent, kicking out one of the few stable pillars in an economy still reeling from last year's currency crisis. "Between the farmers and slaughterers and meat sellers and lorry drivers, something like 10 percent of the Chinese population here have been affected," Lam says. Although in Malaysia the large populations of Hindu Indian and Muslim Malay had not risen against the Chinese, as had happened in neighboring Indonesia, some Western observers feared that the news of a lethal disease borne by pigs could stoke religious hostility.

The scientists hoped that identifying the virus would suggest ways of stopping it. The CDC had confirmed Lam's hunch that the pathogen was a member of the Paramyxoviridae family. "That told us that it is an RNA virus surrounded by a lipid [fatty] envelope, and therefore it is easy to inactivate with heat or detergents," Lam says. The word went out that cooked pork was safe to eat, but still no one wanted to buy it. Nor did publicizing the fact that pig farms could be disinfected with soapy sprays stop the (largely Muslim) army from bulldozing pig farms to rubble.

But having a paramyxovirus as an enemy furrowed brows as well. Few drugs affect them. The microbiologists could suggest only one, ribavirin. "It is expensive," Tan says. "But we had nothing else to give these patients, so we tried it."

Many paramyxoviruses cause respiratory infections that spread in aerosol form, which makes them particularly dangerous. "In fact, we knew that the virus gives pigs a terrible cough—they call it a 'one-mile cough' because you can hear it from a mile away. That is probably how it is spreading among pigs," Lam explains. "Even in humans we have shown that the virus is in the urine and the gargle. But we do not know how infectious those secretions are. It's just like HIV; the virus may be in the saliva but not in enough quantity to transmit the infection."

"The mortality was very high. You would see a son die in the morning and his father pass away at noon."

Even as the outbreak reached its peak in late March, not a single doctor or nurse had caught the Nipah virus. That suggested that it does not move easily from human to human. But to be safe, the CDC tentatively assigned the pathogen to Biosafety Level 4. That elite group of the most lethal, contagious agents—including the Ebola, Marburg and Lassa viruses—can be safely handled only in "hot zone" labs. There are just a few in the world, and none are close to Malaysia.

To stop the outbreak and save as many lives as possible, three questions were now paramount: What does the Nipah virus do to the body? What animals can transmit it? And what is its natural host, the species in which the virus thrives but does not kill?

At the level of gross anatomy, the spectrum of damage wrought by Nipah virus on human bodies can be seen in the encephalitis wards of University Hospital as the neurologists make their morning rounds. Two weeks after the outbreak peaked, the ward is still full with 16 patients. Many are in the same vegetative state as the farmer whose eyeballs roll unresponsively while C. T. Tan, the chief neurologist, lifts their lids and shouts, "Look here! Look here!" in Chinese.

Goh walks up to another Chinese man lying still in bed, seemingly asleep, although his heart monitor shows a pulse rate of 130. A young woman stands beside him. She pats his shoulder. "Hello, Mr. Ching?" Tan says. "Hello?" There is no response, except slight grimaces when one of the interns taps the man's knees with a rubber mallet. The woman clasps her latex-gloved hands tightly and looks at the doctor with fear in her eyes. The entourage moves on.

"This one gives me the greatest hope," Goh says as we approach a middle-aged woman. "Two weeks ago she was comatose and suffered tremors and seizures. Now she can speak a little and almost walk on her own." But after Tan has her take his arm and make a few halting steps, she stops and sways. Her eyelids droop shut. Goh cannot predict how fully she will recover.

Nor can anyone know yet whether those who struggle back to health will retain it. At the next bed a 31-year-old farmhand from Bukit Pelanduk convulses quietly as nurses attend to him. "We treated this man with ribavirin, and after a week he was well enough to go home," Goh recalls. "But then he returned with new symptoms." He was recovering from those, too, when suddenly a blood vessel burst in his brain. His pillow and sheets are stained red and brown. "Now his prognosis is very guarded," the earnest doctor whispers, lowering his head.

This relapse worries Goh. A second Australian horse trainer who caught Hendra in 1994 felt fine for 13 months, then developed encephalitis and died within days. It is possible that the hundreds who survived Nipah infection may still be in danger. "These people will need to be followed for several years to come," Goh says.

Several stories below the ward, neuropathologist Wong Kum Thong straps on a mask and apron and walks over to brightly colored buckets in shelves against the wall of the postmortem room. "We need to be sure that we have observed all the possible changes caused by this disease," the thin neuropathologist says as he pulls a heart from a yellow bucket. Slicing through a thick layer of fat, he cuts a thin section of aorta and hands it to an assistant for labeling. The smell of formalin pricks the nostrils with a sting.

"There is only a small random chance of seeing an important phenomenon in any given section, so you have to look at many, many slides," Wong says. He has moved on to the stomach of one of the Nipah virus victims. Organs from more than a dozen are kept here for study. "There is no drama involved," Wong continues, "just hours on the microscope examining and reexamining samples. It is very tedious work—like most of science."

And yet there are many small moments of discovery. Wong's slides have revealed that the Nipah virus attacks the cells that line the blood vessels in virtually every organ, from brain to lungs to kidneys. That is one way it disables its victims: by inflaming the brain and fouling its blood supply. But the virus can also infect neurons directly, stuffing them with viral particles until they burst. There is undoubtedly more to discover.

"Come look at this," Wong says when he has finished his sections. Out of a blue bucket he lifts a large object suspended by string in the formalin. The brain in his hands is blotched with brown splatters and lines. "There are lots of amorphous hemorrhages here," he observes. But that is not what has caught Wong's attention. He puts a gloved finger to several small black spots, pinhead-size circles that dot many parts of the surface of the brain. "I've never seen anything like these before."

"They are too large to be point failures of capillaries," muses George Paul, the hospital's forensic pathologist. "Why are they there, and are there more inside? We should photograph those."

Wong nods. "If we could just get one more autopsy, I could do an electron microscope study of the blood vessels and neurons in the brain. It would be very elegant to show the virus there, doing its damage. We still do not know how long the virus remains viable after death."

The next day Chua is working in the biohazard lab, preparing serum samples for testing. There is as yet no definitive blood test for Nipah infection, but a screen for Hendra antibodies seems to work well enough. Still, it cannot tell Chua what he really wants to know: whether the immune system also fights Nipah virus with T cells, its strongest weapon, and whether it can wipe out the infection or, as with HIV, only send it into temporary remission.

The lab doorbell rings; it is Wong. He calls Chua over and speaks rapidly. "We have an encephalitis case in which a postmortem is very likely." The 31-year-old patient has just died. "I think it is very important to get live virus from the brain if possible. But I don't want to expose myself. How should I bring the brain up to you?" Here is the opportunity both had been waiting for: a chance to survey the brain after the immune system engaged the enemy, won a battle but then lost the war.

The findings from that autopsy have become only one more piece in the puzzle. With luck and probably many years of work, Lam and his colleagues around the world may be able to find a vaccine for this new Malaysian encephalitis. In the meantime, the veterinarians are still searching for the natural host of the Nipah virus and for clues to how far it has spread.

The Malaysian government's solution to the outbreak—dispatching soldiers in chemical warfare gear to kill all pigs within five kilometers (three miles) of an infected farm—may have panicked some. Farmers around Bukit Pelanduk, unwilling to wait for the army or fearful that their buildings would be razed, dug large pits, herded their pigs in and buried them alive. Others clubbed their swine to death with planks. But it was effective. In just three weeks, 900,000 head of hog were obliterated. Encephalitis cases began to drop.

And yet weeks later the houses in Sungai Nipah and Bukit Pelanduk are shuttered. Some still have laundry on the line and toys abandoned in the yard. A few stray dogs have the streets to themselves, but they are to be shot on sight. The demand for pork is still 80 percent below what it was. The president of the livestock farmers association has reportedly predicted that an industry that once brought in 1.5 billion Malaysian ringgit ($395 million) a year will take more than five years to recover.

That may prove optimistic. In May a nationwide testing program revealed that the Nipah virus has spread to pig farms in other states: Selangor, Johore, Malacca, Penang—virtually the entire western half of the country. One of the Australian veterinary experts recently announced that a quarter of certain species of fruit bats collected in some regions carried antibodies to the virus. No one yet knows, however, whether bats are the virus's natural host—and if they are, what that means for pig farming in southeast Asia.

"We can only hope that the disease is cyclical," Lam says, "and that there will be many years between each cycle," time enough to develop a vaccine or find an effective treatment. While we are hoping, Patrick Tan adds, let us hope there are no nastier viruses than Nipah about to break from their ecosystem to ours. "This experience will stand us in good stead if we have a further encounter with an outbreak," he says. "We learned that the crisis led to a unity of purpose; people were prepared to put themselves second."

And yet a highly skilled scientific team, aiding a government possessed of great power and the willingness to use it, has been humbled by the escape of its new foe. "We cannot be too proud," Tan warns. The virus next time may be even worse. S

Mysterious black spots on the brain of a Nipah virus victim raise but one of scientists' many unanswered questions about the disease.

by Shawn Carlson

Sun of a Gun

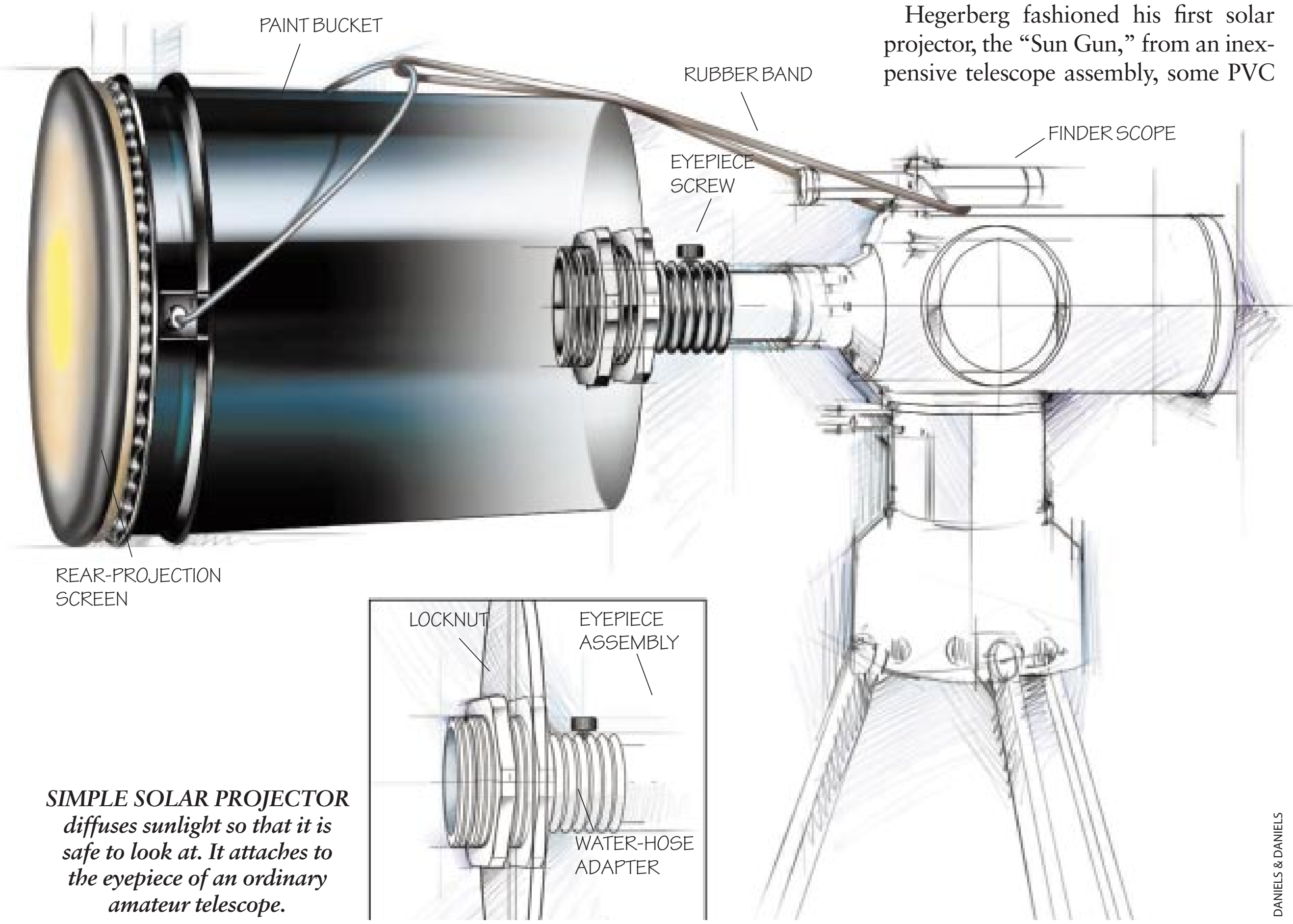
I won my first telescope when I was nine years old by selling 500 boxes of flower seeds door-to-door. (I was a good talker even then.) It wasn't much of an instrument, just a four-inch refractor that suffered from what astronomers call chromatic aberration: it focused different colors at slightly different distances, so that only one color could be in focus at a time. Stars and planets were so blurred that I almost relegated the telescope to my closet. But it was saved by its sun filter, which allowed a smidgen of the sun's green light to pass through. I gasped out loud the first time I used it. Limited to just one color, the solar disk came in razor-sharp, and sunspots appeared like large black islands in a vast emerald sea.

That experience inspired my first amateur research project. Every day that summer at precisely 11:00 A.M., I set up my telescope and carefully sketched the sunspots on a piece of graph paper. I quickly discovered that the sun's surface, unlike the earth's, rotates at different rates depending on latitude. Sadly, my intensive investigations soon wore out the scrawny scope. Since then, I've visited our home star mostly through no. 14 welder's glass duct-taped over binoculars and recently via the World Wide Web [*see box on opposite page*].

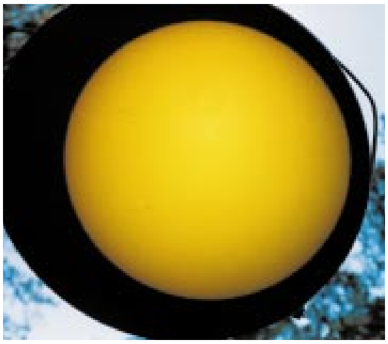
But the total eclipse that will be cutting across Europe and western Asia on August 11 put me on the lookout for better ways to see the sun. So you can imagine my excitement when I learned of an elegant solar projector designed by Bruce Hegerberg of Norcross, Ga. It creates a dazzling daylight display. The so-called limb-darkening effect—that is, the apparent drop in brightness near the sun's edge caused by the longer viewing path through the sun's atmosphere there—is plainly visible. Also, the characteristic structure of sunspots, with a dark inner umbra surrounded by a lighter penumbra, can be clearly seen.

Because the solar image can be easily viewed in daylight by many people at once, Hegerberg's fabulous device is perfect for eclipse watching. Moreover, by presenting such enticing images during the day when it is easiest to reach nonastronomers, this projector could revolutionize sidewalk astronomy—the time-honored practice whereby amateur astronomers set up small telescopes to give passersby a peek at the heavens.

Hegerberg fashioned his first solar projector, the "Sun Gun," from an inexpensive telescope assembly, some PVC



***SIMPLE SOLAR PROJECTOR** diffuses sunlight so that it is safe to look at. It attaches to the eyepiece of an ordinary amateur telescope.*



BRUCE HEGERBERG

***THIS IS A REAL PHOTO** of the sun, although it might look computer-generated.*

piping and a large flowerpot. Those interested in the details should check out his Web site. Here I will describe his second-generation device, the "Sun of a Gun," which can be quickly and cheaply assembled from a paint bucket. If your telescope has a heliostatic (sun-following) motor drive, you'll be able to track the sun's motion for hands-free viewing.

You'll need a plastic five-gallon (20-liter) paint bucket (such as Home Depot part no. 084305355553). Discard the lid and paint the inside of the bucket black to prevent ambient light from coming through the translucent plastic. Cut a 2¼-inch hole in the bottom using a hole saw attached to an electric hand drill. Through the hole, thread a male flexible adapter for a water hose (Ace Hardware part no. 45708) and secure it in place with one two-inch conduit locknut (Home Depot part no. 051411461966). (Obviously, readers outside the U.S. will need to adapt these measurements to a metric equivalent, depending on the availability of hardware.)

Next, drill an ⅛-inch hole about a half-inch from the end of the adapter. Line up this hole with the screw hole in the eyepiece assembly and lock the two together using the screw that normally holds the eyepiece in place. If the adapter does not fit your scope, affix a universal camera adapter (about $30 from Orion Telescopes; 800-676-1343 or www.telescope.com) to your scope and attach the bucket to that.

The sun's image appears on a rear-projection screen of the kind often used in large-screen TVs. Many varieties of screen are available, each with different trade-offs in viewing angle, image brightness, sharpness and contrast. Hegerberg purchases a flexible Da-Tex rear-projection screen for $10 per square foot from Da-Lite Screen Company (800-622-3737 or www.da-lite.com). A 15-inch square will suffice. Secure the screen, polished side facing out, over the open end of the bucket. You can use a 48-inch plastic wire tie positioned just under the bucket's lip. The tie is the same type that can bind large bundles of wire, and Home Depot has them (part no. 728494104805). Pull the screen taut as you tighten the tie, so that the assembly resembles a drum. Alternatively, you can secure the screen with a large rubber band. Cut off the excess screen, leaving about a half-inch of fabric below the tie for future adjustments.

Finally, Hegerberg removes the bucket's handle and slips a large rubber band over it. After reattaching the handle, he connects the band to the finder scope to relieve some of the stress on the focusing assembly [*see illustration on opposite page*]. Depending on the size of your bucket and scope, you might also need to add a counterweight to the telescope tube.

To get a clear image of the sun, you'll need a good eyepiece and a filter that screws into it. Hegerberg recommends Plössl eyepieces because they deliver the sharpest and best color-corrected images, but Huygenian eyepieces contain no cemented elements and so may better survive long-term exposure to the sun's heat. You'll need focal lengths between 17 and 25 millimeters depending on the size of your telescope. If you happen to own a Schmidt-Cassegrain telescope, try a 20-millimeter eyepiece for a four-inch instrument and a 25-millimeter eyepiece for an eight-incher. Sirius Plössl eyepieces retail for about $50 from Orion. If your telescope's aperture is larger than four inches, you must attenuate the light using a piece of cardboard with a four-inch hole in it. Attach this cardboard to the front of your scope. Otherwise, your instrument could overheat.

For the filter, Hegerberg recommends #21 (orange), #11 (yellow green) and #12 (yellow), any of which Orion sells for about $15. But keep in mind that these filters were never intended for direct solar viewing. Just as you would never press your eye over the lens of a movie projector, so you should never look directly into the eyepiece—even with one of these filters. Doing so could permanently damage your vision. The projection screen on the Sun of a Gun diffuses the light so that it is safe to look at.

Because the finder scope can focus sunlight enough to cause burns, always cover it before using the Sun of a Gun. Of course, never look through the finder scope at the sun. To align the telescope with the sun, first adjust its position so that it casts the smallest possible shadow. Then use the focus to sharpen the image on the screen.

Armed with this powerful tool, you'll be ready to explore our home star on any clear day. You, too, may enjoy observing the life cycle of sunspots, recording the ratio of the umbra to penumbra area or mapping their size over time.

For more information about this and other projects from the Amateur Scientist, visit the Society for Amateur Scientists's Web site at www.thesphere.com/SAS/WebX.cgi. You may write to the society at 4735 Clairemont Square, PMB 179, San Diego, CA 92117, or call 619-239-8807.

Solar Web Sites

The National Aeronautics and Space Administration's guide to the August 11 eclipse includes detailed maps of the path.
sunearth.gsfc.nasa.gov/eclipse/TSE1999/TSE1999.html

NASA's Solar and Heliospheric Observatory Web site has real-time solar images and movies of recent solar activity.
sohowww.nascom.nasa.gov

The National Solar Observatory's site shows the sun in various wavelengths.
www.nso.noao.edu/synoptic

NASA's Solar Data Analysis Center has a collection of archived solar images.
umbra.gsfc.nasa.gov/images

The Space Environment Center offers current and archived images.
www.sel.noaa.gov/solar_images/ImageIndex.cgi

The Association of Lunar and Planetary Observers runs a site full of amateur and professional solar images.
www.lpl.arizona.edu/~rhill/alpo/solstuff/recobs.html

Bruce Hegerberg's site offers more information on the project in the article.
www.america.net/~boo/html/sun_gun.html

by Ian Stewart

Sierpinski's Ubiquitous Gasket

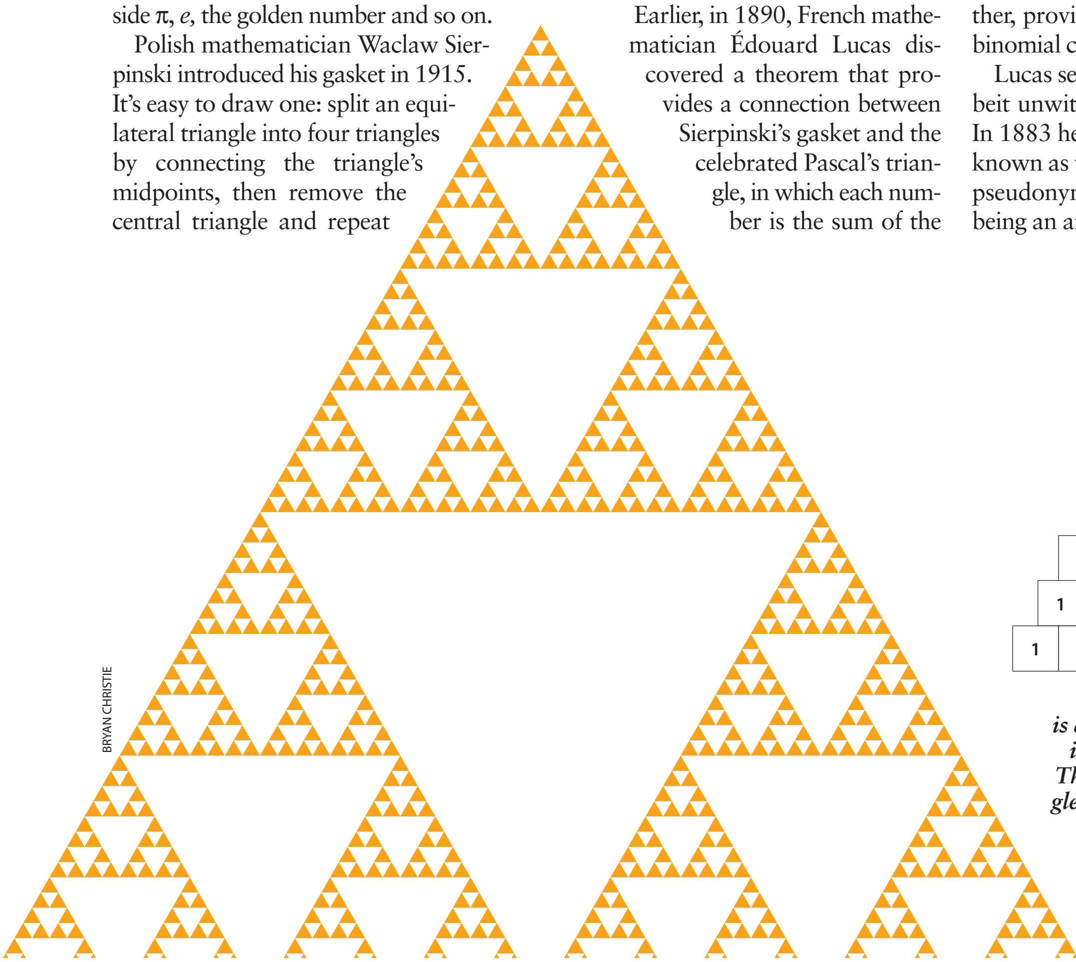
Strange numbers, strange shapes: these are the things that give mathematics its allure. And, even more so, strange connections—topics that seem totally different yet possess a hidden, secret unity. One of my favorite examples is Sierpinski's gasket, the triangular shape shown in the illustration below. In the term made famous by mathematician Benoit B. Mandelbrot, the shape is a fractal—it can be divided into parts that are smaller versions of the whole. But Sierpinski's gasket also has connections with self-intersections of curves, Pascal's triangle, the Tower of Hanoi puzzle, and the curious number 466/885, whose numerical value is roughly 0.52655. This number should be on everyone's list of "numbers that are more significant than they seem," alongside π, *e,* the golden number and so on.

Polish mathematician Waclaw Sierpinski introduced his gasket in 1915. It's easy to draw one: split an equilateral triangle into four triangles by connecting the triangle's midpoints, then remove the central triangle and repeat the procedure on the remaining triangles. If you do this an infinite number of times, you will end up with a curve that crosses itself at every point—a classic instance of a geometric property so counterintuitive that such shapes were originally known as pathological curves. Strictly speaking, the Sierpinski gasket crosses itself at every point except the three corners of the largest triangle. Sierpinski's answer to this objection is that if six copies of this triangle are arranged to form a regular hexagon, then the result is a curve that crosses itself at every point. Recently researchers have designed antennas in the shape of Sierpinski's gasket to take advantage of its jagged form [see "Practical Fractals," News and Analysis, SCIENTIFIC AMERICAN, July].

Earlier, in 1890, French mathematician Édouard Lucas discovered a theorem that provides a connection between Sierpinski's gasket and the celebrated Pascal's triangle, in which each number is the sum of the two above it. These numbers are more technically known as binomial coefficients, and the *k*th entry in row *n* (where we number the rows and entries starting with 0 rather than 1) is the number of different ways to choose *k* objects out of *n*. Lucas asked, When is a number in Pascal's triangle even or odd? The results, shown in the illustration below, are striking and surprising. The odd binomial coefficients look extraordinarily like a discrete version of the Sierpinski gasket.

One curious consequence is that nearly all binomial coefficients are even—that is, as the size of Pascal's triangle gets ever larger, the ratio of odd coefficients to even coefficients gets closer and closer to zero. The reason is that since the gasket is a curve, its area, which in the limit represents the proportion of odd binomial coefficients, is zero. David Singmaster of London's South Bank University has taken this observation further, proving that for any *m*, almost all binomial coefficients are divisible by *m*.

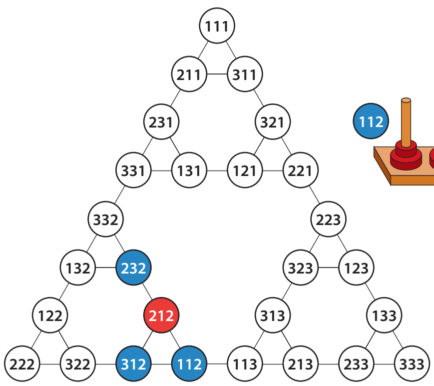
Lucas seems to have been haunted, albeit unwittingly, by Sierpinski's gasket. In 1883 he marketed the famous puzzle known as the Tower of Hanoi under the pseudonym "M. Claus" (the surname being an anagram of his own). The puz-

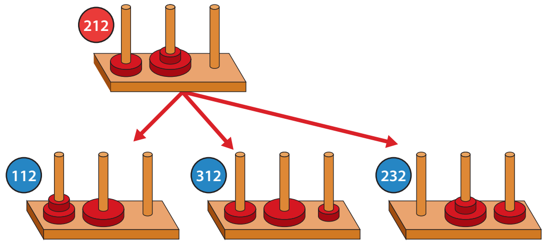


BRYAN CHRISTIE

1
1 1
1 2 1
1 3 3 1
1 4 6 4 1
1 5 10 10 5 1
1 6 15 20 15 6 1
1 7 21 35 35 21 7 1

SIERPINSKI'S GASKET is drawn by dividing and subdividing an equilateral triangle (left). *The odd numbers in Pascal's triangle* (above) *follow a similar pattern.*





BRYAN CHRISTIE

TOWER OF HANOI
graph** (left) **shows all the legal moves in the puzzle. From position 212** (red) **one can move only to 112, 312 and 232** (blue). **The same moves are also illustrated above.

zle consists of eight (or fewer) disks mounted on three pins—the three-disk case is shown in the illustration above—and it is an old favorite of recreational mathematicians. The disks are arranged on one pin in order of size, and they have to be moved one at a time so that no disk ever sits on top of a smaller one. The object of the puzzle is to move all the disks to a different pin from the one they started from.

It is well known that the solution has a recursive structure. That is, the solution of (n + 1)-disk Hanoi can be simply deduced from that for n-disk Hanoi. For instance, suppose you know how to solve three-disk Hanoi, and you are presented with the four-disk version. Start by ignoring the bottom disk and use your knowledge of three-disk Hanoi to transfer the top three disks to an empty pin. Then move the bottom disk to the other empty pin. Now use your knowledge of three-disk Hanoi to transfer the top three disks to that same pin, on top of the bottom disk.

We can interpret this recursive structure geometrically, which is where the connection with the gasket comes in. For any puzzle of this general type, with moving objects and a finite number of positions, we can draw a graph: a collection of nodes (dots) joined by edges (lines). In a Tower of Hanoi graph, the nodes are the possible legal positions of the disks, and the edges represent the legal moves between positions. For n-disk Hanoi, call this graph H_n. What does it look like? Consider H_3, which describes the positions and moves in three-disk Hanoi [*see illustration above*]. Number the three disks 1, 2 and 3, with 1 being the smallest and 3 the largest. Number the pins 1, 2 and 3, from left to right. Suppose that disk 1 is on pin 2, disk 2 on pin 1, and disk 3 on pin 2. The rules imply that disk 3 must be under disk 1. Thus, we can represent this position in the game by the sequence 212, the three digits in turn representing the pins for disks 1, 2 and 3. Each position in three-disk Hanoi corresponds to a similar three-digit sequence. There are $3^3 = 27$ positions, because each disk can be on any pin, independent of the others.

What are the permitted moves from position 212? The smallest disk on any pin must be at the top; we cannot move disk 2 to pin 2, for example, because it would then lie on top of the smaller disk 1. From position 212 we can make legal moves only to 112, 312 and 232. The graph H_3 shows all the possible moves from all 27 positions. It consists of three copies of a smaller graph, H_2, linked by three edges to form a triangle.

Each smaller graph H_2 has a similar triple structure, and this is a consequence of the recursive solution. The edges that join the three copies of H_2 together are the stages at which the bottom disk is moved, and the three copies of H_2 are the ways you can move the top two disks only—one copy for each possible position of the third disk. The same goes for any H_n: it is made from three copies of H_{n-1}, linked in a triangular manner. As the number of disks becomes larger and larger, the graph looks more and more like Sierpinski's gasket.

We can use the H_n graph to answer all kinds of questions about the Tower of Hanoi puzzle. For example, the graph is clearly connected—all in one piece—so we can move from any position to any other. The minimum path from the usual starting position (one corner of the largest triangle) to the usual finishing position (another corner) runs straight along one side of the graph and consists of $2^n - 1$ edges. Hence, the puzzle can be solved in a minimum of $2^n - 1$ moves.

About 10 years ago a German mathematician named Andreas Hinz used the Tower of Hanoi puzzle to calculate the average distance between two points in a Sierpinski gasket. Hinz proved that for n-disk Hanoi, the average number of moves linking any two positions approaches $(466/885)2^n$ as n becomes large. This result implies that the average distance between two points in a Sierpinski gasket is 466/885 if each side of the gasket has a length of 1. (Just multiply the average number of moves by the length of each edge, which is $1/(2^n - 1)$. The product approaches 466/885 as n becomes large.) For the statistically minded, Hinz also proved that the variance of the distance between two random points in a unit-side Sierpinski gasket is precisely 904808318/14448151575. Add that to your list of numbers that are more significant than they seem! ■

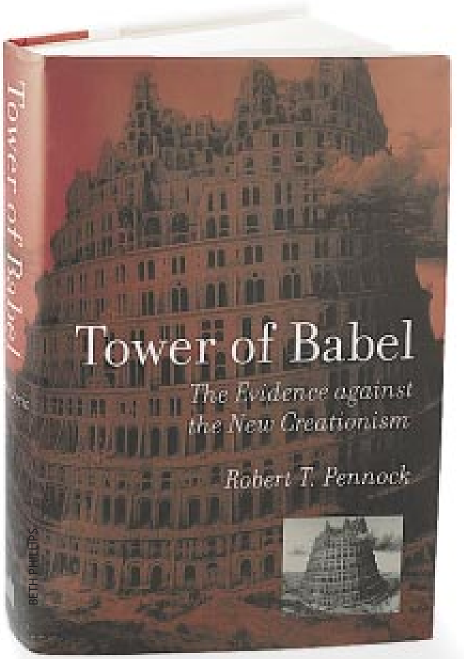
FEEDBACK

In the Feedback that accompanied "Tangling with Topology" [April], I declared that my vague feelings of disquiet about moving-knife algorithms for cake-cutting had been laid to rest. Steven J. Brams of New York University, an expert on such matters, wrote to point out that my original worries are not so easily dismissed. Brams, Alan D. Taylor and William S. Zwicker have analyzed moving-knife schemes in "A Moving-Knife Solution to the Four-Person Envy-Free Cake-Division Problem" (*Proceedings of the American Mathematical Society*, February 1997). They describe a moving-knife procedure for an envy-free allocation among four players that needs at most 11 cuts. No discrete procedure with a bounded number of cuts (however large) is known for four players, and such schemes probably don't exist. Certainly their procedure cannot be made discrete by making "marks" on the cake. The reduction of moving-knife schemes to marks works in some cases—but not all. *—I.S.*

CREATIONISM EVOLVES

Review by Eugenie C. Scott

Tower of Babel: The Evidence against the New Creationism
BY ROBERT T. PENNOCK
MIT Press, Cambridge, Mass., 1999 ($35)



BETH PHILLIPS

Christian creationists have long opposed evolution, first attempting to ban it (as in the Scopes-era antievolution laws) and more recently inventing "creation-science," alleged scientific evidence for biblical literalism. In 1987 the U.S. Supreme Court in *Edwards v. Aguillard* struck down equal-time-for-creation-science laws because creationism is an inherently religious idea and teaching it as the equivalent of science (evolution) unconstitutionally promotes religion. This led to selective pressure to avoid the religious term "creationism," and within a few years of *Edwards,* some creationists were calling not for creation science but for "abrupt appearance theory," "evidence against evolution" or—most recently—"intelligent-design theory." In *Tower of Babel: The Evidence against the New Creationism,* philosopher Robert T. Pennock neatly exposes the creationist roots of intelligent-design theory; from the beginning he refers to "intelligent-design creationism" and shows us how it has descended with modification from its creation science predecessor.

Intelligent-design creationists are primarily conservative Christians greatly concerned over the increasing secularization of U.S. society. They wish to promote Christian theism over philosophical materialism, the view that there are no supernatural forces in the universe, only matter, energy and their interactions. Because science rules out supernatural explanations, intelligent-design creationists believe that it promotes philosophical materialism and thus devalues faith. They accuse scientists of clinging to their naturalistic explanations because of preexisting materialist prejudice rather than the power of empirical evidence.

Because evolution deals with theologically sensitive issues, such as humanity's place in the universe, it becomes the special target of intelligent-design creationists. Movement leader Phillip E. Johnson, a professor of criminal law at the University of California at Berkeley, argues that by showing the weaknesses in evolution, they will drive a wedge into the ideology of materialism, and theism will emerge triumphant. One of the goals is to replace modern science with a "theistic science" in which supernatural explanations will be allowed. It is therefore a religious movement that is both antiscience—at least as science is practiced today—and antievolutionary.

Pennock systematically reveals the philosophical problems inherent in intelligent-design creationism. He shows in several ways that science is not inherently antireligious. Intelligent-design creationists confuse materialist philosophy and the *methodological* materialism of science, which says that science cannot use supernatural cause to explain the natural world. To explain by natural cause does not make a field antireligious; as Pennock wryly notes, science is no more atheistic than plumbing. "To say nothing of God is not to say that God is nothing." Intelligent-design creationism also errs in assuming that if a natural phenomenon can be explained without reference to God, therefore God had nothing to do with it. This brings us to the "design" in intelligent-design creationism.

These creationists have taken William Paley's 18th-century Argument from Design and have established an entire subspecies of antievolutionism around it. Paley found proof of God's existence in the intricacies of nature. Complex structures such as the vertebrate eye "couldn't have occurred by chance," so they must have been designed by an omniscient God, much as the existence of watches implies a watchmaker. Charles Darwin's major contribution to science was showing that structural complexity could be explained through natural processes and did not need the guiding hand of God.

The "God of the Gaps" Problem

Most Christian theologians today believe that God can be Creator and be in charge of the universe without having to line up the chromosomes during each cell division or having to adjust planetary orbits directly. In fact, mainstream Christian theology long ago ceased making design explanations of the natural world, partly to avoid the "God of the Gaps" problem: if the direct hand of God explained unknown natural phenomena, once a natural explanation was discovered for it, God was left with one fewer gap to fill, reducing His majesty.

Although it finds structural perfection in molecular biology and information theory rather than in the vertebrate eye, intelligent-design creationism nonetheless repeats Paley's errors. Pennock details how intelligent-design creationists zero in on currently unsolved problems, such as the origin of life and the Cambrian explosion of invertebrate phyla, and declare them to be "too complex" to be explained by natural cause, requiring explication by an unnamed "intelligent agent." Theologically, you're still stuck with the God of the Gaps, and scientifically, you're confusing the unexplained with the unexplainable.

But the Argument from Design and science as materialism are easy sells to the public, which is more concerned (as Pennock wisely points out) with existential issues of meaninglessness and purpose than with empirical scientific evidence. One of the strengths of *Tower of Babel* is that it specifically addresses these existential issues. A theist himself, Pennock presents a particularly thoughtful discussion of why neither science nor evolution renders life meaningless. He recognizes that some atheist scientists agree with intelligent-design creationists that evolution and religion are incompatible, and he demonstrates the error of "naturalizing God" into a testable hypothesis: it redefines science in harmful ways and, for theists, devalues God.

Polls show that close to half of Americans prefer Genesis-type special creation of humans over human evolution. In an excellent analogy for such Americans, Pennock invokes the biblical Tower of Babel, where God specially created the many different languages of humankind. Linguists have shown that languages have descended with modification: they have evolved by some (though not all) of the same mechanisms as biological species.

Most religious people can accept language evolution. So if it is acceptable that languages evolved rather than having been specially created, why not species? Although languages are used by intelligent humans, languages change not by design or human planning but according to rules that only recently are becoming understood. Citing bibles through the ages, Pennock illustrates English language evolution with the first line of the Lord's Prayer—which is virtually unreadable in its Anglo-Saxon and even in medieval versions. Pennock makes an especially interesting comparison of differences between "designed" languages like Esperanto and "natural" languages: the former are much more regular, orderly and precise; natural languages grow by accretion and look like it. This is directly relevant to the design argument: neither languages nor living things have the orderliness of specially designed phenomena but look far more like "jerry-built jumbles" such as would be produced by evolution.

He That Troubleth His Own Home

Pennock also uses the Tower of Babel as a metaphor to describe the confusion and squabbling among antievolutionists themselves, detailing the nuances of intelligent-design creationists, young earthers, old earthers, progressive creationists and others. Perhaps being mindful of the proverb "He that troubleth his own home shall inherit the wind," Johnson and other leaders try hard to hide theological differences in and outside their camp, claiming that such "details" as the age of the earth, Noah's Flood and the like should be set aside until theism triumphs over the evils of materialist science. Intelligent-design creationists try to keep the peace by avoiding any specific empirical claim about what the designer might have done, relying instead on bashing evolution. In this way, the movement shows its inheritance from its creation science ancestor, which specialized in the negative argument of "if evolution is wrong, then creationism is right."

As Pennock notes, science is no more atheistic than plumbing. "To say nothing of God is not to say that God is nothing."

But Pennock cleverly shows that merely disproving evolution fails to win the day, because (among other reasons) there are more than two alternatives. The Raëlian movement, for example, proposes a purely secular, naturalistic alternative to both evolution and Christian creationism: life on earth is the result of a long-term experiment by technologically and intellectually superior (but fully material) extraterrestrials. Pennock shows that Raëlians marshal the same arguments to support the extraterrestrial intelligent designer that intelligent-design creationists use to promote their Godly intelligent designer—and both arguments share the same weaknesses, of course. Extraterrestrial intelligent design and Godly intelligent design ultimately fail as science (Pennock discusses why at length); either must be taken on faith.

Intelligent-design creationism versus evolution is not just a philosophical and theological intellectual exercise: it's also a fight over what will be taught in our public schools. At the National Center for Science Education, we see more school districts contemplating adding "intelligent-design theory" to the curriculum or being pressed to adopt the intelligent-design textbook *Of Pandas and People*. Pennock illustrates that if they do, they will find the familiar laundry list of long-refuted creation science "arguments against evolution" and the sterile creation science approach of attempting to prove creationism by disproving evolution. The Supreme Court held in *Edwards* that teachers may teach secular and scientific alternatives to evolution, but intelligent-design creationism fails on both counts. At heart it is religious (Pennock relates how, on creationist Web sites and among believers, "intelligent designer" is described as the "politically correct term for God") and to qualify as scientific, it has to argue for the redefinition of science to include "intervention"—miracles, by any other name. One district court already has used "intelligent design" as a synonym for "creation science," so teachers would be advised to use caution when considering advocating it in public schools.

Creation science was rejected by university scientists, but proponents tried by statute to force high school teachers to teach it, arguing that it was only "fair" to teach creation science if evolution were taught. Its descendent, intelligent-design theory, similarly argues "viewpoint discrimination" instead of earning its right to be taught by persuading the scientific community of its veracity.

Continental drift, punctuated equilibrium and quantum theory had to be accepted by the scholarly community before being taught at the high school level, and this is the task for intelligent design. Its proponents aren't there yet: Pennock cites a computerized journal search for "intelligent design" that revealed no scientific research using intelligent design as a biological theory. Intelligent design remains a virtually empty bandwagon. To understand why, instructors might consult Pennock's index for long lists of "problems with arguments" of intelligent-design creationism, of Johnson and other leaders and of terms-of-art like "irreducible complexity," "information" and "explanatory filter."

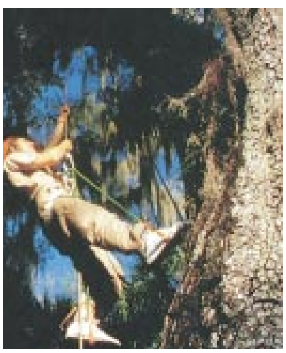
Certainly there are legal and scientific problems with the teaching of intelligent-design creationism. But perhaps of most concern, it misrepresents science as an inherently antireligious enterprise, and evolution as the first step down this slippery slope. This is no way to improve science literacy in America.

EUGENIE C. SCOTT is executive director of the National Center for Science Education (www.natcenscied.org).

THE EDITORS RECOMMEND

LIFE IN THE TREETOPS: ADVENTURES OF A WOMAN IN FIELD BIOLOGY. Margaret D. Lowman. Yale University Press, New Haven, 1999 ($27.50).

Lowman's opening sentence is, "My career is not conventional; I climb trees." Once in a tree, or above the forest canopy on a walkway, a crane or a balloon, she studies the leaves and the creatures that live in the canopy. When she is not in trees, she is director of research and conservation at the Marie Selby Botanical Gardens in Sarasota, Fla., and occupant of the Jessie B. Cox chair in tropical botany there. Her story is part science, part autobiography. She tells of studying leaf growth dynamics in Australia, canopy herbivory in Cameroon, canopy vines in Panama and plant-insect relations in Belize. And she tells of her struggle to balance her career and her tasks as wife and mother. Her hope, she says, is that the book "will offer readers a sense of how a field biologist works and also serve as a stimulus for young people to contemplate a career in science."



FROM *LIFE IN THE TREETOPS*

THE NAZI WAR ON CANCER. Robert N. Proctor. Princeton University Press, Princeton, N.J., 1999 ($29.95).

Proctor treads a narrow path, from which he might encounter on one side condemnation for finding something good to say about a barbaric regime and on the other side praise for bravery in making his point. Recognizing his position, he writes: "I should reassure the reader that I have no desire to efface the brute and simple facts—the complicity in crime or the sinister stupidities of Nazi ideology." But there was, he adds, "a lesser-known 'flip side' of fascism—the side that gave us struggles against smoking, campaigns for cleaner food and water, for exercise and preventive medicine."

He thinks it is worthwhile "to explore the troubling phenomenon of 'quality science' under Nazism: science that we might well celebrate as pathbreaking were the circumstances of its origins peeled away." In particular, he focuses on German efforts to prevent cancer through work on occupational carcinogens and diet and the campaign against tobacco. Proctor, professor of the history of science at Pennsylvania State University, has researched his subject thoroughly.

AIR APPARENT: HOW METEOROLOGISTS LEARNED TO MAP, PREDICT, AND DRAMATIZE WEATHER. Mark Monmonier. University of Chicago Press, Chicago, 1999 ($27.50).

Clever title, rewarding book. Monmonier, professor of geography at Syracuse University, offers here a basic course in meteorology, which he presents gracefully by means of a history of weather maps. The earliest of the many such maps that illustrate the book was published in 1686 by English astronomer Edmond Halley; it showed trade winds and monsoons in, as Halley put it, "the Seas between and near the Tropicks, with an Attempt to Assign the Phisical Cause of the Said Winds." By the end of the book, one is looking at maps based on such high-tech meteorological aids as weather satellites, radar and the Total Ozone Mapping Spectrometer. Contemporary meteorology, Monmonier says, is "arguably today's single most map-intensive scientific enterprise."

FRAGILE DOMINION: COMPLEXITY AND THE COMMONS. Simon Levin. Perseus Books, Reading, Mass., 1999 ($27).

In what he calls "a cautionary tale," Levin asserts that "Mother Earth is in trouble" as a habitat for humanity because of pollution, new diseases and "staggering losses" of biological diversity. To have any hope of dealing with the complex combination of threats to human survival, he says, we must study the earth as an integrated physical and biological system. "By understanding what makes that system work, we will understand how it can fail, thereby finding a way to prioritize actions and maintain the Earth's ability to continue to nurture and sustain us." Levin is professor of biology at Princeton University and founding director of the Princeton Environmental Institute. Drawing on Legos, Scrabble and the Harlem Globetrotters for analogies, he writes of ecological systems, the environment and the biosphere and concludes with "the eight commandments of environmental management."

MIND OF THE RAVEN: INVESTIGATIONS AND ADVENTURES WITH WOLF-BIRDS. Bernd Heinrich. HarperCollins, New York, 1999 ($25).

The raven (*Corvus corax*) is the largest crow, weighing between 1,200 and 1,400 grams (about 2.5 pounds), compared with about 400 for a standard American crow. It has a long-standing reputation as one smart bird. Heinrich, professor of biology at the University of Vermont, has raised raven chicks in his home ("the world's worst roommate," he says), observed ravens in an aviary and spent a great deal of time watching the behavior of wild ravens. He admires the raven's intelligence and describes numerous examples of it.

Among the behaviors he or others have seen are flying upside down, doing barrel rolls, using objects to displace gulls from nests and rocks in defending their own nests, and poking holes in the bottom of their nests on a hot day. He inclines to the view that such behaviors

FROM *MIND OF THE RAVEN*

are conscious, thinking acts. But it is a cautious conclusion. "Extraordinary cleverness can often be explained by 'simpler' hypotheses," he says. "With ravens I'm no longer always sure of how to distinguish a simple from a more complex hypothesis, how to know whether all of the ravens' behavior is somehow complexly preprogrammed or whether they know or learn to know what they are doing."

THE PIONEERS OF FLIGHT: A DOCUMENTARY HISTORY. Phil Scott. Princeton University Press, Princeton, N.J., 1999 ($24.95).

"For some years I have been afflicted with the belief that flight is possible to man." Thus, on May 13, 1900, Wilbur Wright began the first of many letters that he exchanged over the next decade with Octave Chanute, a retired civil engineer in Chicago who had studied and thought deeply about flight and had published in 1894 a volume entitled *Progress in Flying Machines*. Chanute and the Wright brothers are among the many pioneers of flight whose writings on the subject appear in Scott's book. He is a writer living in New York; this book is an outgrowth of his earlier work, *The Shoulders of Giants: A History of Human Flight to 1919*. The 56 documents he has chosen begin with Ovid's tale of Daedalus and Icarus and range through six time periods to 1914. Scott is profoundly impressed by the impact of flight on human affairs. "It has changed our world in more ways than any invention before or since."


FROM THE PIONEERS OF FLIGHT

THE FEEJEE MERMAID AND OTHER ESSAYS IN NATURAL AND UNNATURAL HISTORY. Jan Bondeson. Cornell University Press, Ithaca, N.Y., 1999 ($29.95).

Zoological curiosities, some real and some legendary but credited as real by gullible folk, are Bondeson's subject. He is a British physician, specializing in rheumatology and internal medicine, who for recreation investigates "various odd, macabre phenomena in medicine and natural history that are ignored by the modern, rationalist textbooks of the history of science." Among the real zoological curiosities he describes are animal showers (fish, frogs and worms falling with rain or snow) and Jumbo the elephant, one of P. T. Barnum's famous exhibits. Among the unreal ones are the Feejee Mermaid, which also found its way into Barnum's hands after a time as a popular exhibit in Europe, and the many toads (real themselves) that have been falsely reported as emerging alive after being entombed for long periods in stone or lumps of coal. Bondeson supplies plenty of pictures of his subjects and the often fanciful claims made for them.


FROM THE FEEJEE MERMAID

GREAT STONE CIRCLES. Aubrey Burl. Yale University Press, New Haven, 1999 ($30).

The ancient, haunting stone circles that dot the British countryside have had many explanations. As archaeologist Jacquetta Hawkes wrote in 1967 of the most famous of them, "Every age has the Stonehenge it desires—or deserves." Burl, retired principal lecturer in archaeology at Hull College of Higher Education in Yorkshire, considers the fables, fictions and facts associated with 12 such sites and ventures his own explanations. Writing in particular of one of them, Swinside, at the southwest corner of the Lake District, but generalizing to all of them, he says: "So far from being 'rude stone monuments,' unplanned and casually thrown up; so far from being celestial observatories for astronomer-priests; these were centers of magical protection. Swinside was a perfection of the encircling landscape built in stone, a unity of the physical and the imagination, a symbol of the determination of man to survive against the threatening spirits that loomed everywhere, invisible, high, inhabiting and affecting the precarious and dangerous world of the sky."

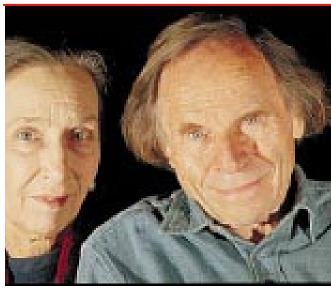
THE DARK SIDE OF MAN: TRACING THE ORIGINS OF MALE VIOLENCE. Michael P. Ghiglieri. Perseus Books, Reading, Mass., 1999 ($26).

Ghiglieri asks if males are born to be violent. "The answer is yes. Aggression is programmed by our DNA." And he examines the forms that male aggression takes: rape, murder, war and genocide. Then he asks if anything can be done about it. Again, yes. "Our intelligence, self-awareness, morality, and culture make us the most amazing and capable beings in the known universe—but not so amazing that we can safely ignore our evolutionary roots in natural selection. These roots are still with us—for evil, as in the lethal and genocidal violence by men, or for good, as in understanding and cooperating to solve the atavistic aggression that is our evolutionary legacy. Our fate lies in our hands." Ghiglieri, associate professor of anthropology at the University of Northern Arizona, is not one to shy from controversy, and it is doubtful that every reader will agree fully with his argument, but he makes it vigorously.

MEMORY: FROM MIND TO MOLECULES. Larry R. Squire and Eric R. Kandel. Scientific American Library, New York, 1999 ($34.95).

Descartes was wrong, the authors say. It is not, "I think, therefore I am" but "I am, therefore I think." Moreover, "We are not who we are simply because we think. We are who we are because we can remember what we have thought about." So saying, Squire and Kandel (respectively, professor of psychiatry, neurosciences and psychology at the University of California School of Medicine at San Diego, and university professor and founder of the Center for Neurobiology and Behavior at Columbia University) present what they call "the molecular biology of cognition." Their account, amply and imaginatively illustrated, describes how memory functions and the molecular events that take place in the brain as a memory is formed. They also treat such malfunctions of memory as amnesia, Alzheimer's disease and age-related memory loss. Their target is "the general reader who enjoys science and is interested in becoming acquainted with the remarkable new discoveries about how the nervous system learns and remembers."

FROM MEMORY: FROM MIND TO MOLECULES



COMMENTARY

WONDERS

by Philip and Phylis Morrison

Dining on Ammonia

DUSAN PETRICIC

The New York of Herman Melville and Walt Whitman was already the largest city in our country, its unceasing traffic fueled by hay for horses and crops for people. Much of these provisions grew on sandy farmlands across the East River. But a reduced yield from long-cultivated acres was becoming noticeable. The farmers understood the need to replenish soil nutrients, as the ancients had done worldwide. Both the fallowing of land and the rotating use of leguminous crops demand more acreage, scarce on islands. So for a decade or two, Manhattan itself became a veritable manure factory.

Whereas the complex cycling of nitrogen through the living world was not at once grasped by agronomists, it was clear to them by the 1840s that available nitrogen was a necessity. Some English crops had been fertilized by seabird guano, dug out of three rainless Peruvian islands not many miles from Lima. New York followed the trend. Whole cliffs of the stuff were carried off in the waiting fleet of hundreds of sailing ships. By the 1880s this unique resource, the most powerful natural fertilizer known, supplying both phosphorus and nitrates, was depleted. Guano was easily replaced as a source of phosphorus by widespread deposits of phosphate rocks (still the global standard). Luckily, geologically old deposits of mineral sodium nitrate from Chile were found as well, and the sea trade in natural nitrates grew again. Many authors would point out—most famously, physicist William Crookes in 1898—that a grain crisis would grip the industrial world once the Chilean nitrate trove was gone. Only the chemists' ability to synthesize nitrates cheaply could save us all from famine.

Although the ocean is certainly an inexhaustible source of water, we cannot drink it directly; indeed, we need freshwater. Our second worldwide ocean—we call it the air—is a subtler case of unusable surfeit. We breathe air in and out for a lifetime, four fifths of it molecules of nitrogen, to which we are biologically almost indifferent. There is enough nitrogen in air to construct all living matter 1,000 times over, yet to win our daily bread we need a new small supply of nitrogen atoms bound more loosely than those in the ambient N_2. That diatomic molecule is so strongly bound—by three covalent bonds—that it was brought into the dance of biochemistry only by the microbial kingdom. We multicellulars cannot subsist on dinitrogen, however common.

Life's need for nitrogen atoms is evident. All proteins—typically some 5 percent of nitrogen by weight—all nucleic acids and many more biomolecules incorporate recycled nitrogen atoms. Whence did available N first arise? The romantic answer is probably a true one. High temperature is enough to break that stubborn triple bond; the fragments rearrange into a variety of compounds of adequate stability, in which they link mainly with oxygen, hydrogen and carbon, not rare constituents. Lightning bolts and meteor trails are hot enough to make measurable amounts of reactive nitrogen compounds high in the open air, one day to come down.

In the late 1800s Manhattan became a veritable manure factory.

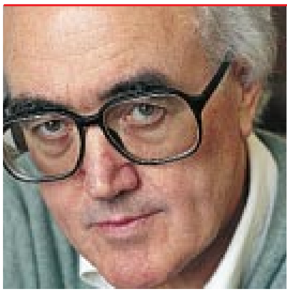
People need about six or eight pounds of reactive nitrogen per year. A good medieval crop of wheat provided enough nitrogen out of natural precipitation to nourish half a dozen adults from 10 fallow acres and a couple of acres planted to wheat. Losses and variability can reduce this optimistic estimate. In most well-fed places, manures, both animal and plant wastes, came to be used on the spot. Nitrates and guano first added nitrogen from afar until World War I, when the chemists fulfilled Crookes's plea: after pioneering a few less economical paths, they synthesized ammonia catalytically, at very high pressure and quite high temperature, out of water, air and a good supply of energy from burning coal. The names of Carl Bosch, chemical engineer, and Walter Haber, chemist, will always stand for this vital process. It provides the proteins today for a billion humans at least and a meaty oversupply for half a billion more of the well-off, as feed for livestock.

Where is most synthetic nitrogen used? As a matter of existential necessity, just where most people sit at table: China. The Chinese now intensively cultivate a large crop area with enough nitrogen fertilizer to yield from one acre food for a dozen people on their largely vegetarian diet. This is the poor man's technology; 60 percent or more of all nitrogen synthesis is now carried out in the developing world, although the plants are designed mainly by a single highly competent American engineering firm.

The cost of this new nitrogen is falling steadily, both in dollars and in energy input per pound of usable nitrogen produced: pressures are lower, thereby reducing the cost of reaction vessels; catalysts continue to improve; and natural gas allows more efficient use of energy than coal or coke does. Field use is easy now because (outside the U.S.) the bulk of the ammonia is converted to a bland, pelletized solid—urea, $CO(NH_2)_2$.

Continued on page 98

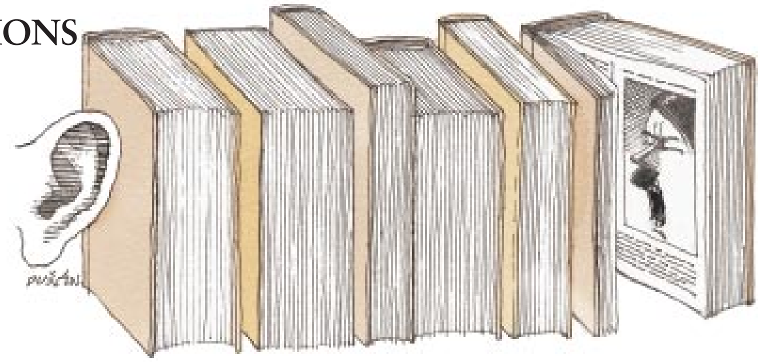
COMMENTARY



CONNECTIONS

by James Burke

Sound Ideas



DUSAN PETRICIC

I got a minor infection in one ear recently and temporarily lost the ability to locate sound sources accurately. Made me really appreciate the way they used to plot the trajectories of incoming World War II V2 rockets (aimed at me—well, London—by you-know-who). British antiaircraft artillery did the plotting with a number of separate microphones, each one picking up the sound at marginally different times, triangulating the sound of the bangs. Consultant to these missile monitors was the youngest Nobelist ever, physicist Lawrence Bragg, who had earlier spent part of his World War I army service locating artillery by the same technique, known as sound ranging. Enemy gun positions were thus made as clear as crystal.

Which is what Bragg got his Nobel for: crystals. In the summer of 1912 he and his dad (another Nobelist) worked out how to tell the composition of crystals by bouncing x-rays against their atomic lattice. As the rays reflected (Bragg's term) off the line of atoms, they interacted with one another and created interference patterns that told you how the atoms were arranged and what the crystal was made of.

The basic technique had been worked out earlier that same year by a German named von Laue, who had done it to prove that x-rays were very short electromagnetic waves (and would therefore mutually interfere if you bounced them off tiny things like atoms). Von Laue made his interference patterns visible by exposing a photographic plate to them. The result being known as Laue diagrams. All these minutiae had been inspired by a French ex-priest I've mentioned before: René-Just Haüy, who was talking to a colleague one day about a bit of calcite when he dropped it. And noticed to his stupefaction that the fragments all looked remarkably similar. So he took his little hammer and started smashing all the crystals he could find. Sure enough, what he would eventually describe as the "ultimate particles" of each type of crystal were all the same shape. In the case of calcite: rhombohedrons (as I'm sure you know). In 1801 this led Haüy to write the usual tome, establishing the science of crystallography and stating that there were six basic crystal forms.

One particular German researcher took this news particularly hard. His name was Friedrich Mohs, and he argued (in 1822) that there were hardly six types. More likely, four. His opinion on the subject had hardened while he was working hard to produce something that today is hard to avoid anytime a lady wants to check that her sparkler isn't paste. By which I mean that the well-known fact of a diamond's being hard enough to scratch anything less hard is only well known thanks to friend Mohs and his "Mohs hardness scale." In which he ranked the hardness of 10 materials, from talc (1) to diamond (10). (Later additions to the scale included, for some strange reason, fingernails.) Mohs's proximity to precious stones gave him an entrée with the well-heeled, and he ended up counselor to the imperial exchequer in charge of money matters.

Later additions to the hardness scale included fingernails.

In 1825 Mohs had a visit from a Brit who was keen to prep for a soon-to-be-available job of prof of mineralogy. He got the job. Then, in 1841, the vice-chancellorship of Cambridge. Whereupon he dragged the university curriculum kicking and screaming into the 19th century. His name was William Whewell, and I have a bit of a soft spot for him because he was a science popularizer and connectionist 150 years before "Connections." Whewell was one of those Victorian polymaths: tidal expert, mathematician, writer of hexameter verses, German translator, Greek scholar, and inventor of the terms "ion," "anode," "cathode," "physicist" and "scientist." He also repudiated pointed arches in favor of flying buttresses as the defining principle of Gothic architecture. And if he hadn't been a clergyman, would have been a great boxer, they said. Whewell knew and organized the entire English scientific establishment and became the noodler's noodler.

As a schoolboy he had taken lessons from "the blind philosopher" John Gough, up north in the English Lake District where Whewell came from. Gough was quite good in math and botany—he felt plants with his tongue and lips—and also produced a mathematical theory of the speaking-trumpet, studied ventriloquism and, in an echo of my opening paragraph, investigated the "position of sonorous objects." Wordsworth and Coleridge thought Gough weathered his affliction remarkably well. An obsession with the weather was something he passed on to another pupil, John Dalton, who went on to make more than 200,000 daily meteorological observations. In 1844 Dalton fell out of bed and died, after a last feeble entry: "Little rain this day." Years of watching the behavior of water in the air naturally enough led to an interest in the behavior of air (or any gas) in water.

Experiments to force various gases under pressure into water led Dalton to the startling thought in 1803 that what he called "light, single" particles of gas were absorbed into water less readily than heavier, "complex" particles were. The list of light and heavy particles he added to the end of a paper on the subject was the first version of what we call the atomic weights table.

In 1792 Dalton was appointed professor at the Unitarian New College in Manchester, which opened after the demise of the nearby Dissenters' Warrington Academy. Where Joseph Priestley had taught before being succeeded by Reinhold Forster. From 1772 to 1775 Reinhold and son Georg were the naturalists on the HMS *Resolution* when Captain Cook went looking for the hypothetical southern continent. When they returned, they beat Cook to the punch with a book on the voyage that put them in such bad odor with the harrumph naval establishment that Georg departed for Germany. In 1790 he spent three months going down the Rhine with Alexander von Humboldt, presumably bending his ear with tales of naturalist derring-do from the great days of the Cook expedition. Whether Humboldt took notes or not, later on during his wanderings in South America he did much the same as had the Forsters in the Pacific.

Humboldt's writings turned on a footloose geographer and travel writer, Friedrich Ratzel, who went off on a tour of the U.S. and studied the dwindling population of native Americans. In 1901 he came up with a theory about how population was related to space: the more of the latter, the more of the former. In 1921 Karl Haushofer, professor of geopolitics at Munich, was teaching this stuff to packed classes. Two years later he visited an ex-student who happened to be sharing a prison cell with a fellow who was writing up some great thoughts and who jumped at Ratzel's *Lebensraum* theory of space because it accorded perfectly with his own ideas about the future expansion of Germany as a world power. Haushofer's ex-student was named Rudolf Hess, and his fellow jailbird was the same guy who would later on be lofting over those V2s I mentioned at the beginning of this column: A. Hitler.

Who also had his own hearing problems, as I recall.

Wonders, *continued from page 96*

Of course, the biosphere found its own way, beyond lightning. The legumes that invigorate the soil dwell symbiotically with a family of nitrogen-fixing bacteria held in root nodules on the host plant, some form of bean, pea or vetch. The synthesis is catalyzed enzymatically, as in all biochemistry. Obviously, the molecular biologists would like to train wheat and maize roots to be so hospitable—so far no success despite considerable effort. It turns out that the rice paddy has long had its own microbial alliance. The green layer that floats on the water of flourishing tropical paddies is rich in a tiny aquatic fern that harbors its own cyanobacteria, which are clever enough to fix nitrogen from the air. The Chinese rice farmer has known this for a very long time, taking care to inoculate every new paddy with a little thriving paddy green.

The free-living cyanobacteria are distinct from the symbiotic bacteria the legumes support, but they all share the same enzyme, able at ambient pressure and temperature to split the Gordian tie of N_2. No catalyst can change energy balance, so the synthesis costs the organism plenty of energy, just as it does the engineers. Perhaps that is why it is restricted to so few organisms. Vaclav Smil, not an author to err toward hyperbole, suggests that the total world mass of that prince of proteins—vital nitrogenase—may be less than a dozen kilograms.

The graphs show a nearly exponential rise in world annual synthetic nitrogen production, from a pre-Haber 25 tons in 1900 to about 90 million tons in 1990! The side effects of newly surplus reactive nitrogen are pretty clear. Much soluble nitrogen and gaseous ammonia leaks out of fields and feedlots. Unprecedented blooms of algae and aquatic plants have turned many a sweetly clear pond green; nitrate runoff endangers drinking water supplies; hot engine exhausts produce nitrogen oxides, too, and an authentic Los Angeles smog in a complicated reaction chain involving ozone. Will such side effects put a stop to our grain production, a rain of reactive nitrogen becoming as bad as too little?

No. The figures of the 1990s imply a maturing of the fixation industry just ahead. We can reasonably expect to nourish the 10 billion diners of 2070 if present trends continue.

WORKING KNOWLEDGE

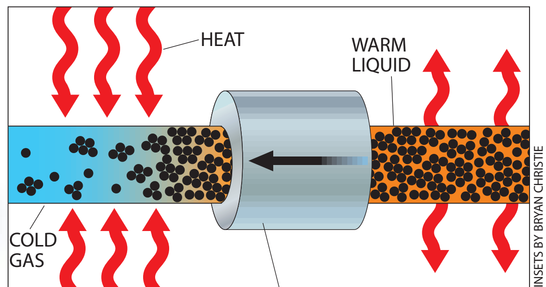
AIR CONDITIONERS

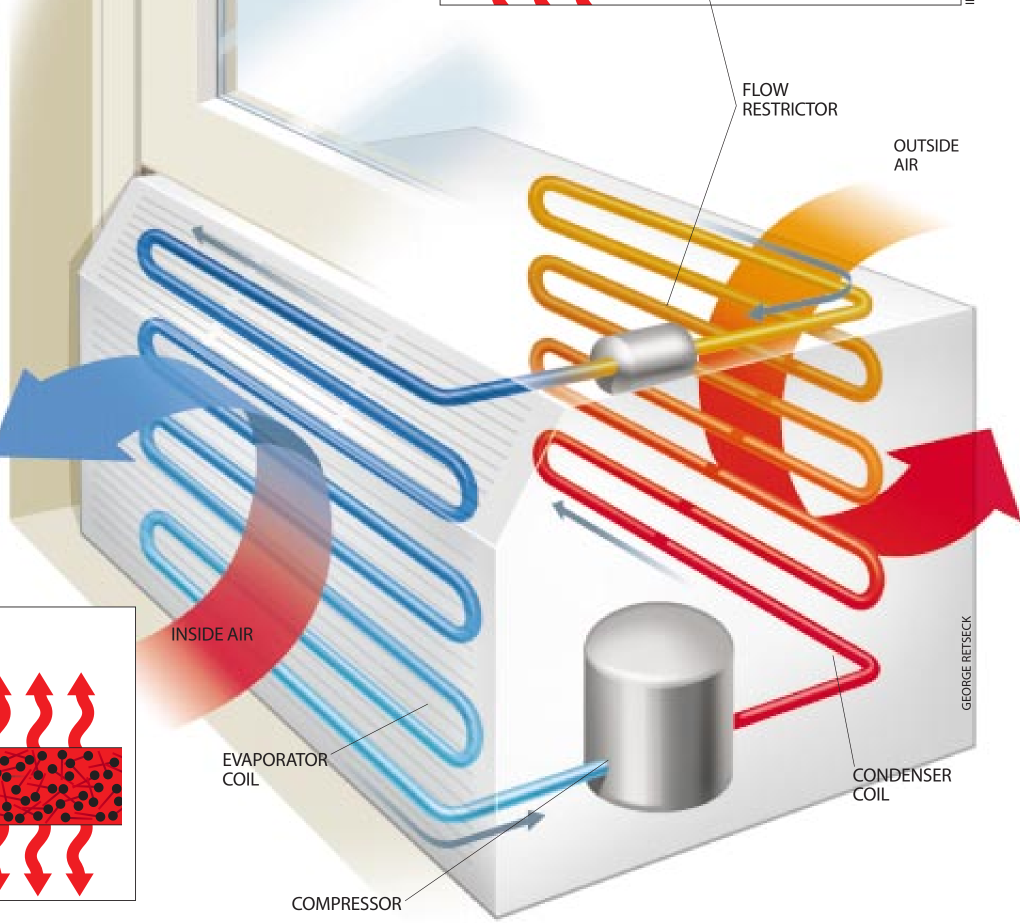
by Louis A. Bloomfield
Department of Physics, University of Virginia
Author of How Things Work:
The Physics of Everyday Life

Thermal energy, or "heat," naturally flows from hot to cold, which is why air in your room gets warmer when it is hot outside. An air conditioner has the challenging task of pumping heat the other way—from the room to the outside. It does this job with the help of a chemical, called a working fluid, that can change easily from gas to liquid or from liquid to gas. The air conditioner controls the phases of the working fluid by changing its pressure and density.

The surface between a liquid and a gas is always a busy place, with molecules moving between the two states. When the gas density is low, more molecules leave the liquid than return, and the liquid evaporates. Conversely, when the gas density is high, more molecules return to the liquid than leave, and the gas condenses. These changes in phase take place as the working fluid travels through the various components of the air conditioner, and, as described in the captions, this process moves heat from one place to another.

1 BECAUSE ENERGY is needed to separate the molecules in a liquid, the working fluid absorbs heat from the environment when its liquid form evaporates into a gas. The first step in this process takes place in the flow restrictor. The working fluid enters as dense liquid; the flow restrictor decreases the pressure on the liquid so that it begins to evaporate when it comes out the other side. (As liquid evaporates, it cools, so the working fluid is cooling rapidly as it emerges from the flow restrictor.) As the working fluid then travels the length of the evaporator coils, it continues to evaporate into a gas and to absorb heat from the room.





2 WHEN THE GAS reaches the compressor, it has absorbed a lot of heat from the room and is becoming warm. It enters the compressor, which pushes all the molecules together, increasing the pressure and density of the gas. When the molecules are forced together, the temperature of the working fluid itself increases. As this dense, hot gas travels through the condenser coils, it releases heat to the outside, thereby becoming a liquid. Ultimately, it reaches the flow restrictor, ready to start the whole cycle again.