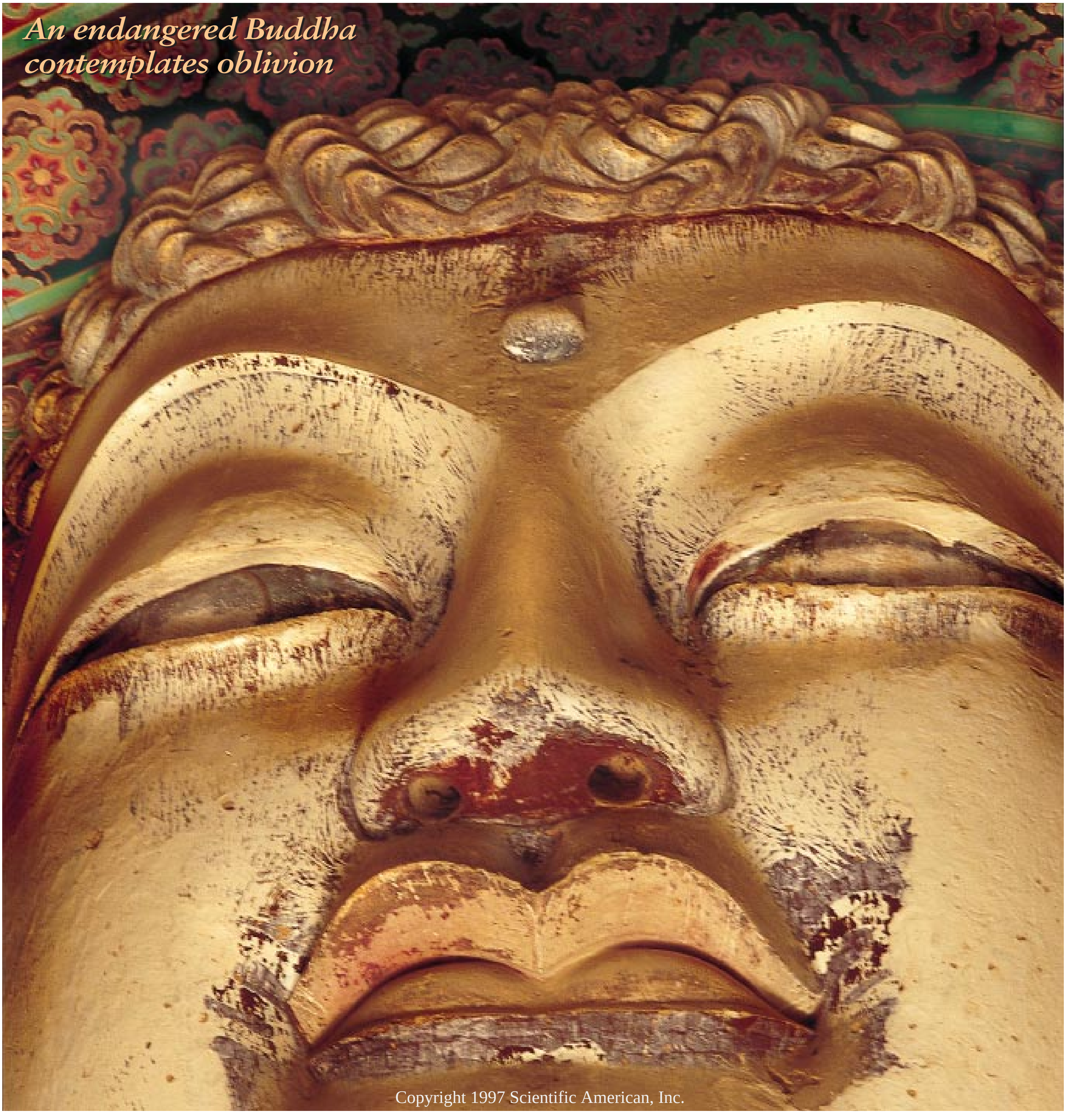
ASBESTOS TOOTHPASTE • BAFFLING GAMMA-RAY BURSTS • HIGH-TECH SAILING

SCIENTIFIC AMERICAN

JULY 1997 $4.95

STUPID COMPUTER TRICKS: HOW VIRTUAL REALITY, SPEECH RECOGNITION AND OTHER GOOD IDEAS CAN HURT BUSINESS

An endangered Buddha contemplates oblivion



SCIENTIFIC AMERICAN

July 1997 Volume 277 Number 1

Scientific American (ISSN 0036-8733), published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017-1111. Periodicals postage paid at New York, N.Y., and at additional mailing offices. Canada Post International Publications Mail (Canadian Distribution) Sales Agreement No. 242764. Canadian BN No. 127387652RT; QST No. Q1015332537. Subscription rates: one year $34.97 (outside U.S. $47). Institutional price: one year $39.95 (outside U.S. $50.95). Postmaster: Send address changes to Scientific American, Box 3187, Harlan, Iowa 51537. Reprints available: write Reprint Department, Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017-1111; fax: (212) 355-0408 or send e-mail to info@sciam.com Visit our World Wide Web site at http://www.sciam.com/ **Subscription inquiries: U.S. and Canada (800) 333-1199; other (515) 247-7631.**

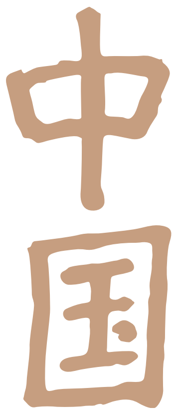
About the Cover

Known as the Colossal Buddha, this towering statue rises to a height of 30 meters inside a pagoda at the Mogao Grottoes in China. It dates back to the early Tang dynasty, circa 695 C.E. Photograph by G. Aldana, courtesy of the Getty Conservation Institute.

The Future and Past of China

China's name means "the Middle Kingdom," a title that places this giant country at the geographic, cultural and intellectual hub of the world. With the repatriation of Hong Kong, the Middle Kingdom is again indeed at the center of the world's attention. Much of that attention is frankly dread: many observers fear what the economic and human-rights climates will be in Hong Kong under communist rule. The situation raises new security problems and moral quandaries of direct concern to many scientists and technologists, as stories in our News and Analysis explain, beginning on page 15.

Science and technology will of course shape China in the years ahead, and vice versa. Feeding its huge population will continue to be China's top priority (see "Can China Feed Itself?" by Roy L. Prosterman, Tim Hanstad and Li Ping, in the November 1996 issue), but the country is nonetheless trying to make rapid progress. Many Chinese scientists are currently hobbled by lack of access to tools and instruments like those of their Western colleagues. If the changing fortunes of China lift those barriers, it may yet again become a Middle Kingdom of scientific influence.



LAURIE GRACE

THE MIDDLE KINGDOM, pronounced "zhōng guó," is China.

If the best way to grasp China's future is to look to its past, then one place to look is in the Mogao Grottoes. On a 1,600-meter-long cliff face at the outskirts of the Takla Makan Desert, near the Silk Road that for 1,000 years linked China by trade with more western Asia and Europe, sit hundreds of caves rich in Chinese cultural history. A prior wave of archaeological pillaging, a current wave of tourism and the steady scourge of the elements have eroded the grottoes and their prizes. Fortunately, the Getty Conservation Institute and Chinese authorities have in recent years been working to preserve the site. Neville Agnew and Fan Jinshi tell the story of the grottoes and of the conservation efforts in "China's Buddhist Treasures at Dunhuang," beginning on page 40.

On the subject of past accomplishments, I'm delighted to report that SCIENTIFIC AMERICAN has won a National Magazine Award for its September 1996 single-topic issue, "What You Need to Know about Cancer." The American Society of Magazine Editors presents the National Magazine Awards annually for outstanding accomplishments in magazine publishing. The other members of the Board of Editors and I are grateful for this honor, but the lion's share of our gratitude still goes to the many researchers who contributed to that issue with their words and their discoveries.

JOHN RENNIE, *Editor in Chief*
editors@sciam.com

WATERWORLD

I have just finished David Schneider's article "The Rising Seas" [Trends in Climate Research, March]. A question came to mind as I read of the difficulty in determining the actual increase in ocean levels caused by melting polar ice caps. Wouldn't continued deforestation and desertification add water to the oceans? If less water is being stored as groundwater, it has to be somewhere, and wouldn't that inevitably be the oceans?

PHILLIP IRWIN
Winnipeg, Manitoba

Schneider replies:

Irwin astutely points out that I did not mention several factors contributing to changing sea level. The justification for ignoring certain processes is that, in the overall scheme, they probably make little dent. The burning of forests, for instance, is thought to add only 0.03 millimeter to the nearly two millimeters of sea-level rise that goes on every year. And scientists are not sure whether the combination of such secondary influences (including the mining of groundwater, deforestation, drainage of wetlands and the impoundment of water behind dams) amounts to a net positive or negative effect on ocean level.

M. GUNTHER Bios/Peter Arnold, Inc.

FEWER TREES, more water?

EMERGING DISEASES

The increasing prevalence of mental illnesses worldwide, described by Arthur Kleinman and Alex Cohen ["Psychiatry's Global Challenge," March], can be viewed through the prism of emerging diseases. Recent research suggests that many infectious diseases can also cause psychiatric complications. For example, Borna viruses may be associated with depression and mood disorders; pediatric obsessive-compulsive disorders can follow streptococcal infections; toxins from algal blooms can impair memory and learning. Studying the links between infectious agents and certain psychiatric disorders could provide a common agenda for the infectious disease and psychiatric professions.

EDWARD MCSWEEGAN
National Institutes of Health

INTERNET SPECIAL REPORT

Perhaps Michael Lesk in his article "Going Digital" [March] should have distinguished between research and public libraries. Although material in a research library may lend itself to the digital format, this is not necessarily true for the public library. Public libraries will stock whatever format the public demands, whether it be a bound book, a digital book, a book-on-tape or a video. And until a digitally formatted book can surpass the mobility and browsability of a bound book, I would rather curl up on the couch with a paperback edition of *Gone with the Wind.*

JOAN LUBBEN
Orange City, Iowa

Our heartfelt thanks to all at Scientific American for printing "Websurfing without a Monitor," by T. V. Raman [March]. It is a very well written and extremely enlightening article. Besides people with visual impairments, there are many thousands of others with learning disabilities or brain injuries who are unable to read print materials and rely on speech synthesis software. Many of our staff members use computers without monitors as well as reading machines to access the world of print, including your magazine.

CLYDE SHIDELER
Director, CE Disabled Services
San Luis Rey, Calif.

ELEMENTARY, MY DEAR WHAT SON

It seems we have a mystery here. How could a reputable scientific magazine mistakenly report that voice-recognition technology is just now being invented by Microsoft ["Making Sense," by W. Wayt Gibbs, News and Analysis, February]? Following is an uncorrected quote from *The Adventure of the Blue Carbuncle,* by Arthur Conan Doyle, that I prepared using IBM VoiceType software—voice-recognition technology that is currently on the market.

> I had called upon my friend Sherlock Holmes upon the second morning after Christmas comma with the intention of wishing him the complement of the season. He was lounging upon the sofa in a purple dressing down comma a pipe rack within his reach upon the right comma and a pile of crumbled morning papers, evidently newly studied comma near at hand. Beside the couch was a wooden chair comma and on the angle of the back on a very CD and disreputable hard felt hat comma much the worse for wear comma and crack in several places.

KEVIN MYERS
Phoenix, Ariz.

Gibbs replies:

As I pointed out in my story, the present state of voice-recognition technology is clearly inadequate for general use. Indeed, Myers's example demonstrates the problem rather well. In three sentences, I count 13 errors. To distinguish "compliment" from "complement" and "seedy" from "CD," computers must learn more about the grammatical and semantic relations among words. Encoding such relations is difficult and time-consuming. The computational approach Microsoft linguists are pursuing is newsworthy because of its relative efficiency.

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. Letters may be edited for length and clarity.

ERRATA

In the article "Extremophiles," by Michael T. Madigan and Barry L. Marrs [April], it was stated that "water tends to flow from areas of high solute concentration to areas of lower concentration." The reverse is true. The image accompanying "All in the Timing," by Corey S. Powell [News and Analysis, January], was provided by ROSAT, MPE Garching.

50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

JULY 1947

GUZZLING GAS—"Unfortunately for the development of the light car in the U.S., much of the public thinking has been concerned with 'keeping up with the Joneses.' General Motors and Ford have apparently shelved their plans for such cars, feeling it 'inopportune' to divert materials and manpower to the production of light cars which have high mileage per gallon of gasoline. Such moves leave Crosley Motors alone with the opportunity to develop a leading position in the low-priced car market." [*Editors' note: Crosley Motors went out of business in 1952.*]

METAL ATOMS—"From experiences with hot metals and casting, science is evolving a theory: Given a supply of energy and half a chance, atoms may wander from one metallic crystal to another, forming new patterns. Cold welding, at temperatures below the molten, had been done for thousands of years, but nobody understood why the metals joined each other. What the atoms seem to need is more time to wander back and forth within their own crystals and to emigrate from crystal to crystal. The crystals would then seem to be locked by each other's atoms into a true weld."

JULY 1897

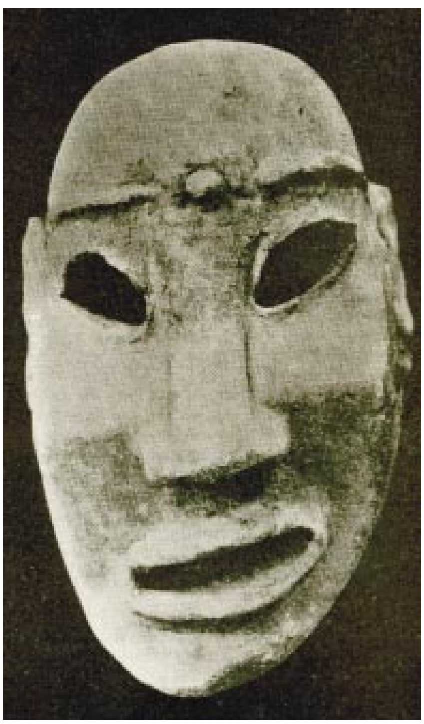
GOOD BACTERIA—"So much has been said about bacteria as causing and propagating disease that it is difficult to make the public regard these minute organisms as anything but mischief makers. Nevertheless, they serve a useful purpose in nature, and contribute quite as much to one's pleasure as to one's discomfort. The reason some kinds of butter and cheese have better flavors than others is that different species of bacteria have been commercially developed."

WORLD'S LARGEST CAMERA—"An enormous camera has been constructed by Theodore Kytka, artist and expert in micro-photography. The telescope part of this camera is 25 feet long when extended to its full capacity. The police have employed this camera to assist in the case where a check on the Nevada Bank was raised from $12 to $22,000. The check was placed before the camera and photographed, and enlarged, emphasizing not only the fiber of the paper but the lines on it. The camera brought out faintly the letters 'lve' which had been erased with acid by the forgers before they changed the word 'Twe-lve' to 'Twenty Two Thousand.'"

SYNTHETIC DIAMOND—"Thanks to the success of Prof. Henri Moissan, diamonds can now be manufactured in the laboratory—minutely microscopic, it is true, but with crystalline form and appearance, color, hardness, and action on light the same as the natural gem. Iron packed in a carbon crucible, put into the body of the electric furnace and heated to a temperature above 4,000° C, was plunged in cold water until it cooled below a red heat. The expansion of the inner liquid on solidifying produced an enormous pressure, under stress of which the dissolved carbon separated out as diamond." [*Editors' note: Moissan's experiments have been repeated a number of times and have not produced unequivocally any hard crystalline material other than spinels.*]

LUDDISM IN PARIS—"The works of the Carriage Builders' Society, in the Rue Pouchet, Paris, caught fire on July 12, and sixty horseless carriages were destroyed. It is believed that the fire was of incendiary origin. It is a well known fact that the Paris cab drivers are very much opposed to the introduction of horseless carriages, which they believe are destined to interfere with their means of livelihood."

A CARTHAGINIAN MASK—"A most interesting find from a Punic necropolis of Carthage is a terra cotta mask, which is illustrated herewith. The mask is 8 inches in height and preserves a few traces of black paint. The mouth and eyes are cut out through the thickness of the clay and the ears are ornamented with rings. Above the bridge of the nose it bears the mark of its Punic origin in the crescent, with depressed horns, surmounting the disk—an emblem that is very frequent upon the votive stelae of Carthage. These sorts of masks were usually placed alongside of the dead."

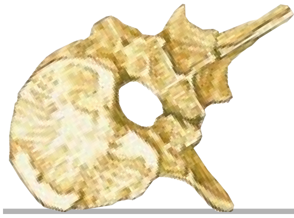


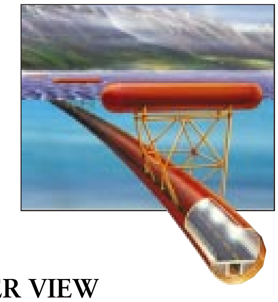
Terra cotta mask from Carthage

JULY 1847

HATCHING FISH IN CHINA—"Hatching of fish by artificial heat is well known in China. The sale of spawn for this purpose forms an important branch of trade. The fishermen collect with care from the surface of the water, all the gelatinous matters that contain spawn fish, which is then placed in an eggshell, which has been fresh emptied, and the shell is placed under a sitting fowl. In a few days the Chinese break the shell into warm water. The young fish are kept until they are large enough to be placed in a pond. This plan counteracts the great destruction of spawn by troll nets, which have caused the extinction of many fisheries."

NEWS AND ANALYSIS





IN FOCUS

On July 1, China regains control of Hong Kong, raising many political, economic and social issues. Two that concern scientists and technologists are explored here.

STRATEGIC INVESTMENTS

China plans to make Hong Kong its high-tech gateway

They are going to paint the British-style red postboxes green in Hong Kong—to match those of China. It is a small but visible sign of the enormous changes that July 1, 1997, will bring to this 400-square-mile territory on the southern tip of China. Hong Kong, ceded to the U.K. in 1842 as a result of the Opium War, is to be handed back to China at midnight on June 30.

The world's press has been full of stories, with most concentrating on whether Hong Kong's Western-style freedoms will be preserved. But China prefers to see Hong Kong as an economic city, and leaders of both regions are paying less attention to constitutional developments and instead rethinking Hong Kong's industrial strategy.

Traditionally, Hong Kong has prided itself on its policy of "positive nonintervention." It did not offer tax incentives or other breaks to attract specific industries, as did many other Asian tiger economies, such as Singapore. "I should have thought," crisply remarked one Hong Kong finance chief in the early 1970s, "that a good business for Hong Kong was one which didn't require help from the government." (That's a slight fudge on the facts, though: government bodies such as the Trade Development Council spend millions of dollars a year promoting Hong Kong around the world.)

GREG GIRARD *Contact Press Images*

***COUNTDOWN CLOCK IN TIANANMEN SQUARE** in Beijing has shown for the past three years the days and seconds left before July 1, 1997.*

The incoming team of chief executive designate Tung Chee-hwa may be about to change this policy to encourage more high-tech, service-oriented businesses to invest in Hong Kong. Since 1979, when Deng Xiaoping started economic reforms in China, the Hong Kong economy has changed immeasurably. Production facilities shifted across the border to neighboring Guangdong Province. Manufacturing in Hong Kong peaked in the early 1980s, employing more than 870,000; that figure now stands at 350,000. Manufacturing's share of the gross domestic product has shrunk from 24 percent in 1979 to around 10 percent today.

With a service-oriented economy, some future leaders, such as James Tien, chairman of the Hong Kong General Chamber of Commerce, fear that the territory has "all its eggs in one basket." But most other leaders aren't bothered. Two recent reports both encourage service-sector development.

One report—*The Hong Kong Advantage*—was written by Michael J. Enright, a visiting professor at the University of Hong Kong Business School, and his colleagues. It says the decline of manufacturing is a myth: Hong Kong's producers, like those in the U.S., have just sought out lower-cost areas to assemble. The report calls for more R&D spending by government, venture capital incentives for high-tech start-ups and low-cost housing for scientists and engineers. The other report, by Suzanne Berger and Richard K. Lester of the Massachusetts Institute of Technology, makes similar calls. Many local politicians, and especially those close to top Chinese officials, would add tax breaks for high-tech investment.

It is no coincidence that politicians dear to China's rulers should lead the charge. Never mind Hong Kong's huge reserves of cash: Hong Kong serves as an import-export gateway. Its open society and economy and huge throughput of ships and containers make Hong Kong an ideal conduit for China to acquire high technology.

The main customer is the military. Its People's Liberation Army (PLA) maintains a publicly listed company in Hong Kong called Poly Investment Holdings. Many believe the army also has hundreds of other front companies operating in the territory, trading property and investing the profits in unknown ventures. "The PLA has been here for years," says one former Hong Kong policeman. "Some of it is simple profiteering or a way of presenting projects in China as foreign-funded ventures for tax purposes, but you'd be blind not to see there was another agenda." At least one supercomputer ostensibly bound for use in seismologic prediction in a Chinese university turned up in a weapons factory. A similar fate befell machine tools supposedly for civilian manufacturing, according to reports in the *Far Eastern Economic Review*.

On the way out often go arms—an airplane from Beijing was recently found to be carrying bomb cases apparently headed for Israel and improperly declared for customs. The export of some nuclear and missile technology to Pakistan is also said to have tripped through Hong Kong.

China's desire for Hong Kong to develop in the technological market is not driven only by military desires, of course. The hope is that if Hong Kong climbs the value-added chain, China will follow right behind. For example, the State Council of China (a cabinet-level group) has a listed arm in Hong Kong, called China Everbright Technology. It focuses on acquiring foreign high-technology firms. In the past, acquisitions were decidedly low-tech—for instance, they bought an Australian car battery manufacturer. But in early May, Everbright's parent company bought 8 percent of Hongkong Telecommunications, the monopoly provider of international communications in the territory and a cornucopia of vital skills and technology to China, which is building a vast digital network.

Perhaps the main obstacle to Hong Kong's transformation is its shortage of skilled staff, especially in electronic-related disciplines—despite the presence of four universities, including a dedicated University of Science and Technology. And getting the best candidates into science programs is tricky in a place where the foremost money-making proposition is dealing in real estate. But given China's commitment to the new strategy, Hong Kong's emergence as a preeminent technology center seems as inevitable as green mailboxes along Queen's Road, Central. —*Simon Fluendy in Hong Kong*

RIGHTS OF PASSAGE

Scientists may be the last credible advocates of human rights in China

The tradition goes back to the beginnings of modern science, when Galileo challenged the Roman Catholic Church. In spite of persecution, scientists have invariably advocated free thinking, political openness and other human rights. In confronting the People's Republic of China, though, concerned researchers in the U.S. and other nations face a dilemma: how to help their Chinese counterparts while not aiding a government that could repress them.

Complicating that quandary is the increasingly intricate relationship between the U.S. and China. The U.S. faces more pressing policy considerations than militating on human rights, and as China assumes an ever more prominent stature in world affairs, the scientific community could become one of the last voices to speak out against intellectual persecution by Beijing. But they have yet to adopt that role, one that neither the U.S. government nor private enterprise is likely to fulfill.


ASSOCIATED PRESS

***HONG KONG COMMEMORATION OF TIANANMEN VICTIMS** occurs every June 4. Whether it will continue is unknown.*

Until a few years ago, the U.S. challenged China on its human-rights record mainly through threats to its trade standing. In past years, the U.S. blustered that it would not renew China's most favored nation status—which confers low tariffs on Chinese imports—if it did not shape up on certain key rights issues. The U.S. subsequently backed down with minimal concessions from Beijing. In 1994 President Bill Clinton dropped the connection between trade status and human-rights progress. Since then, the U.S., though officially disappointed with China's progress, has had no cohesive strategy, argues Andrew J. Nathan of Columbia University. "It's all been pretty namby-pamby," concludes Nathan, who also chairs the advisory committee of Human Rights Watch/Asia.

Entrepreneurs won't be at the forefront of reform, either. Making human-rights waves may alienate the ruling Communist Party and thereby jeopardize lucrative opportunities. Rather businesses typically assert that their presence in China would naturally foster reform (echoing arguments put forth a decade ago by American companies that invested in apartheid South Africa).

"There's overwhelming evidence to the contrary," says Joseph L. Birman, a physicist at the City University of New York and chair of the Committee on Human Rights of Scientists of the New York Academy of Sciences. "E-mail has become increasingly restricted. Every scientist with a terminal has to register the secret password with the police. This was put in 15 months ago, just during the period of explosive economic activity." And advocates believe freedoms in Hong Kong, China's primary business hub as of July 1, are at stake. Already Beijing has curtailed civil liberties there by making criticism of its policy on dissidents illegal.

With politicians and business leaders reluctant to step up, researchers may be the last hope. Scientists, in fact, have a responsibility to help, argues Xiao Qiang, a physicist by training who heads Human Rights in China, based in New York City. "Science is an international enterprise that goes across borders, across races." Scientists are not like businesspeople, who have other priorities, he adds; their truth-seeking nature gives them a unique credibility. So Beijing may be more responsive to scholars' opinions rather than to direct political intervention, which is often viewed as meddling or posturing.


CHIP HIRES Gamma-Liaison

"GODDESS OF DEMOCRACY" was erected by students during the Tiananmen Square uprising in 1989.

But U.S. researchers as a whole lack the fervor that rights violations inspired during the cold war with the Soviet Union. Soviet expatriates in the U.S. "were very much supportive of the human-rights issues being raised," Birman says. In contrast, "the Chinese-American community is by and large indifferent, at least in public." Xiao draws similar conclusions. "When counterparts in the Eastern bloc were being persecuted, scientists here were very outraged," he notes. "They were taking strong actions, like boycotts" of scientific meetings.

Such strident measures would probably backfire with China. "It's not clear to me that refusing to engage in scientific cooperation with China is necessarily to anyone's benefit," says Douglas Erwin, a paleobiologist with the Smithsonian Institution's National Museum of Natural History. "Most of my colleagues in China have as little connection to their government as I do to mine," he adds. So discussions of human rights rarely come up. Besides, "you don't want to expose your colleagues to unfortunate consequences," Erwin warns.

Tentativeness may also stem from China's improved record on human rights. "Compared to 20 years ago, China has undergone the biggest change in the entire world," remarks Shi Yigong, a molecular biologist now at the Memorial Sloan-Kettering Cancer Center in New York City. Shi was among the student demonstrators and hunger strikers at Tiananmen Square in 1989. "If the trend continues, China will satisfy all the Western standards," he thinks. "It's just a matter of time."

What could threaten that trend, Shi opines, is direct confrontation. Dominated by older Chinese intellectuals who came to the U.S. in the early 1980s, discussions of China in the U.S. media present a distorted view, as if the Chinese people were sulking about in depressed spirits, Shi insists. The real picture, he says, can only be discovered by talking to the masses in China, which can be difficult: Chinese are traditionally rather tight-lipped. With regard to the government, "young people tend to be supportive rather than radical," Shi expounds. "The truth is, people appreciate the stability so much so they don't want the unrest." (Certainly, instilling a little paranoia in the people keeps order, too: one person with family members in China remarked at being nervous about talking to Scientific American.)

Indeed, the need to feed and clothe the populace—29 percent still reside in abject poverty, according to the World Bank—is often invoked by Beijing as taking priority over the relatively few jailed dissidents, of which there are at least 2,000, by China's own estimate. It is not obvious, however, how nonpolitical "rights" to a decent living, health care and education necessarily conflict with human rights as defined by international convention. "What do food and clothes have to do with locking up someone for 14 years?" Xiao asks.

With the death of Deng Xiaoping earlier this year, repression has increased because the current leaders have no credibility, activists say. "There's no vision leading China toward the direction of respecting human rights," Xiao insists. If scientists "do not take a position, then the human-rights issue is not necessarily going to get any better."

Columbia's Nathan has advice for well-known researchers. "Some high-profile scientists who have access to top [Chinese] leadership can probably play a helpful role if they take the opportunity to explain" their concerns, he says.

Fang Lizhi, the exiled astrophysicist sometimes compared to Andrei Sakharov, offers a number of suggestions for less prominent researchers. "Scientists should speak out on human-rights abuses [and] refuse to be a partner of projects which essentially are for military needs" or that strengthen the current dictatorship, says Fang, now at the University of Arizona. Collaborations instead should be with individuals.

Petitions, too, are a minimal but helpful activity, Birman observes. Such actions do work, albeit gradually, he admits. "We are in an uphill activity, but I feel we are making progress." *—Philip Yam*

ASTROPHYSICS

TWIST AND SHOUT

Astronomers claim the universe has a preferred direction

One of the bedrock tenets of physics and astronomy, dating back not just to Albert Einstein but to Isaac Newton and even Johannes Kepler, holds that space possesses a property called rotational symmetry. Spin a chunk of cosmos sideways or upside down, and measurements of events within it yield the same results.

Physicists were thus startled by a report in the April 21 *Physical Review Letters* stating that this principle may be violated on a cosmic scale. In the paper Borge Nodland of the University of Rochester and John P. Ralston of the University of Kansas presented evidence that measurements of light from distant galaxies vary depending on the galaxies' position in the sky.

Other theorists doubt whether the claim will stand up to close scrutiny; almost immediately, critical analyses began appearing on the Internet. For the moment, however, even the critics can savor the frisson of a tremor rocking their field's foundations. "Nobody would be happier than me if they were right," says Sean M. Carroll of the University of California at Santa Barbara.

The surprising work on cosmic asymmetry began three years ago, while Nodland was working for his doctorate under Ralston's supervision. In a search for signs of large-scale nonuniformity, the two researchers decided to investigate whether the polarization of light from galaxies changes in any unusual ways as a function of direction or distance. (Polarized light typically oscillates within one plane rather than in all directions, as is the case for ordinary sunlight.)

Polarized light often twists as it propagates through space, as a result of its encounters with electromagnetic fields; this well-understood phenomenon is called the Faraday effect. But Nodland and Ralston wondered whether additional twisting effects might be at work. To find out, they focused on studies of galaxies that emit large amounts of synchrotron radiation, a highly polarized form of electromagnetic radiation emitted by charged particles passing through a strong electromagnetic field. After scouring the published literature, Nodland and Ralston compiled polarization data for 160 galaxies.

Their investigation involved a crucial assumption: that the initial angle of polarization of the light from each galaxy is correlated in a specific way with the galaxy's major axis. Given this assumption and the estimated distances to the galaxies (inferred from their redshifts), Nodland and Ralston could calculate whether the light underwent any twisting other than that caused by the Faraday effect.

The researchers' calculations showed that polarized light from galaxies does indeed exhibit an extra rotation, to a degree proportional to the galaxies' distance from the earth. The fact that the effect varies with distance, Nodland says, rules out the possibility that it is local, stemming from phenomena occurring in the vicinity of our solar system.

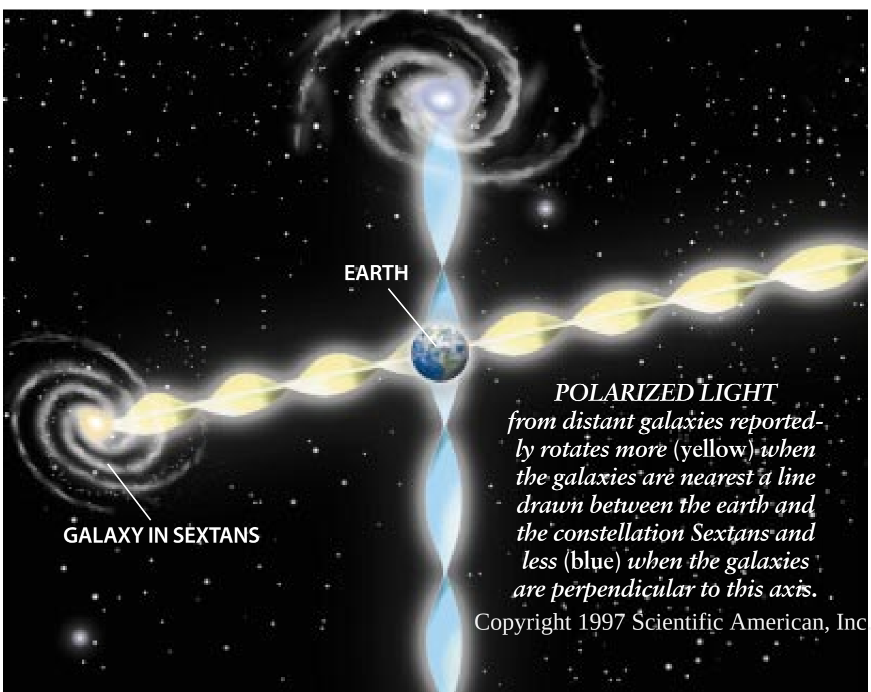
But the biggest surprise is that the amount of rotation depends on the direction of each galaxy in the sky. Nodland and Ralston define this effect in terms of the angular distance between each galaxy and the constellation Sextans. The twisting appears strongest when the direction to the galaxy is nearly parallel to the earth-Sextans "axis" and weakest when the direction is perpendicular to the axis.

The effect may derive from a heretofore undetected particle, force or field, Nodland suggests, or even a property of space itself that gives it a preferred direction. The universe, he elaborates, may not be "as perfect and symmetric and isotropic as we think."

Other astronomers suspect that the imperfection lies in the analysis by Nodland and Ralston. Three days after their article's publication, a paper faulting their statistical methods was released on the Internet by Daniel J. Eisenstein of the Institute for Advanced Study in Princeton, N.J., and Emory F. Bunn of Bates College. Among other points, they charged that Nodland and Ralston's analysis led them to downplay the possibility of bias in the original observations and thus to underestimate the chance of a false positive.

A similar critique was posted shortly thereafter by Carroll and George B. Field of the Harvard-Smithsonian Center for Astrophysics. Carroll and Field were unusually well prepared for such an analysis. Seven years ago, along with Roman Jackiw of the Massachusetts Institute of Technology, they examined exactly the same set of galaxies for the existence of preferred directions in space and time. They found no such effects.

For now, Nodland and Ralston stand by their paper. Ralston hopes their research, at the very least, will force theorists to reexamine some of their long-held beliefs about how the universe works. "That would make a good contribution," he reflects, "even if another analysis comes along, and this effect goes away." —*John Horgan*



BRYAN CHRISTIE

POLARIZED LIGHT from distant galaxies reportedly rotates more (yellow) *when the galaxies are nearest a line drawn between the earth and the constellation Sextans and less* (blue) *when the galaxies are perpendicular to this axis.*

PALEONTOLOGY

MOROTO MORASS

A fossil ape unexpectedly resembles modern apes and humans

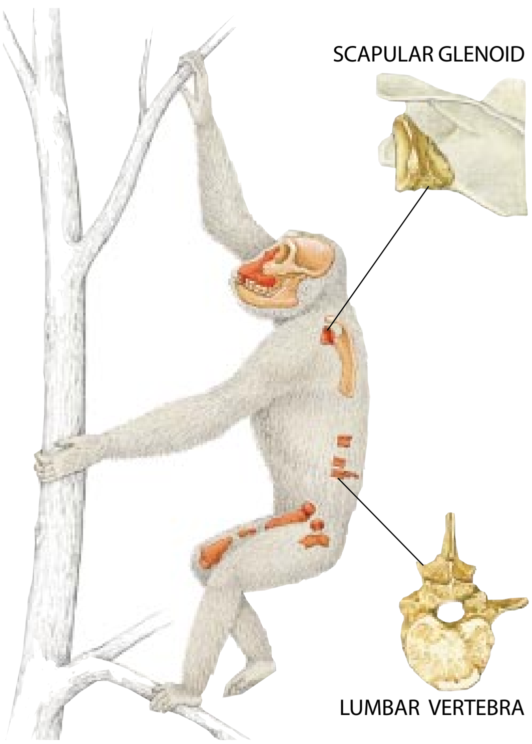
The arid, scrub- and acacia-dotted hills of Uganda's Moroto region in East Africa are not where you'd expect to find an ape. But more than 20 million years ago, during the Miocene epoch, this area was the woodland home of a surprisingly modern-looking ape that may have swung through the trees while its primitive contemporaries traversed branches on all fours. According to a report in the April 18 issue of *Science,* this ape displays the earliest evidence for a modern apelike body design—nearly six million years earlier than expected—and may belong in the line of human ancestry.

The authors—Daniel L. Gebo of Northern Illinois University, Laura M. MacLatchy of the State University of New York at Stony Brook and their colleagues—first focused on fossils found in the 1960s. The facial, dental and vertebral remains, originally dated to 14 million years, revealed a hominoid (the primate group comprising apes and humans) with a puzzling combination of features—its face and upper jaw resembled those of primitive apes, but the vertebral remains were more like modern apes. Consequently, paleontologists were at a loss to classify the Moroto hominoid definitively and tentatively placed it in various, previously established taxonomic groups.

Now Gebo and MacLatchy are placing this ape in its own genus and species, *Morotopithecus bishopi,* based on newly discovered pieces of shoulder and thigh bone and a high-quality radiometric date suggesting an age of at least 20.6 million years for all of the remains. The researchers infer that *Morotopithecus* weighed between 40 and 50 kilograms and had an advanced "locomotor repertoire" that included climbing, hanging and swinging from branch to branch. This form of locomotion "allows you to be a big animal and still exploit an arboreal environment," says MacLatchy, who suspects that *Morotopithecus* was a typical fruit-eating ape.

Critical to their locomotor reconstruction is the recently unearthed scapular glenoid, or shoulder socket. Monkeys have glenoids that are teardrop-shaped in outline, whereas modern apes, humans and, according to the researchers, *Morotopithecus* have glenoids that are rounder, which enhances shoulder mobility for hanging and swinging. This and other features, the authors contend, make it more closely related to living apes and humans than are some considerably younger fossil apes.

Others are not so sure about the shoulder evidence. Monte L. McCrossin, a paleoanthropologist at Southern Illinois University, points out that because nothing else is preserved to identify it conclusively, "the possibility exists that the glenoid will turn out not even to be from a primate." He is also skeptical about the proposed novelty of this shoulder morphology. Scapular glenoids have not been recovered for other early Miocene apes, so they, too, might share the rounded features. "Absence of evidence shouldn't be taken as evidence of absence," he quips.



TOMO NARASHIMA AND PORTIA ROLLINGS *(ape)*; PORTIA ROLLINGS *(bones)*

ANCIENT APE MOROTOPITHECUS, *reconstructed from key fossils* (highlighted), *reportedly had an advanced body design, based on bones from the shoulder and spine.*

IN BRIEF

Galactic Geyser of Antimatter
A fountain of hot gas and antimatter sprays from the Milky Way's center to its outer limits, James D. Kurfess of the Naval Research Laboratory and his colleagues have concluded. The group examined new data collected by NASA's Compton Gamma Ray Observatory, which measures the radiation produced when an electron collides with and destroys a positron. The researchers were surprised to find that the same radiation in the Milky Way's plane also appeared some 3,000 light-years out from the galaxy's disk. Just what gives rise to the radiation at the galaxy's core is debatable, but astronomers suggest that a black hole or supernova explosions may be responsible.

Forty-Something Fat
Certain things in life are inevitable. And middle-aged men can now add weight gain to that list. In a study of 4,769 male runners under age 50, Paul Williams of the Lawrence Berkeley National Laboratory found that even dedicated athletes fight an uphill battle with increasing age. Per decade, an average six-foot-tall man will add about 0.75 inch—or 3.3 pounds' worth of flab—to his waist. In a separate study of 2,150 male runners over 50, Williams found that this group, too, gained girth with each passing decade, although they generally lost muscle mass at the same time. Abdominal fat is linked to such conditions as high cholesterol, high blood pressure, diabetes and heart disease.

EVERETT COLLECTION; 20TH-CENTURY FOX

Grading the Gender Gap
The Educational Testing Service recently tracked the scores of more than 15 million students on a broad range of exams over four years. They concluded that although girls tend to excel at writing and boys at math, the gender gap—particularly in the sciences—is narrowing. Indeed, the greatest differences they measured reflected low English scores among boys, not low math scores among girls. Critics note that the finding further puts in question the fairness of the SAT, on which boys do much better than girls in math.

More "In Brief" on page 24

The evidence from the shoulder joint, Gebo and MacLatchy argue, is compatible with earlier analyses of the vertebrae suggesting that the Moroto hominoid had a short, stiff spine approaching that of modern apes. William J. Sanders, a University of Michigan paleontologist, studied the lumbar vertebra and found it "apelike, not monkeylike," but warns that similarities between *Morotopithecus* and large modern apes may just reflect adaptations to life in the trees and not necessarily common ancestry. "That's where you have to make a big jump, and that's where I would like to see a lot more evidence."

Proof may come when Gebo and MacLatchy return to the site next year. Until then, the jury is still out on the ape from Moroto and its role, if any, in our own genesis. "Only when we understand hominoid evolutionary relationships," asserts University of Missouri anthropologist Carol V. Ward, "can we accurately reconstruct what the common ancestor of chimps and humans, from which we evolved, was like in its anatomy and behavior." *—Kate Wong*

ORNITHOLOGY

PARROTS AND PLUNDER

Are monk parakeets pests? Ornithologists aren't sure

Bright green and noisier than a kindergarten class at playtime, flocks of monk parakeets have become a vivid—and growing—addition to the fauna of many U.S. towns and cities. The creatures now thrive in at least 76 localities in 15 states, according to Stephen Pruett-Jones, an associate professor of ecology and evolution at the University of Chicago. "In the next 20 years," he adds, "I believe they will be all over the United States."

Although some find the sight of parrot flocks charming, particularly in grayish northern cities, it is possible that their existence all over the country would be a problem. No one really knows for sure whether they will be, and hardly anyone is trying to find out.

The conventional wisdom that the birds are agricultural pests, like starlings and Africa's quelea bird, is based on studies done in Argentina and Uruguay—two of the five South American countries where the birds are native—since the 1960s. That notion has been challenged in recent years by a distinguished Argentine ornithologist, Enrique H. Bucher. In one paper, Bucher wrote that "neotropical parrots do not fit the typical profile of a successful pest species. They lack the typical combination of high mobility, flock feeding and roosting, opportunistic breeding, and high productivity that characterize successful pest birds."

DON SIMONELLI

MONK PARAKEET is the only one of 330 species of parrot that builds its own nest.

Although they may disagree whether the monk parakeet is a pest, ornithologists generally agree that the bird is highly unusual. "It is one of the most interesting parrot species in the world," Pruett-Jones says. It is the only one of the 330-odd species of parrot that builds its own nest. The nests can be simple abodes for one nesting pair or compact-car-size monstrosities that shelter half a dozen or more families in separate chambers, apartment-style. "Their nests, for

In Brief, continued from page 22

Fur-ensic Evidence

In 1994 a mother of five on Prince Edward Island disappeared, leaving only one clue: her car was found near a bag that contained a blood-soaked jacket and a few white hairs. Detectives hoped the hairs belonged to the murderer—but, in fact, the hair was a cat's. It was not altogether bad news. A certain feline named Snowball lived with the woman's estranged husband. But none of the forensic labs they called were willing to test Snowball's DNA. Eventually a team led by Stephen J. O'Brien, an NIH expert on genes and cats, examined blood samples. Compared with the cat hairs in the bag, Snowball's DNA was a near-perfect match. The defendant was sentenced to 18 years for second-degree murder last August. O'Brien's analysis appeared in *Nature* this past April.

Is Deep Blue Through?

So the IBM chess-playing computer, Deep Blue, deep-sixed Garry Kasparov, the world's greatest human contender, in a six-game competition this past May. But was that really the brain's last stand? Probably not. Kasparov and Susan Polgar, the world's female champion, have challenged all 512 microprocessors to a rematch—given one handicap. Because humans are vulnerable to fatigue and psychological stress, Deep Blue has to let them rest between games. Also, Kasparov wants to see printouts of Deep Blue's calculations after each round to understand how the machine makes its decisions.

JAMES LEYNSE SABA

Making Music and Immunity

Soothing music may help combat the common cold. In a recent survey Carl Charnetski and Francis Brennan, Jr., of Wilkes University measured levels of immunoglobulin A (IgA) in volunteers' saliva before and after they listened to 30 minutes of Muzak, radio jazz, silence or tones and clicks. They found that levels of IgA rose on average in the Muzak listeners by 14.1 percent and in jazz listeners by 7.2 percent. In contrast, IgA levels dropped by less than 1 percent in volunteers hearing silence and by a whopping 19.7 percent in those hearing tones and clicks.

More "In Brief" on page 26

a parrot, are totally bizarre," says Jessica Eberhard of the Smithsonian Tropical Research Institute in Panama. Nests are often further aggregated into colonies of perhaps hundreds of birds.

The social behavior of monk parakeets also appears to be unusual. Eberhard has found that some breeding pairs were assisted by a third monk parakeet, probably an offspring, which performed various odd jobs, such as helping to build the nest or bringing food to the female during incubation and brooding. Altruism like that had never been seen before in wild parrots.

But family values are not likely to

ANTI GRAVITY

The Emperor's New Toilet Paper

Roger Penrose is a serious man with serious ideas. He is the Rouse Ball Professor of Mathematics at the University of Oxford. He shared the 1988 Wolf Prize for Physics with Stephen W. Hawking. He was knighted in 1994. He has mused about the physics underlying human consciousness in two well-received books, *The Emperor's New Mind* and *Shadows of the Mind*. He is also in a big fight over toilet paper.

Two decades ago Penrose did some back-of-the-envelope doodling and created a pattern using two different diamond shapes, one wide and the other thin. One nifty thing about this pattern was its nonperiodicity—although it looks orderly, it never quite repeats itself. Scientists later discovered that atoms can assume arrangements known as quasicrystals, which are naturally occurring Penrose patterns.

Materials containing quasicrystals may have interesting properties. Some are unusually hard. Some are quite slick, making them good nonstick coatings for frying pans. At the other end of the alimentary canal, however, are innocent-looking rolls of Kleenex toilet paper. The rolls are thick and soft, thanks to their special patterned quilting, a feature especially appreciated in a country where the cuisine has been explained away by actor John Cleese's remark, "We had an empire to run."

Empires are at first held together and, of course, ultimately destroyed by, bureaucracies, which leads us to the copyright office. The other really nifty thing the Penrose pattern had going for it, besides irregularity, was that Penrose copyrighted it. A company called Pentaplex Ltd. licenses Penrose's designs for puzzles and other products. When Penrose and Pentaplex got wind of the toilet paper, they started producing paper of their own. First came the writ, alleging copyright infringement. Then they moved their vowels to produce a press release explaining the writ, in which Pentaplex said, "Kimberly-Clark® marketed and sold in the United Kingdom a Kleenex brand of quilted toilet tissue which is embossed with a pattern acknowledged in one of the parent company's patents as being the same in overall appearance as that of a section taken from 'The Penrose Pattern.'"

Pulling up the rear was Pentaplex director David Bradley's statement to the media: "So often we read of very large companies riding roughshod over small businesses or individuals, but when it comes to the population of Great Britain being invited by a multinational to wipe their bottoms on what appears to be the work of a Knight of the Realm without his permission then a last stand must be taken."

Penrose himself declined to pass any comments. But analysis of the statement reveals that what the knight objects to is less the use of his creation for toxic dump cleanups than for his designs to have fallen through the cracks of the assiduous guardians of the law—that is, "without his permission." Had they but asked, perhaps the whole mess could have been avoided. Armed with the copyright, however, Penrose, no matter what other names his opponents may call him, will probably smell sweet in the end. *—Steve Mirsky*

MICHAEL CRAWFORD

warm the hearts of farmers, who insist that monk parakeets feed on many different crops. “I can tell you that one of the bird species that has been a problem for growers of lychee and longan is the monk parakeet,” says Jonathan H. Crane of the University of Florida’s Tropical Research and Education Center. “They will come in and devastate a crop.” Some electric utilities have also had problems, because nests are often built on transformers, causing the equipment to overheat or short out.

In Argentina, widespread crop damage in some provinces has prompted officials to institute extermination programs. In Entre Rios, for example, landowners are required to kill the parakeets living on their land. In Buenos Aires province, the government makes systematic killing sweeps every five years.

No one knows for sure how the birds got to the U.S., although it is presumed that many were simply released by people who had bought them in the 1960s as pets and became annoyed by their squawking. By the early 1970s, there were so many monk parakeets that a national eradication program was launched; it reduced the population to perhaps several hundred birds in seven localities. The birds have rebounded so well, however, that they are now the most widely distributed of recently introduced bird species in the U.S., Pruett-Jones claims. Anywhere from 5,600 to 28,000 of the creatures live in the wild (the wide range results from the difficulty in counting them). Pruett-Jones further estimates that the monk parakeet population doubles every 4.8 years.

One of the few states that is hostile to monk parakeets is California, where the birds are prohibited as pets and are sporadically eradicated in some places, according to Annamaria van Doorn, a graduate student at the University of Florida. Florida, an agricultural state that has the largest number of the birds by far, does not control or regulate them. Given the way the birds have rebounded from control programs in Argentina and the U.S., however, van Doorn questions the effectiveness of eradication.

What will it be like if parrots thrive in the wild in most states? Fun for birdwatchers, but costly for many farmers. “If they are an agricultural pest, the effects could be similar to those of the starling, which would be devastating,” Pruett-Jones says. “But no one knows for sure whether they are or are not.”

—*Glenn Zorpette*

SCIENTIFIC AMERICAN CORRESPONDENCE

Reprints are available; to order, write Reprint Department, Scientific American, 415 Madison Avenue, New York, NY 10017-1111, or fax inquiries to (212) 355-0408. E-mail: info@sciam.com

Back issues: $8.95 each ($9.95 outside U.S.) prepaid. Most numbers available. Credit card (Mastercard/Visa) orders for two or more issues accepted. To order, fax (212) 355-0408.

Index of articles since 1948 available in electronic format. Write SciDex®, Scientific American, 415 Madison Avenue, New York, NY 10017-1111, fax (212) 980-8175 or call (800) 777-0444.

***Scientific American*-branded** products available. For free catalogue, write Scientific American Selections, P.O. Box 11314, Des Moines, IA 50340-1314, or call (800) 777-0444. E-mail: info@sciam.com

Photocopying rights are hereby granted by Scientific American, Inc., to libraries and others registered with the Copyright Clearance Center (CCC) to photocopy articles in this issue of Scientific American for the fee of $3.50 per copy of each article plus $0.50 per page. Such clearance does not extend to the photocopying of articles for promotion or other commercial purposes. Correspondence and payment should be addressed to Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923. Specify CCC Reference Number ISSN 0036-8733/96. $3.50 + 0.50.

Editorial correspondence should be addressed to The Editors, Scientific American, 415 Madison Avenue, New York, NY 10017-1111. Manuscripts are submitted at the authors’ risk and will not be returned unless accompanied by postage. E-mail: editors@sciam.com

Advertising correspondence should be addressed to Advertising Manager, Scientific American, 415 Madison Avenue, New York, NY 10017-1111, or fax (212) 754-1138. E-mail: advertising@sciam.com

Subscription correspondence should be addressed to Subscription Manager, Scientific American, P.O. Box 3187, Harlan, IA 51537. The date of the last issue of your subscription appears on each month’s mailing label. For change of address notify us at least four weeks in advance. Please send your old address (mailing label, if possible) and your new address. We occasionally make subscribers’ names available to reputable companies whose products and services we think will interest you. If you would like your name excluded from these mailings, send your request with your mailing label to us at the Harlan, IA address. E-mail: customerservice@sciam.com

Visit our Web site at http://www.sciam.com/

In Brief, continued from page 24

It's Just a Movie, Really

For clues to the course of evolution, scientists have long hoped to extract ancient DNA from creatures encased in amber. Unfortunately, DNA often decays soon after a cell dies. Even so, some researchers had, in recent years, reported successful extraction. But attempts to replicate these findings at the Natural History Museum in London have now failed. Despite all-new facilities and two years' time, the team, led by Jeremy Austin, could not rescue any genetic material from 30-million-year-old specimens. Experts see the result as definitive evidence that *Jurassic Park* will remain fiction.

Bad News Bugs

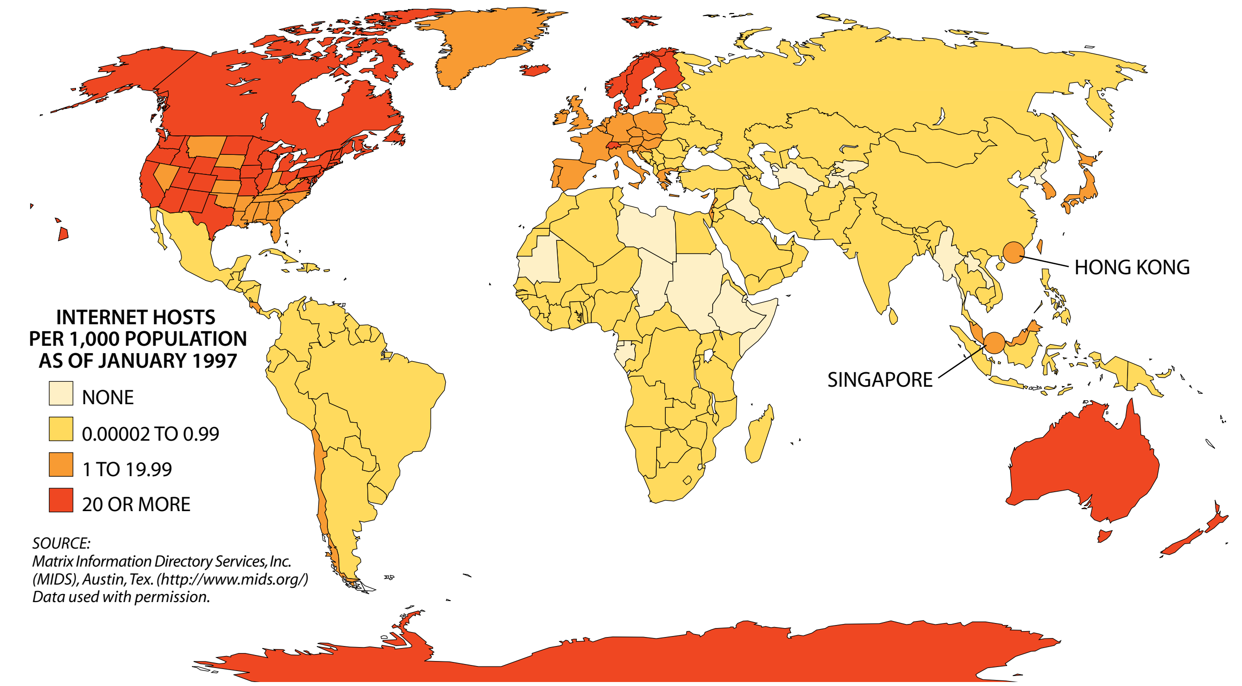
Asthma-related illnesses are especially prevalent among inner-city children, for reasons that have long proved elusive. Physicians typically blamed bad air quality, inadequate health care and increased exposure to dust mites, animal dander and mold spores. But in the May 8 issue of the *New England Journal of Medicine*, a research group reported that another allergen is largely at work. They found that among 476 urban children with asthma, 37 percent were allergic to cockroaches. And when they sampled the dust in the children's bedrooms, they found that half had high levels of cockroach allergen; only 10 percent or so had similarly high levels of the other irritants.

—*Kristin Leutwyler*

DONALD SPECKER *Animals Animals*

BY THE NUMBERS

Access to the Internet



The map shows the number of Internet hosts per 1,000 population, a host being more or less any computer providing access to Internet services. (Some computers are home to more than one host.) By January 1997 there were 16.1 million hosts worldwide serving 57 million people, not including 14 million who have e-mail only. As recently as 1986, the Internet was an esoteric tool used by a few thousand scientists, but it has developed into a popular diversion while also becoming widely used in business and education.

In January 1997 it encompassed about 70,000 lesser networks in 194 countries, all connected by a common protocol. Of those countries with a population of a million or more, only 17 were not wired to the Internet. The leading country in terms of hosts per 1,000 population is Finland, with a rate of 63, but six states in the U.S. have higher rates. New Mexico, at 202 hosts per 1,000 population, has the highest rate of any state, reflecting the proliferation of connections at Los Alamos National Laboratory. Several states, including Massachusetts and California, were ahead of others because of their large computer industries and because their leading universities were connected early. Among metropolitan areas, San Francisco is the most densely networked. The rate in France shown on the map is low because the government has sponsored a widely used system called Minitel, which is not directly connected to the Internet.

The U.S. accounted for 58 percent of all Internet hosts in January 1997, but this proportion is bound to decline as the Internet continues its strong growth worldwide. And there is indeed room for growth: the number of users as of January 1997 represented less than 2 percent of world population and less than 16 percent of the U.S. population age 15 and older. The growth of the Internet is made possible by its open design, which allows any independent network to connect and which permits improvements, such as the World Wide Web.

Two thirds of U.S. and Canadian users are male; they tend to be young to middle-aged, highly educated and affluent. Students and those in the military and in professional, technical and managerial occupations are the most likely to log on, but as the Internet expands, the typical user is becoming somewhat more like the average American or Canadian. —*Rodger Doyle*

RODGER DOYLE

PROFILE: MICHAEL L. DERTOUZOS

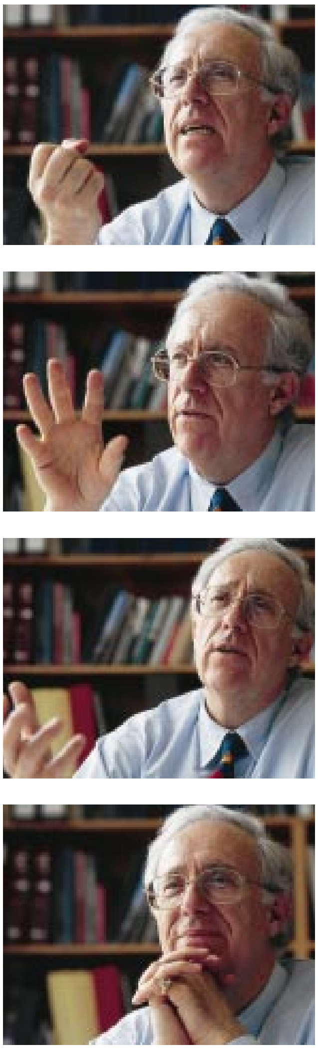
What Will Really Be

A professor from the Laboratory for Computer Science (LCS) at the Massachusetts Institute of Technology gives me some advice for interviewing his boss, Michael L. Dertouzos: start with a real stumper. "It's a tradition at faculty meetings to ask the hardest questions first," he chuckles. "It'll loosen him up." But I'm less than eager to test Dertouzos's rumored good humor. After all, what could possibly catch him off guard? As director of LCS for 23 years, he regularly fields queries from some of the world's most prominent scientists, politicians and business leaders—most of whom undoubtedly have to back up to see the six-foot, four-inch computer maven eye-to-eye.

So instead, when I meet Dertouzos the next day, I pose the most obvious questions up front: Why, after writing many successful books—such as *Made in America,* on difficulties facing U.S. industry—has he focused his latest work, *What Will Be,* on the future of information technology, a topic so well traveled in texts like Bill Gates's *The Road Ahead* that it leaves many readers numb? Why has he weighed in now, less than two years after another Greek seer at M.I.T., Nicholas Negroponte, made similar forecasts in his best-seller, *Being Digital*? Why is being digital on the road ahead *not* what will be?

Dertouzos settles in his chair with an easy smile. "This book has been a baby in the making for 20 years," he reminds me. In 1980 he prophesied an "information marketplace," where people would exchange data and services by way of computer networks—in essence, an early take on today's Internet.

"When I first presented my ideas, there was a lot of resistance," he notes. "But now I've built my model up to where, in my head, it is incredibly likely and consistent. The whole thing hums. And I don't see this picture anywhere."



INFOPROPHET
Dertouzos calls for a de-Enlightenment to draw science and the arts back together.

PAUL FUSCO *Magnum*

What he does see, he tells me, are "grand skews," such as the one that says cyberspace will abduct ordinary citizens from their daily lives. "This is not some metallic, gigabyte-infested world out there that we're going to visit, any more than in the industrial era we visited 'motor space,' ooooo," he sighs, adding an eerie sound for effect. "Did we go to motor space? No. Come on. That's bananas." So, too, he balks at visions of humanlike programs. True artificial intelligence, he feels, may be centuries off, if possible at all. And dumb or smart, no technology will be able to transmit what he terms forces of the cave: fear, touch, trust. "It'll be at best like going to a Stephen King movie," he says. "You say, okay, I'm here, scare me, but you know you are going to walk out alive."

In keeping with this commonsense approach, Dertouzos rails against the idea that entertainment drivel will dominate the information marketplace. "Books, movies, all traditional content is only 5 percent of the U.S. economy; information, such as office work, is 60 percent—12 times bigger! But nobody is talking about that." Similarly, he feels that, as happened in past socioeconomic revolutions, impractical applications will not last. "I fully expect this revolution by the end of the 21st century to be done with, to have given us up to a 300 percent productivity increase in the office—which is just about what the second industrial revolution gave us—and on top of that to have offered utility or been thrown away."

Dertouzos pins the hype on infoprophets who fail to consider what is both feasible and useful at once. "Techies," as he calls computer scientists in his book, too often ignore human nature in making their predictions. And "humies"—historians and the like—too often assert how future technology will affect society without understanding its limits. His exasperation gives way to giggles. "I think what this book really brings to the world is the mixed-salad approach of what is possible with forefront technologies—which I think I have a pretty good grip on—and the human uses of all this stuff. There, I'm not an expert, but I think I qualify with having grown up in the Athens flea market, having been bombed, having eaten and loved and done all the things that people do."

He has done a lot in his 60 years. As the only son of a ranking admiral, young "captain" Dertouzos steered destroyers around the Mediterranean and cruised the seas in submarines. "If you're in the Greek navy, things are a little loosey-goosey," he chuckles, "so I had a lot of fun, and it got me interested in machinery and Morse code." A math teacher got him interested in algebra and by snapping his suspenders embarrassed him into straight A's. At age 16 Dertouzos knew what he wanted to be. "I read Claude Shannon's article in *Scientific American* and his work on a mechanized mouse," he remembers. "I became so infatuated that I decided I was going to come to M.I.T., and I was really going to be a professor."

"There was no question about finding yourself," he laughs. "Having gone through World War II, we were all marching tanks, going with purpose." The war was a difficult period for Dertouzos, whose family endured famine. "We had to make do with a lot of little things," he recounts. As an example, he describes how they boiled new brooms, which were made out of wheat stock, to extract the nutrients. "There was a lot of death. I played with explosives," he adds, shaking his head. "God, how I survived this period. But the war was very instructive."

A Fulbright scholarship landed him in the U.S. for college—but in Arkansas, the sponsoring senator's home state. Dertouzos remembers well his first impressions of the University of Arkansas in the Ozarks. "There were all these football players talking about *milk,*" he jokes, straining his voice, "and I was talking about political virtue, and they said, 'Do you want *milk*?' " But he had no problems fitting in. "There were the gorgeous women with their flared-out skirts and white bobby socks, and they said, 'Can you teach us Greek dancing?' " He drove 200 miles to the nearest Greek priest to learn how.

Dancing didn't stop him from finishing a bachelor's and master's degree in four years. And at age 21, after a handful of inventions for such things as mechanical encoders, he became the head of research and development at a subsidiary of Baldwin Piano, then building tuning wheels (devices for producing pure tones) that had defense applications. But M.I.T. was still on his mind, and so after a few years he applied for graduate work. "That was the first time I had to kneel down since my high school days," Dertouzos says. "But when I finished my doctorate they gave me the opportunity to join the faculty." As a new professor, he started Computek, a small firm that built the first intelligent terminals. "We just put a couple of processors in them. That was all," he shrugs. "But this was 1968."

He enjoyed juggling this commercial enterprise with his academic career for six years. "But as exciting as a company is, it's really maximizing the difference between two numbers—income and expenditure," he says. "I kind of wanted something a little more." So he sold Computek in 1974 and that same year became director of LCS—where he has been noted for infusing the lab with realism. "He likes to use Greek expressions," Victor Zue, the lab's associate director, tells me. "One favorite, roughly translated, is 'Keep one hand reaching for the stars and one hand playing in the dirt,' which is really what he asks us to do. With so many august scientists around here, it's easy to get lofty. But he keeps us in check."

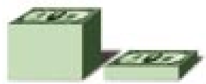
Dertouzos puts it another way: "I'm interested in our lab not just doing things because they are exciting. This lab's motto is to make the technology useful to humanity." LCS's credits reflect that directive: its researchers have created the spreadsheet, the Ethernet, time-shared computing, RSA public-key cryptography and other vital innovations. Currently LCS coordinates the World Wide Web Consortium—a collective of 160 organizations, led by the Web's inventor, LCS member Tim Berners-Lee. The group strives to keep the Web as standardized as possible. This kind of work doesn't get as much attention as robotic butlers that wash windows and speak Swahili, but function makes up for the lack of flash. As Zue adds: "Michael jokes that we're M.I.T.'s best-kept secret."

In *What Will Be,* Dertouzos is quick to point out that, niceness aside, tailoring technology to human needs has economic benefits as well. "In the world of office work, I, Michael, see incredible, unprecedented, unbelievable inefficiencies today—comparable to what we had early in the industrial era, when we were still shoveling by hand." The problem, he explains, is that we have not yet harnessed "electronic bulldozers," devices that could take over mental tasks, much as real bulldozers filled in for physical labor. He notes that standardizing electronic forms so that a computer could negotiate, say, airline reservations might offer a 6,000 percent efficiency gain. Software makers would need only agree on the meaning of a small set of words—number, date, from, to, available, understood, book and confirmed. Telling a computer that you want to go to London next Monday or Tuesday takes 10 seconds, but typing such a request, waiting for a response and so forth, could take 10 minutes.

"I'm impatient with my fellow techies who say, 'Don't confuse me with purpose—we have to pursue our science.' We made a big mistake 300 years ago when we separated technology and humanism," he remarks, slapping his palms together in the air as if shaking off dust. "So there for the Enlightenment, guys. It's time to put the two back together." Granted it will take a while—at least a century by Dertouzos's estimate. But he is busy initiating new faculty members at LCS to his way of thinking: "I tell them that intelligence alone does not impress me. Cooperative work, character issues, issues of kindness—show me what you can do to help humanity." That is, ask the hardest questions first. *—Kristin Leutwyler*

Five Myths of the Information Age, *according to Dertouzos*

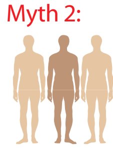
Myth 1:



Information technology will close the gap between the rich and poor.

"The gap can be bridged, but left to its own devices, the information marketplace won't close it. We will need concerted efforts, charity, and more."

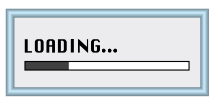
Myth 2:



Information technology will bring about frictionless capitalism, in which buyers and sellers will deal with one another directly.

"There will be a growth of intermediaries. You still need middlemen because you are buying a lot more than just the product. You buy trust, the ability to return it, to ask questions, to find it amid the growing infojunk."

Myth 3:



The information revolution is moving too quickly for most to keep up.

"We've been four decades into this business, and we've hardly done anything. The second industrial revolution took nine decades. So relax."

Myth 4:

Information technology will force a universal culture on everyone.

"This technology simultaneously strengthens tribalism and diversity. Tribal forces are powerful, but each of us belongs to multiple tribes. So we'll develop only a thin veneer of universal culture."

Myth 5:

Information technology creates the need for new laws.

"Human nature is immutable. The angels and the devils of infocollaborators on the good side and infocriminals on the bad side are not in the technology. They are in us. Technology acts as a lens."

ICONS BY LAURIE GRACE

CIVIL ENGINEERING

DAM SAFETY

Does record flooding threaten the Aswan High Dam?

A surge of 164 billion cubic meters of water bursts through the 100-meter-high walls of a dam, emptying its 500-kilometer-long reservoir in one catastrophic instance. A city three kilometers downstream is rocked by a gale-force wind similar to that preceding a tsunami. Seconds later a 30-meter-high wall of water barrels through, toppling buildings as tall as 10 stories. The head of the flood continues pulsing toward the sea, streaming for the capital city of 15 million people. It reaches the capital on the sixth day, traveling at 30 kilometers an hour. The streets are inundated; water reaches 15 meters high. In comparison, the flood in Grand Forks, N.D., this past spring would stand as a mere footnote in the annals of urban flood calamities.

No, this isn't the latest treatment for the standard Hollywood disaster fare. It actually comes from the 1973 German novel *Aswan!,* by Michael Heim. Based on solid engineering data, it may accurately represent a threat facing Egypt—Cairo, in particular. If the Nile River is the country's lifeline, then the Aswan High Dam is its Achilles' heel. The dam impounds Lake Nasser, Cairo's hedge against drought. But recent floods, including last September's record Nile overflow, have raised the reservoir to unprecedented levels. The sheer weight of the water has seismically destabilized the area, raising the possibility that the reservoir weight could make underlying faults slip and cause the dam to falter under shifting earth.

This effect, called reservoir-triggered seismicity, is well recognized if incompletely understood. It was determined or at least suspected to be the culprit in many past disasters. Two noteworthy cases showed that the effect could severely damage the dams themselves. One was Xinfengjian, near Canton, China. An earthfill structure like Aswan, it was shaken by a magnitude 6.1 quake in 1961. The Koyna Dam near Poona, India, almost collapsed in 1967 when jolted by a magnitude 6.5 event. Lloyd Cluff, an engineer now with Pacific Gas and Electric, saw Koyna's damage firsthand. "It didn't fall, but it came very, very close," he recalls.

Cluff led an investigation commissioned by the U.S. Embassy in Egypt shortly after a magnitude 5.3 earthquake struck the region in 1981. That temblor had its epicenter just 55 kilometers from the High Dam and 10 kilometers from the reservoir, along the Kalabsha Fault, which is normally inactive. The dam itself remained intact, but several control buildings were damaged. Cluff's two-year study found "significant correlation between reservoir water levels and recent earthquake occurrences." It concluded, "For engineering evaluations, it is considered prudent to assume that…earthquake activity will continue and have magnitudes as large as or larger than those that have already occurred."

The report also details the aftermath of a hypothetical dam break. But those descriptions remain secret; the Egyptian military apparently fears a terrorist strike. Even engineers who helped on the study were not given a copy and know only its sketchiest outline. Anecdotes gleaned from its engineers, though, depict a scenario eerily similar to that described by the novelist Heim. "It looked like something out of the Bible—flooding for 40 days and 40 nights," says Egypt's senior undersecretary for water resources, Abd al-Rahman Shalaby.

At the moment, Egyptian officials have deemed the dam immune from natural disasters. Additional analyses of the fault system and pressure caused by the weight of the reservoir predict an earthquake of no greater than magnitude 7.0, and stability modeling of the dam showed it would hold if an earthquake of this force were to strike within a 600-kilometer area around the structure. Still, as a precaution against pressure on the dam, Egypt constructed emergency spillways 178 meters above sea level to empty water harmlessly into a desert depression 250 kilometers away. (The maximum water level for which dam safety cannot be guaranteed is 183 meters.)

Last year's record flooding, though, revives some concern of dam failure. When the 1981 earthquake struck the region, the reservoir held 125 billion cubic meters of water. The level of last fall's Nile flood, determined by monsoons in the Ethiopian highlands, was almost twice the average. In September alone, some 25 billion cubic meters of water poured in, pushing the reservoir to its full 137.5-billion-cubic-meter capacity and for the first time triggering the emergency spillways.

Although the spillways divert excess water and thereby limit the force the reservoir exerts on the underlying Kalabsha Fault, it is not simply a matter of water volume. Seepage into the 400-meter-thick layer of Nubian sandstone underlying and to the west of the dam may be more crucial, according to Dave Simpson, a seismologist at IRIS, a Washington, D.C.–based university consortium on seismic research.

T. PIERCE SABA

ASWAN HIGH DAM
could be threatened by the weight of the reservoir it impounds.

"The 1981 earthquake occurred six years after the reservoir had reached its historic high—it took that long for the stone to fully saturate and the added weight to trigger the fault. Then came several drought years, with the sandstone presumably drying out," Simpson says. So trouble could brew down the road, especially if flooding persists over the next few seasons. "It'll take a few years for the stone to resaturate, and that's when we're most likely to see Kalabsha's next shot at the dam," he warns. *—Louis Werner in Aswan*

CONSTRUCTION

TUNNEL VISIONS

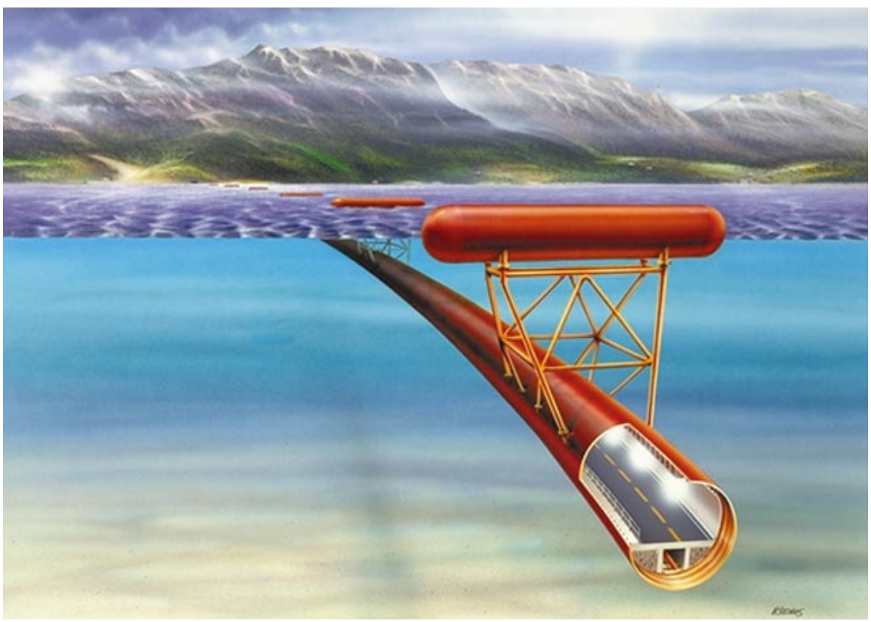
Subsurface conduits may traverse fjords

In the late 1800s Sir Edward James Reed, a member of the British Parliament from Cardiff, proposed the idea for "tubes" that would let trains traverse the English Channel from Dover to Calais. His plan envisaged a tunnel suspended on top of caissons placed at regular intervals along the crossing. This concept did not gain support among Reed's fellow members of Parliament—a tunnel, after all, could provide a route for an invasion of the British Isles.

More than a century later similar ideas may be finally tested in less turbulent waters. The Norwegian Public Roads Administration will propose to the nation's parliament later this year a 1,400-meter-long tunnel that would float 25 meters below the surface of the 155-meter-deep Høgsfjord near the western city of Stavanger. The tunnel, apparently the first of its kind anywhere, would replace a ferry crossing with a two-lane automobile conduit and a bicycle-pedestrian path.

A submerged floating tunnel, or SFT, poses a novel engineering challenge. The air-filled tube, made up of either concrete or steel, is lighter than its watery medium and so must be prevented from rising to the surface.

The various designs borrow elements from offshore oil platforms, the superstructure of bridges and conventional immersed tunnels, which are ballasted sufficiently to rest on the sea bottom. One proposal, forwarded by the company Aker Norwegian Contractors, would keep the tunnel from rising with technology used to position oil platforms in the North Sea. Steel pipes, called tension legs, would tether the tunnel to steel boxes implanted in the seabed. Alternative plans from other companies would push the tunnel down to its intended depth. A series of surface-floating pontoons—connected to the top of the tunnel with various types of tubing—would hold the cylinder in place.



KVÆRNER ROSENBERG

FJORD CROSSING IN NORWAY
may be built as a floating tunnel. One proposal, a pontoon structure, would keep the 25-meter-deep tunnel from rising to the surface.

The project will by no means be a textbook construction exercise. "You have to take into account strange things like subsurface waves," says Håvard Østlid, the project manager for the Norwegian Public Roads Administration. "We don't really have long experience with this." Computer modeling and tests with a scale model at the Norwegian University of Science and Technology show that currents may cause the tunnel to move slowly a meter or so from side to side. Østlid says that although these oscillations will not damage the structure, they must be imperceptible to drivers.

The projected $130-million cost would be about the same for a tunnel drilled below the seabed. But an SFT, whose construction may begin in the year 2000, would assuredly cost less than a bridge. As experience is gained with the technology, it might prove less expensive than conventional tunnels for deep-water spans. And unlike a tunnel in the bottom, it would not require steeply graded approaches and egresses, which cause cars and trucks to consume more fuel.

In past years the cost and novelty of these structures have engendered caution. Since the late 1960s Italy has considered an SFT across the Messina Strait from Calabria to Sicily. And the idea for one at Høgsfjord was first put forth in 1985. The Høgsfjord tunnel appears to be the first that will move beyond a sketchy preliminary design. "This is not research anymore," Østlid says.

Curiosity about the technology has begun to percolate widely. The European Union has established a study group to evaluate SFTs. And an international conference on the technology was held in Sandnes, Norway, in May 1996. More recently, Norwegian construction companies and engineering groups formed a promotional and technical organization called the Norwegian Submerged Floating Tunnel Company.

A number of possible sites for SFTs have been targeted throughout the world. In Japan three crossing points have been studied, including a nearly 30-kilometer-long tunnel to cross Funka Bay in Hokkaido Prefecture. An SFT would let a rail line straddle Switzerland's Lake Lugano without ruining the beauty of this much visited tourist attraction. It would also minimize the traffic congestion around the lake. The Jules Verne–like conception of a tunnel that floats may finally cross the straits from imagination to reality.*—Gary Stix*

CARDIOLOGY

HELPING HEARTACHE

Surgeons blast holes through the heart to relieve chest pain

At the very beginning of our lives, we hardly look human at all. With a tail and gill clefts, the three-week-old human fetus could easily be mistaken for an amphibian or reptile embryo. By four weeks, however, our paths diverge from that of our evolutionary predecessors, with the formation of our first organ: the heart. Now surgeons are finding that for some people nearing the end of their life, their ailing, painful hearts can be helped by making them a touch less human and a bit more reptilian.

The human heart muscle is nourished by arteries that crisscross its exterior. But rich diets and sedentary living clog those arteries, and balloon angioplasty to clear them or surgical grafts to bypass them have become almost a rite of passage from middle age to seniority. Unfortunately, some people cannot take that path. Their arteries are too small to graft, or their vessels are already so heavily patched that surgical plumbing can no longer help. Hence, blood slows to a trickle, the heart grows sicker from lack of oxygen, and the stabbing chest pains of angina cut short exercise, movement and eventually life itself.

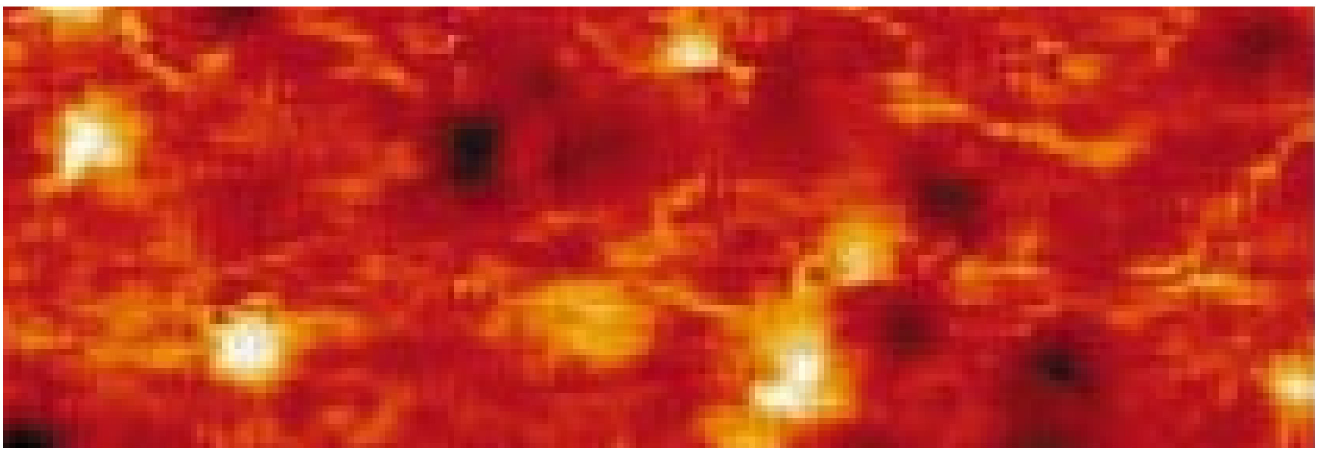
This does not happen to middle-aged reptiles, because their hearts are fed from within by channels that wick up some of the blood pumped through the ventricle. Now several companies are producing experimental laser systems that can create similar channels in human hearts. The clinical results have been so promising that one, PLC Systems in Franklin, Mass., expects to receive permission this summer to market its device in the U.S. Two other firms, Eclipse Surgical Technologies and CardioGenesis, both in Sunnyvale, Calif., are close on its heels.

Israel J. Jacobowitz, chief of cardiovascular surgery at Lenox Hill Hospital in New York City, says the procedure, called transmyocardial revascularization, "may offer an exciting complement for angina treatment." Indeed, this past April surgeons from eight U.S. hospitals published impressive results from their use of PLC's 1,000-watt carbon dioxide laser to punch 20 to 30 holes, each a millimeter wide, through diseased parts of the heart.

Before the operation, 80 percent of the 200 patients in the study had severe chest pains at rest or during small movements. Angina affected the remainder during moderate exercise, such as climbing stairs. One year after the treatment, 30 percent of the patients felt no chest pain, even during strenuous exercise. Three quarters had improved significantly. In another April report, Eclipse claimed that surgery using its holmium-based laser alleviated regular chest pains for 86 percent of the patients in its clinical efficacy trial. Drug therapy, in contrast, helped only 12 percent.

"There is still risk involved in the surgery—about 3 percent of patients never leave the hospital," warns Douglas Murphy-Chutorian, Eclipse's chief executive. "But this patient population has an annual mortality of 20 percent or more, plus severe restrictions on their lifestyle.

The Infinitesimal Gets Smaller



LUCENT TECHNOLOGIES

Not so long ago, atoms seemed infinitesimal; even the most powerful microscopes could not quite make them out. Then physicists discovered that by dragging a supersharp needle across a surface, they could sketch atomic outlines for all to see. The boundary of the infinitesimal receded to subatomic particles, in particular the electron, which is to an atom what a sperm cell is to a basketball.

In April, physicists at Lucent Technologies's Bell Laboratories announced that they had briefly crossed that tiny frontier by running wires down either side of the sharpened glass needle on their scanning probe microscope. The wires connect at a flat tip just 500 atoms wide, forming a single electron transistor so sensitive that it can detect one hundredth of an electron charge. Moving the instrument across a surface doped with silicon ions (similar to a microchip), the researchers produced this image of the atoms' electrical fields, which consist of clumps of electrons (see http://www.lucent.com/press/0497/970425.bla.html). By shooting light at the atoms and then comparing how the images change, the group claims to have seen individual electrons moving about. The investigators expect to be able to boost the power of the device by a factor of 100 and thereby image single electrons more directly—a view that could reveal the secrets of exactly how charges move in semiconductors. Now if only we knew what quarks look like.... *—W. Wayt Gibbs in San Francisco*

We seem to be making the time patients have left more comfortable. We don't know yet whether the procedure increases their survival."

Doctors are also uncertain just how piercing the heart helps it. "In principle," Jacobowitz says, "you make a hole that stays open on the inside and forms this chain of lakes that increases blood flow to the heart. But no one has been able to demonstrate that these things remain open." Autopsies last year of eight patients at the German Heart Institute in Berlin found that most of the new tunnels had filled with scar tissue. But those researchers and others have observed new capillaries forming in the gaps. They suspect these vessels boost the blood supply to the sick muscle in not a reptilian but an entirely human fashion.

—W. Wayt Gibbs in San Francisco

FIELD NOTES

MUG MACHINE

Software tries to find something in a face

The Rockefeller University is one of the world's leading biomedical research institutions. But I haven't come to inspect fruit flies or to consider cell cycle control in yeast. Rather I've come to find myself.

Joseph J. Atick, a Rockefeller researcher in biocomputation, wants to show me FaceIt, software that is supposed to tell the difference between me and you. Atick places himself in front of a computer. His video image appears on the screen. A blinking red circle moves to the area around Atick's eyes and suddenly turns green. A voice with a metallic lilt that would make Arthur C. Clarke's HAL jealous emerges from the speaker: "I SEE JOSEPH ATICK."

For many years, the 33-year-old Atick saw himself as a physicist, not a computer nerd. As a 15-year-old living on the West Bank near Jerusalem, he wrote an introductory physics textbook in Arabic. Later, Atick gained admission to a Stanford University graduate program in physics without ever having obtained even a high school degree. By the mid-1980s he moved to the Institute for Advanced Studies in Princeton, N.J. There he authored a paper with the noted physicist Edward Witten on the subtleties of superstrings, the theory that everything in the universe is made up of tiny, oscillating strands of linguini compacted into 10 dimensions.

Atick quickly realized that it would never be possible to prove these conjectures through experiments. He decided to ratchet down from 10 dimensions to two or three and began to develop theories, modeling the way that the brain extracts useful signals from the noisy real world. This work began in Princeton and later continued at Rockefeller.

PETER PEIRCE *Visionics*

"I SEE YOU,"
notes face-recognition software that compares the encircled area it observes with a camera to a collection of photographs stored in a database.

On the side, Atick devised FaceIt with two other lapsed physicists (A. Norman Redlich and Paul A. Griffin, with whom he formed the company Visionics). The software represents topographical features in localized areas of the face—the position of the nose relative to the eyes, for instance. Unlike other often used face-recognition techniques, which generate a mathematical description of the entire face, it isn't confused by a head tilt or a yawn presented to the camera. The technique, called local feature analysis, checks whether the nose-to-eye configuration remains constant, even if the mouth has broken into a big toothy grin.

FaceIt is designed as a tool for use against bank fraud and illegal aliens. Atick shows me on a laptop computer how a digitized video of people driving through a Mexican border station can be fed into FaceIt, which succeeds in matching most of the faces against photographs stored in its database, while registering few errors. The software, scheduled for a field test in coming months, will attempt to confirm the identity of preregistered frequent travelers crossing the Mexican border.

After learning all this, I'm ready to meet the machine. FaceIt takes my photograph and files it in its database. It then tries to compare my image, as taken by the video camera, to its collections of stored images. Several times it makes the positive ID, but the machine is not foolproof. Often a red circle just blinks away stupidly.

I'm starting to get nervous. Atick knows about the physics of supersymmetry, a theory related to superstrings. But I'm thinking about the type of symmetry that intrigues evolutionary biologists: the supposition that a lack of facial alignment makes one less fit to be chosen as a mate. Is it my crooked nose?

Atick assures me that the problem is the tint on my glasses, which causes glare. All that's needed, he says, to make me persona grata is a polarizing filter from the Edmund Scientific catalogue. Maybe so. But it doesn't reassure me when he shows me a videotape of a pretty CNN commentator registering a positive ID every time. I probably shouldn't go to Mexico without contact lenses and the services of a good cosmetic surgeon. *—Gary Stix*

www.batmobile.car

Imagine this: data streaming to consumers anytime, anywhere—inside cars. Drivers accessing voice mail, e-mail and travel-related tips such as restaurant and theater locations, traffic jams ahead and weather warnings while zipping along at 60 miles per hour. Passengers downloading a fax, marking it up with an electronic pen and faxing it back to a waiting associate without getting out of the back seat.

Far-fetched? This past May a demonstration car with "Intel Inside" showed up at the Cyberhome 2000 exhibit in San Francisco. It had two game kiosks in the back seat and a notebooklike computer console next to the gearshift. But Intel's car was mostly for show. A Mercedes-Benz experimental World Wide Web car built by Daimler-Benz Research and Technology Center in Palo Alto, Calif., is for go.

The Internet Multimedia on Wheels Concept Car comes complete with an onboard Web server, a local-area network and several browsing devices placed throughout the interior—all inside an experimental Mercedes E420. It connects to the Web through an integrated wireless communications system. According to Daimler-Benz researcher Akhtar Jameel, this Web car is like any other node on the Internet. It has its own unique Internet-Protocol (IP) address and uses standard server and browser technology. Not just a mock-up, this E420 can be seen running around town, although there are no immediate plans to make production models.

In future cars like it, browsers won't be of the standard point-and-click variety. A display device might be placed in the back of the headrest for passengers in the back seat. But a hands-free, voice-controlled browser will reside in the dashboard for the driver. Both the Intel and Mercedes-Benz demonstration cars currently contain limited speech recognition, allowing the driver to ask for directions or the location of the nearest French restaurant without diverting eyes and hands from driving. Wireless ports also permit various handheld electronic devices to integrate into the car's local-area network, providing additional browser capability. In short, a Web car is every bit as much of an information appliance as a desktop personal computer is, except that it can move.

But why would anyone want to surf the Web while cruising the boulevards? Of course, there are the obvious reasons, such as avoiding traffic congestion or getting roadside assistance. These features can be had through existing technology, such as onboard Global Positioning System (GPS) devices, cellular telephones and AM radio. So what's the big deal?

Perhaps the most important reason for Web cars, aside from giving men another reason not to ask for directions, is that they open up a whole new market for virtual communities, personalization and automation of highways. When integrated with a GPS and two-way digital communications, a Web car becomes an entirely new platform to market services of all kinds. With this financial motivation, Web-equipped cars may become as common as cars with radios and heaters. When they do, perhaps sometime in the next decade, electronic commerce will reach millions of consumers ready to spend millions of dollars from inside their automobiles.

GLENN MATSUMURA

***BROWSING WHILE DRIVING** is possible in this Mercedes.*

As a platform, the Web car may be even more important than the PC. Axel Fuchs of Daimler-Benz envisions future cars as being cyberplaces where people meet, interact and purchase information services just as briskly as at home. "Drivers and passengers will access a new class of services that will go well beyond classical navigation. These could range from remote diagnostics to locating a teenager who has missed curfew," he says.

The car can be continuously monitored, because its electronic control unit will be addressable through standard Internet protocols. In fact, the very concept turns every auto into a probe with vast implications for traffic guidance and control. Instead of instrumenting the highways, as many have proposed, one can instrument the cars that run on the roads. Putting intelligence into vehicles is a cheaper and quicker way to manage traffic than drilling holes in millions of miles of pavement. Web cars know where they are, how fast they are going and what time it is. This could make congestion a thing of the past. It could also be a major reason why Web cars are highly likely to become mainstream.

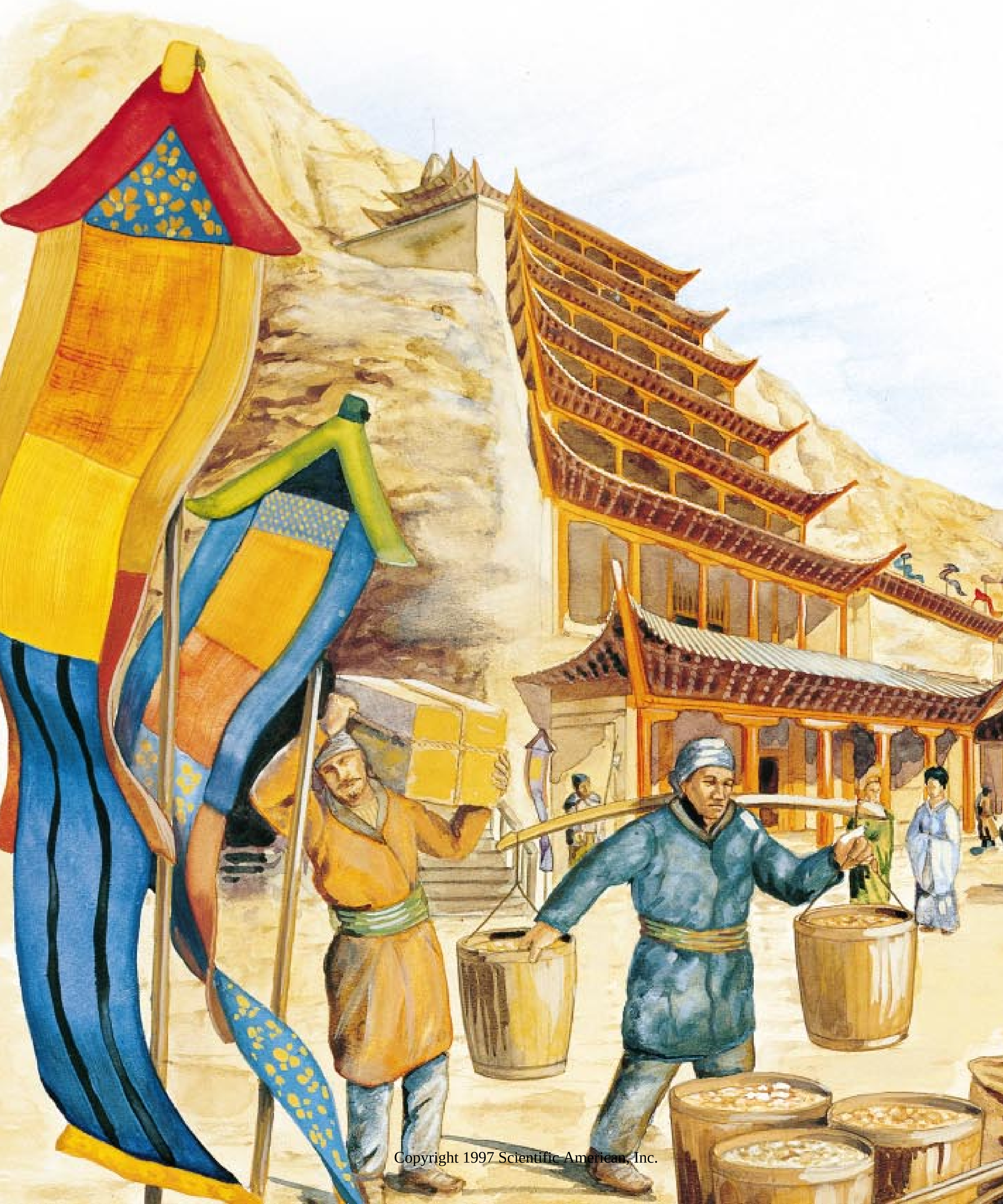
Such cars also portend deeper changes in how we use information. As information flows in and out of your automobile, it can be analyzed by sophisticated data-mining software. These techniques can learn about driver and passenger likes and dislikes such as eating, sporting and driving-pattern preferences. These kinds of data could modify both driving and general buying habits. Serious privacy issues obviously arise, more so than with desktop browsing, because anyone in principle can track your movements. Daimler-Benz claims that it is possible for the system to maintain driver anonymity, though.

If, as many pundits think, everyone in the next decade will have a personal Web address, then, soon after, everyone's car will have one, too, like www.batmobile.car or www.whitehouse.car. The society of Web cars will be able to get themselves out of traffic jams, avoid bad weather and keep their inhabitants well informed and entertained. With such a huge potential market waiting for manufacturers, Web cars are inevitable. Exactly what form they will take remains to be seen.

—Ted Lewis in Monterey, Calif.

TED LEWIS (tedglewis@friction-free-economy.com) is the author of a book on winning principles of the new wired economy, The Friction-Free Economy, *to be published by HarperCollins (New York) this September.*

China's Buddhist

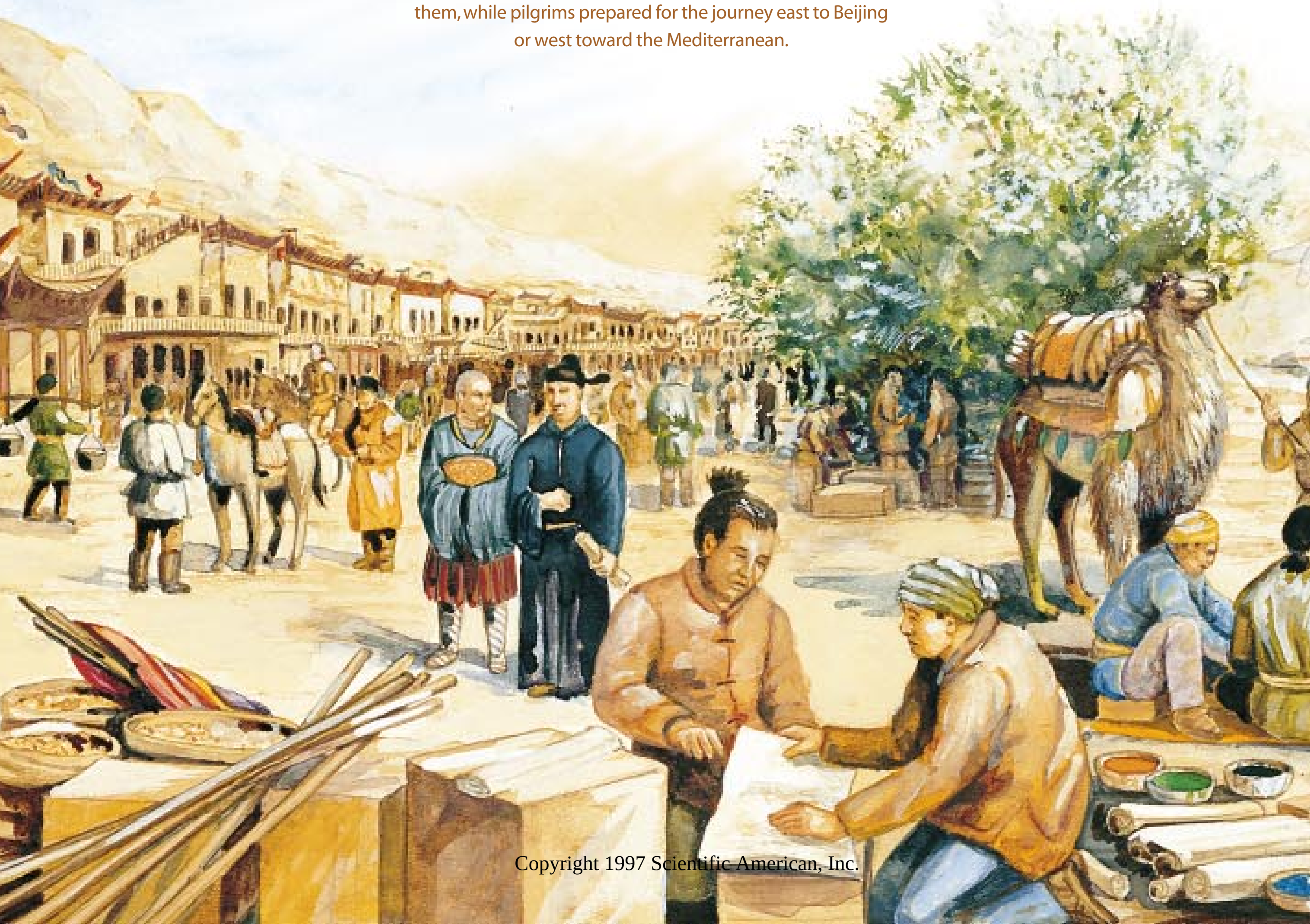


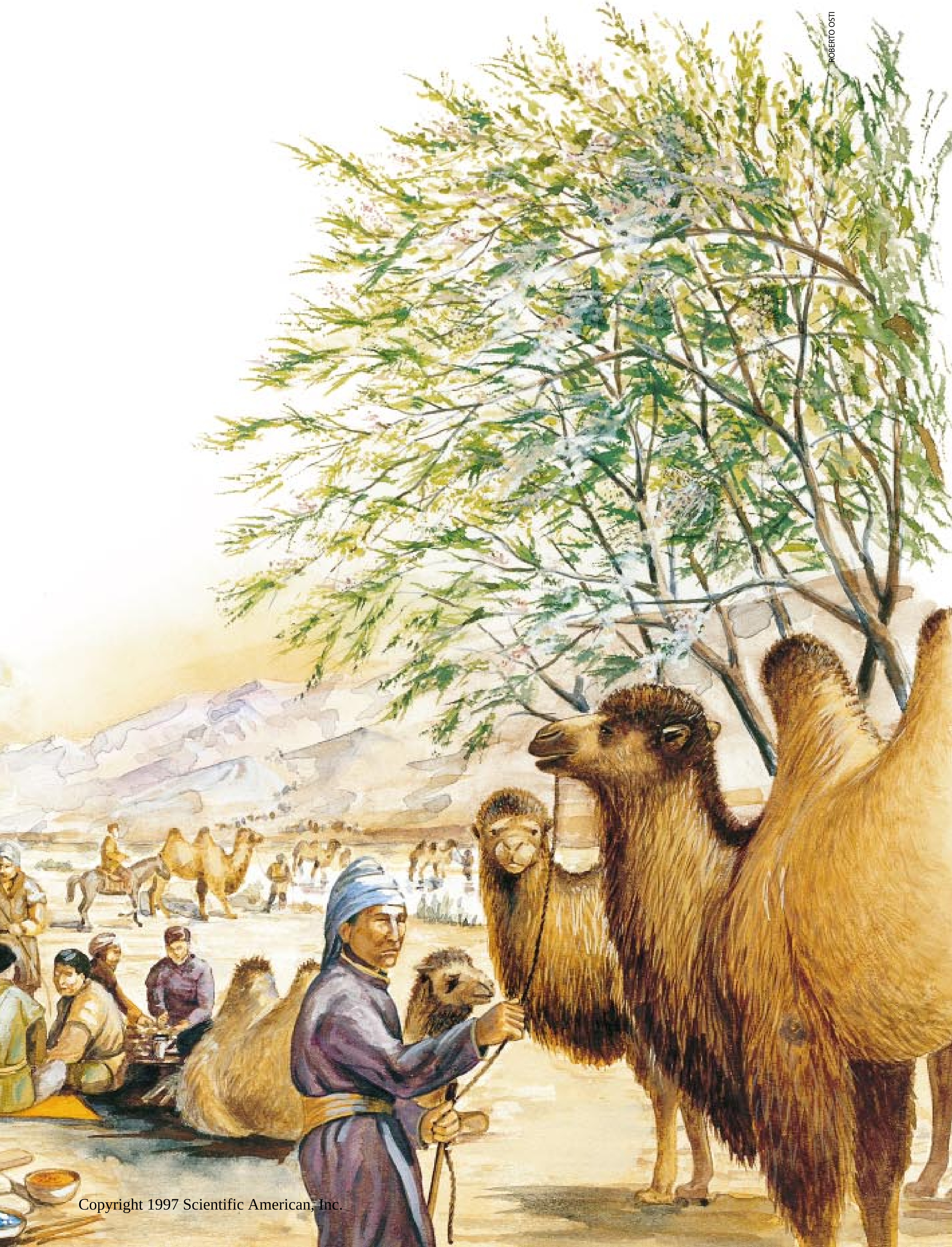
Treasures at Dunhuang

Cave temples along the ancient Silk Road document the cultural and religious transformations of a millennium. Researchers are striving to preserve these endangered statues and paintings

by Neville Agnew and Fan Jinshi

MOGAO, near the city of Dunhuang, was a vibrant way station on the Silk Road, a place for travelers and merchants to rest and to worship. Depicted here during the middle of the Tang dynasty (618 to 907 C.E.), the oasis was a lively haven for caravans emerging from the surrounding deserts. As pivotal points along the great trade route, Mogao and Dunhuang were sites of immense cultural, religious and material exchange. Buddhist practitioners prayed in the caves that they carved into the cliff face and hung ceremonial banners to decorate them, while pilgrims prepared for the journey east to Beijing or west toward the Mediterranean.




ROBERTO OSTI

GETTY CONSERVATION INSTITUTE

G. ALDANA *Getty Conservation Institute*

ENCROACHING SAND threatens the Mogao Grottoes (*above*) as it pours over the cliff face. The reinforced concrete facade (*right*), built in the 1960s, strengthens some of the grottoes that have been eroded by wind and weakened by earthquakes. As the map of the Silk Road (*below*) shows, Dunhuang sat on the very outskirts of China, at the point where the two arms of the trade network joined after circling the deadly Takla Makan Desert.

ROBERTO OSTI

LOIS CONNER; COLORIZED BY LAURIE GRACE

NEVILLE AGNEW

CELESTIAL DEITIES, called apsarasas, painted on this grotto ceiling date from the Western Wei dynasty (535 to 542 C.E.).

One thousand nine hundred kilometers due west of Beijing, on the edge of both the Gobi and the Takla Makan deserts, sits one of the world's most important cultural gateways. The city of Dunhuang—which means "blazing beacon"—represented the last oasis for Chinese travelers setting out for the West along the northern or southern arm of the Silk Road. The two routes skirted the deadly Takla Makan Desert, joining again on the far side at Kashi (1,600 kilometers to the west). For travelers coming to the East, the two forts of Dunhuang—the Jade Gate, or Yumen Barrier, and the Yang Barrier—meant successful passage around the Takla Makan, where the way was marked by the bleached bones of camels, horses and unfortunate voyagers. This fortified outpost formed the furthermost extension of the Great Wall of China.

From the fourth through the 14th century, the 7,500-kilometer Silk Road linked China to Rome and to every place in between, including Tibet, India, Turkestan, Afghanistan and the Arabian Peninsula. The road—its name coined by the 19th-century explorer Baron Ferdinand von Richthofen—was more than a trade route. It was the first information highway, spanning a quarter of the circumference of the globe and virtually the entire known world at that time. Out of the Middle Kingdom came the astonishing riches and technological innovations of China: silk, ceramics, furs and, later, paper and gunpowder; from the West came cotton, spices, grapes, wine and glass. Art and ideas moved along with these goods,

GETTY CONSERVATION INSTITUTE

WORSHIPING BODDHISATTVAS adorn Cave 328. These statues, from the high Tang, are covered with the fine dust that blows down from the Mingsha Dunes, obscuring the sculptures and the wall paintings.

DESERT ENVIRONMENT stretches in all directions around the Daquan River, which provides the water for Mogao. The Mingsha Dunes can be seen in the far distance; directly in front of them, next to the river, lie the trees and the cliff face, honeycombed with grottoes.

KNEELING FIGURE from the middle Tang resides in Cave 384. Statues such as this one provide detailed information about the costumes of medieval China.

RU SUICHU *ChinaStock*

goods, back and forth along the bandit-rid-den trail, transforming vastly different cultures.

It was along the Silk Road that Buddhism, which originated in India in the 6th century B.C.E., traveled to China. The full flowering of this religion is powerfully evident in the rock temples near the town of Dunhuang. Around 360 C.E., Buddhist pilgrims journeying through Dunhuang began to carve caves in a 1,600-meter-long cliff, 25 kilometers southeast of the city. In these soft sandstone and conglomerate rock grottoes, the worshipers built shrines, lodgings and places for sacred works and art; they also made offerings and prayed for safe passage. Over the next 10 centuries, monks carved hundreds of shrines in the rock, honeycombing the cliff face.

Some 490 of these grottoes remain today, home to 2,000 or so clay statues of the Buddha and 50,000 square meters of wall paintings. These works of art reflect the changes of 10 periods and dynasties, including the Tang (618 to 907 C.E.)—which, in its middle period, marked the full unfolding of Chinese art and culture. The murals from the high Tang document the daily life of the many people from all social classes who passed through and lived in Dunhuang; those from earlier periods depict a somewhat austere Buddhism. The paintings also record trade, manufacturing practices, customs, legends and sutras (sacred prayers). And they show the transformation of Indian Buddhism into its Chinese form: Chinese myths and patterns are gradually incorporated into Indian iconography, until a purely Chinese Buddhist art emerges. These Mogao Grottoes, as they are called, represent the largest collection of Buddhist mural art in China and an unsurpassed repository of information about life in ancient China and along the Silk Road.

The Silk Road closed during the 15th century as the Takla Makan oases dried up, no longer replenished by receding glacial streams of the Qilian Mountains, and as invaders swept through the region, converting large parts to Islam. Much of Dunhuang's Buddhist legacy remained intact because of its location. Indeed, the city's physical isolation often proved its salvation. During the two eras when Buddhists were persecuted by

NEVILLE AGNEW

THE GREAT MONASTERY at Mount Wutai in Shanxi Province is depicted in this wall painting from the Five Dynasties period (907–960 C.E.), found in Cave 61. Mogao has 50,000 square meters of wall paintings.

Chinese emperors—in 446, by the Emperor Wu, and in 845, by the Emperor Wuzong—Dunhuang proved too remote from the center of power to be much affected. This also held true during the Cultural Revolution of the late 1960s. (Although Tibetans conquered the city twice, in 781 and again in the early 16th century, the invaders revered the site and worshiped there. Their stylistic influence can be seen in some of the caves.)

At the turn of this century, however, "foreign devils" in the form of archaeologists began the systematic discovery and removal of the cultural heritage of the Silk Road. These men embarked on a frenzied race to gather as many artifacts as they could transport. Among the most renowned of them were Swedish explorer Sven Hedin, Parisian Paul Pelliot, Harvard University's Langdon Warner, and Aurel Stein, a Hungarian-born British collector. Stein arrived on the scene in 1907. He had apparently heard of the site from the first known Western visitors—fellow Hungarian count Bela Szechenyi and his two companions, who had made their way there in 1878.

Stein is most reviled by contemporary Chinese scholars for carting off the 7,000 ancient Buddhist texts and paintings that are now housed in the British Museum—including the earliest known book, a block-print version of the Diamond Sutra from 868 C.E. These manuscripts were taken from Cave 17, a library that had been sealed around 1000 C.E. and only rediscovered in the early 1900s by a resident Taoist priest, Wang Yuanlu. Wang fell victim to Stein's persuasion, and later Pelliot's, secretly selling off manuscripts for a pittance, which he used to "restore" the rock-cut temples. (Other less significant texts that were removed include model apologies for a drunken guest to send to his host of the previous evening, along with the appropriate response from the host.) By the time China was finally closed to foreign archaeologists in the mid-1920s, the European explorers had removed not only many thousands of texts but

PO-MING LIN *Getty Conservation Institute*

COLLAPSED CEILING of Cave 460 is indicative of the weakness of the soft sandstone and conglomerate rock of the grottoes, which have been thinned over time by erosion.

G. ALDANA *Getty Conservation Institute*

EVER PRESENT SAND had to be constantly brushed and carted away (*above*), until researchers designed five-kilometer-long fences (*right*) to contain the sand above Mogao. To stabilize the sand still more, they planted vegetation adapted to the desert—including *Tamarix chinensis, Haloxylon ammodendron, Calligonum arborescens* and *Hedysarum scoparium* (*inset*).

also statues and even some of the wall paintings themselves. These are now held by many major institutions in Europe, India, Japan and the U.S.

Today the threats to the Mogao Grottoes are of a different nature, originating in the immediate surroundings. Over the years, constant winds have eroded the cliff, and sand has cascaded down the face, covering the entrances, partly filling the grottoes and obscuring both the sculpture and the wall paintings with a fine dust. Where moisture from rain and snow has seeped in through the cracks and holes, the paintings have deteriorated, and the clay plaster on which they were painted has separated from the rock face. The weak conglomerate sandstone has been extensively fractured during earthquakes, most recently in 1933, and entire grottoes have collapsed.

Visitors have taken their toll as well. In older times, passersby would light fires in the caves, coating the paintings with soot. More recently, a steady stream of tourists has introduced humidity into the caves, threatening the fading pigments and eroding the floor tiles, some of them 1,000 years old. Mogao was opened to the public in 1980, and more flights to Dunhuang's enlarged airport have resulted in a rapid increase in tourism to the area. Dunhuang has been transformed from an ancient town into a modern city as new hotels have mushroomed.

Since 1988 the Getty Conservation Institute in Los Angeles has worked with the Dunhuang Academy and the State Bureau of Cultural Relics of China to help conserve the famous site, which UNESCO designated a World Heritage Site in 1987. Together scientists and preservationists from the academy and the Getty, aided by members of other Chinese research organizations, have built five-kilometer-long windbreak fences. These barriers, made with both synthetic fabrics and desert-adapted plants, stand above the grottoes to reduce the amount of sand being blown over the cliff face. Previously, 2,000 cu-

GETTY CONSERVATION INSTITUTE

GETTY CONSERVATION INSTITUTE

PRESERVATION includes monitoring paintings to see if the pigment is fading or has changed in hue, sometimes even from white to black (*right*). Scientists also track heat, humidity and other atmospheric parameters on the cliff (*far right*). Information on changes in the internal environment can be used to determine how many visitors can enter the caves and for how long a period.

DUSAN STULIK *Getty Conservation Institute*; PO-MING LIN *Getty Conservation Institute (inset)*

bic meters of sand had to be removed from outside the caves annually. The fences have cut this volume by 60 percent; dust filters and seals have been fitted on the doors to the caves to protect against the sand that is still blown down. To strengthen the caves, scientists are measuring cracks, particularly the large ones that intersect the rock of several caves, and are planning to pin and stabilize them.

To monitor environmental conditions and their impacts on the site, researchers have installed a solar-powered meteorological station on the cliff face. The equipment records baseline data such as wind speed and direction, solar radiation, humidity and precipitation. Various substations in selected caves record relative humidity, carbon dioxide, temperature as well as the number of visitors. Readings about the internal microclimate are compared with data from caves that are closed to people and with data from the outside. Taken together, this information is being used to develop tourism strategies.

Despite vigilant monitoring of the caves, it was clear that the parade of visitors had to be limited, especially in the popular caves that depict some of the well-known parables from the life of the Buddha. So the Dunhuang Academy built a large museum and exhibition gallery nearby, where about 10 caves are replicated. Because these full-size facsimiles are well lit, unlike the grottoes themselves, viewers can spend more time in them than they are allowed to in the original caves.

As with many areas of science, archaeology has undergone a form of revival in China in the past 10 to 20 years; in a few instances, joint efforts between foreign and Chinese archaeological teams have been part of this renaissance, though, for the most part, excavations have been undertaken strictly with the professional and scholarly resources of China alone. The most prominent recent discoveries include the tomb of the First Emperor Qinshihuang—filled with thousands of terra-cotta soldiers and horses—in Xi'an in 1974; the 4,000-year-old Caucasian mummies from the southern part of the Takla Makan Desert; and the 13th-century B.C.E. tomb unearthed in the province of Jiangxi, which was filled with pottery as well as bronze vessels, bells and weapons adorned with an iconography never seen before.

The importance of saving Mogao and other sites cannot be emphasized enough. Even the remoteness of a site such as the Mogao Grottoes does not guarantee its preservation. The collaboration between the Getty and the Dunhuang Academy represents a new stage in Chinese preservation of cultural heritage. Scientists must continue to explore ways to protect these cultural legacies so that today's pilgrims, traveling perhaps less harsh routes than those encircling the ever deadly Takla Makan, can witness the world's history. SA

The Authors

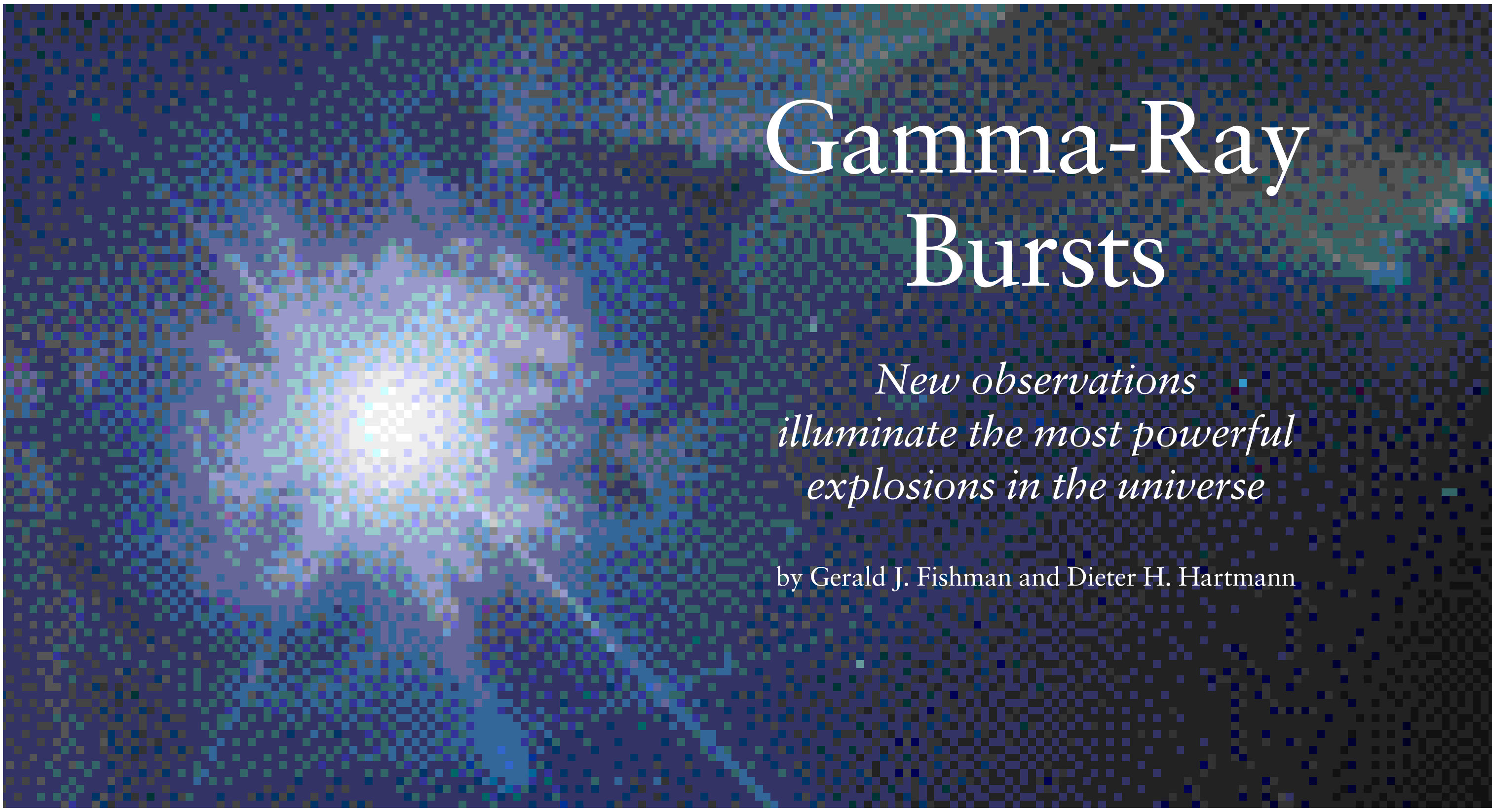
NEVILLE AGNEW and FAN JINSHI work together on the preservation of the Mogao Grottoes at Dunhuang. Agnew is associate director for programs at the Getty Conservation Institute in Los Angeles, where he has been since 1988, and holds a doctorate in chemistry. Fan is deputy director of the Dunhuang Academy, where she has worked since 1963. She has written extensively about many aspects of the history, art and archaeology of the Mogao Grottoes.

Further Reading

FOREIGN DEVILS ON THE SILK ROAD: THE SEARCH FOR THE LOST CITIES AND TREASURES OF CHINESE CENTRAL ASIA. Peter Hopkirk. University of Massachusetts Press, 1980.

DUNHUANG, CAVES OF THE SINGING SANDS: BUDDHIST ART FROM THE SILK ROAD. Roderick Whitfield. Photography by Seigo Otsuka. Textile and Art Publications, London, 1995.

CONSERVATION OF ANCIENT SITES ON THE SILK ROAD. Proceedings of an International Conference on the Conservation of Grotto Sites: Mogao Grottoes, Dunhuang, the People's Republic of China. Edited by Neville Agnew. Getty Conservation Institute, Los Angeles, 1997.



Gamma-Ray Bursts

New observations illuminate the most powerful explosions in the universe

by Gerald J. Fishman and Dieter H. Hartmann

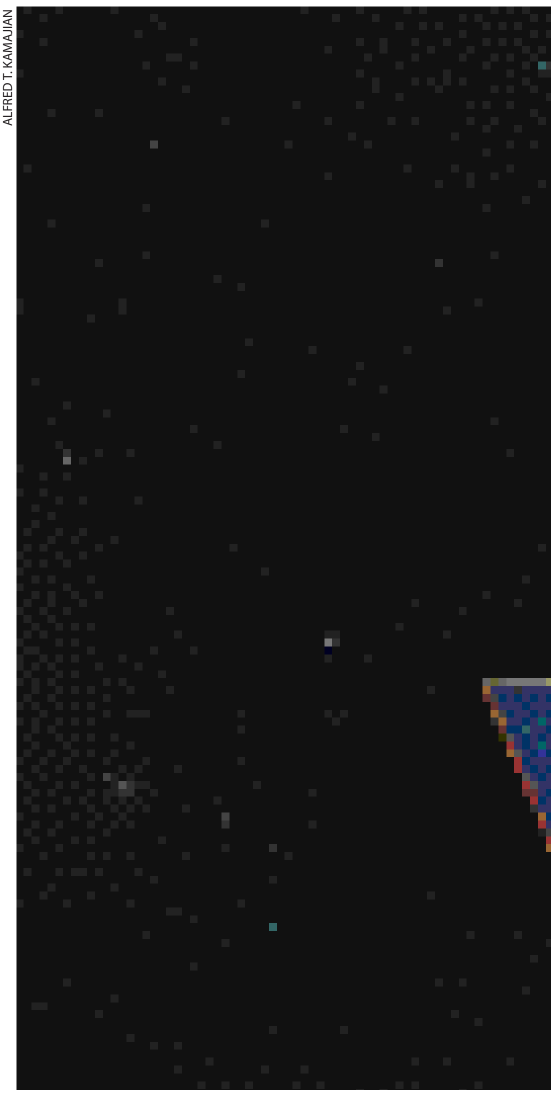
About three times a day our sky flashes with a powerful pulse of gamma rays, invisible to human eyes but not to astronomers' instruments. The sources of this intense radiation are likely to be emitting, within the span of seconds or minutes, more energy than the sun will in its entire 10 billion years of life. Where these bursts originate, and how they come to have such incredible energies, is a mystery that scientists have been attacking for three decades. The phenomenon has resisted study—the flashes come from random directions in space and vanish without trace—until very recently.

On February 28 of this year, we were lucky. One such burst hit the Italian-Dutch Beppo-SAX satellite for about 80 seconds. Its gamma-ray monitor established the position of the burst—prosaically labeled GRB 970228—to within a few arc minutes in the Orion constellation, about halfway between the stars Alpha Tauri and Gamma Orionis. Within eight hours, operators in Rome had turned the spacecraft around to look in the same region with an x-ray telescope. They found a source of x-rays (radiation of somewhat lower frequency than gamma rays) that was fading fast, and they fixed its location to within an arc minute.

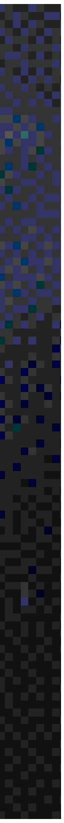
Never before has a burst been pinpointed so accurately and so quickly, allowing powerful optical telescopes, which have narrow fields of view of a few arc minutes, to look for it. Astronomers on the Canary Islands, part of an international team led by Jan van Paradijs of the University of Amsterdam and the University of Alabama in Huntsville, learned of the finding by electronic mail. They had some time available on the 4.2-meter William Herschel Telescope, which they had been using to look for other bursts. They took a picture of the area 21 hours after GRB 970228. Eight days later they looked again and found that a spot of light seen in the earlier photograph had disappeared.

There is more. On March 13 the New Technology Telescope in La Silla, Chile, took a long, close look at those coordinates and discerned a diffuse, uneven glow. The Hubble Space Telescope later resolved it to be a bright point surrounded by a somewhat elongated background

ALFRED T. KAMAJIAN



DISTANT BURST of radiation hits the earth and the detectors on board the Beppo-SAX satellite. Although incredibly intense, most of the radiation does not penetrate the atmosphere. But telescopes pointed toward a recent gamma-ray burst, called GRB 970228, found an optical afterglow that persisted for weeks.



object. Many of us believe the latter to be a galaxy, but its true identity remains unknown as of this writing.

If indeed a galaxy—as current theories would have—it must be very far away, near the outer reaches of the observable universe. In that case, gamma-ray bursts must represent the most powerful explosions in the universe.

Confounding Expectations

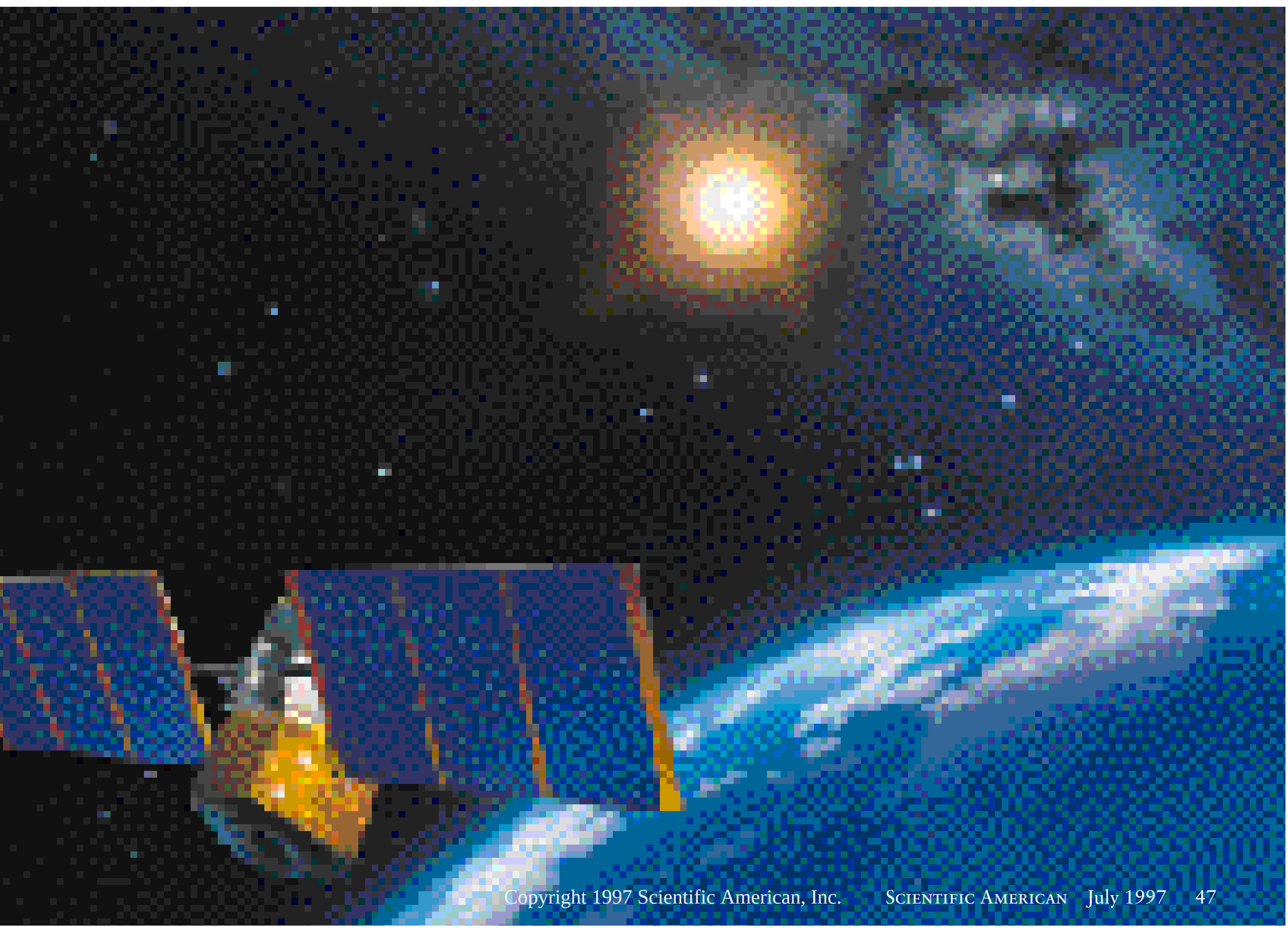
For those of us studying gamma-ray bursts, this discovery salves two recent wounds. In November 1996 the High Energy Transient Explorer (HETE) spacecraft, equipped with very accurate instruments for locating gamma-ray bursts, failed to separate from its launch rocket. And in December the Russian Mars '96 spacecraft, with several gamma-ray detectors, fell into the Pacific Ocean after a rocket malfunction. These payloads were part of a carefully designed set for launching an attack on the origins of gamma-ray bursts. Of the newer satellites equipped with gamma-ray instruments, only Beppo-SAX—whose principal scientists include Luigi Piro, Enrico Costa and John Heise—made it into space on April 20, 1996.

Gamma-ray bursts were first discovered by accident, in the late 1960s, by the Vela series of spacecraft of the U.S. Department of Defense. These satellites were designed to ferret out the U.S.S.R.'s clandestine nuclear detonations in outer space—perhaps hidden behind the moon. Instead they came across spasms of radiation that did not originate from near the earth. In 1973 scientists concluded that a new astronomical phenomenon had been discovered.

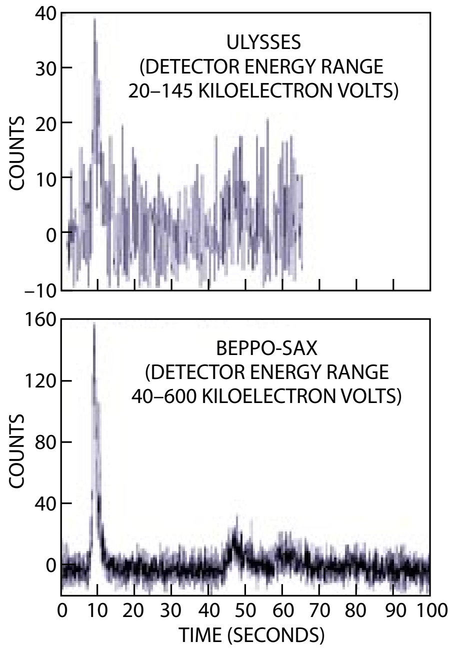
These initial observations resulted in a flurry of speculation about the origins of gamma-ray bursts—involving black holes, supernovae or the dense, dark star remnants called neutron stars. There were, and still are, some critical unknowns. No one knew whether the bursts were coming from a mere 100 light-years away or a few billion. As a result, the energy of the original events could only be guessed at.

By the mid-1980s the consensus was that the bursts originated on nearby neutron stars in our galaxy. In particular, theorists were intrigued by dark lines in the spectra (component wavelengths spread out, as light is by a prism) of some bursts, which suggested the presence of intense magnetic fields. The gamma rays, they postulated, are emitted by electrons accelerated to relativistic speeds when magnetic-field lines from a neutron star reconnect. A similar phenomenon on the sun—but at far lower energies—leads to flares.

In April 1991 the space shuttle *Atlantis* launched the Compton Gamma Ray Observatory, a satellite that carried the Burst and Transient Source Experiment (BATSE). Within a year BATSE had confounded all expectations. The distribution of gamma-ray bursts did not trace out the Milky Way, nor were the bursts associated with nearby galaxies or clusters of galaxies. Instead they were dis-



ALFRED T. KAMAJIAN



COURTESY OF KEVIN HURLEY *University of California at Berkeley, Space Sciences Lab*

TIME PROFILE of GRB 970228 taken by the Ulysses spacecraft (*top*) and by Beppo-SAX (*bottom*) shows a brief, brilliant flash of gamma rays.

tributed isotropically, with any direction in the sky having roughly the same number. Theorists soon refined the galactic model: the bursts were now said to come from neutron stars in an extended spherical halo surrounding the galaxy.

One problem with this scenario is that the earth lies in the suburbs of the Milky Way, about 30,000 light-years from the core. For us to find ourselves near the center of a galactic halo, the latter must be truly enormous, almost 600,000 light-years in outer radius. If so, the halo of the neighboring Andromeda galaxy should be as extended and should start to appear in the distribution of gamma-ray bursts. But it does not. (Special models in which the neutron stars beam in the same direction as their motion can, however, overcome this objection.)

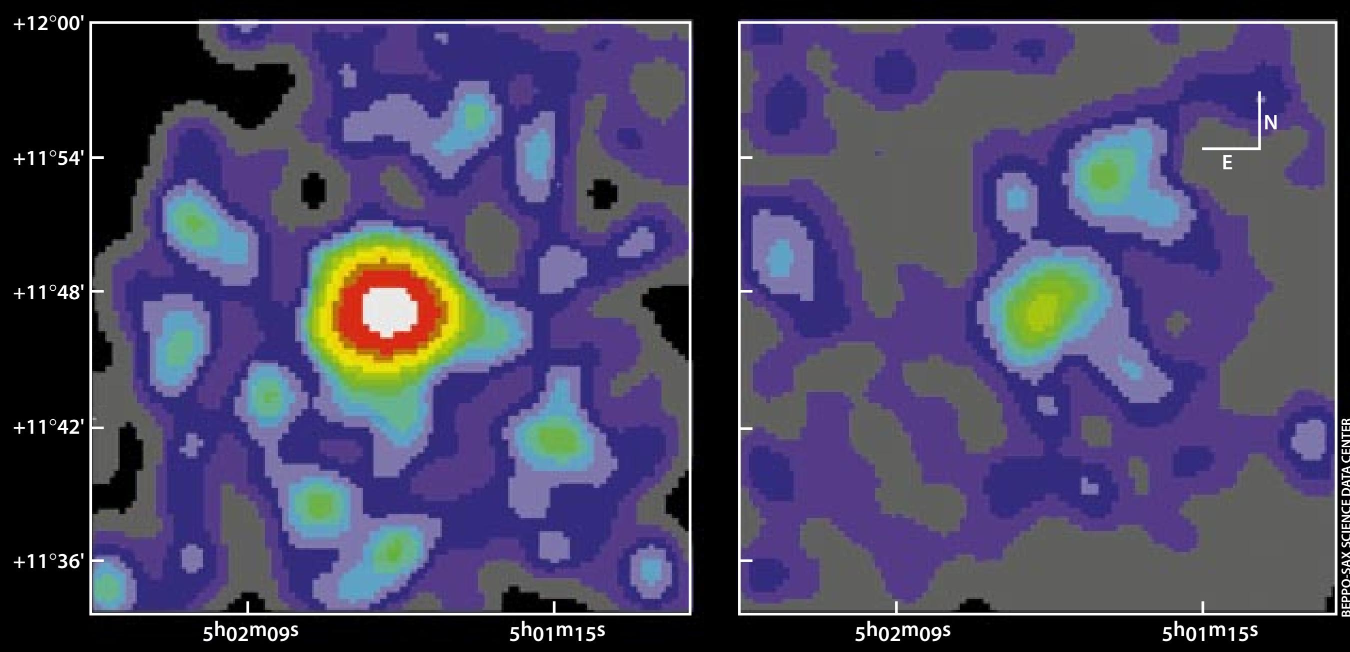
This uniformity has convinced most astrophysicists that the bursts come from cosmological distances, on the order of three billion to 10 billion light-years away. At such a distance, though, the bursts should show the effects of the expansion of the universe. Galaxies that are very distant are moving away from the earth at great speeds; we know this because the light they emit shifts to lower, or redder, frequencies. Likewise, gamma-ray bursts should also show a "redshift," as well as an increase in duration.

Unfortunately, BATSE does not see, in the spectrum of gamma rays, bright or dark lines characterizing specific elements whose displacements would betray a shift to the red. (Nor does it detect the dark lines found by earlier satellites.) In April astronomers using the Keck Telescope in Hawaii obtained an optical spectrum of the afterglow of GRB 970228. It is smooth and red, with no telltale lines. Still, Jay Norris of the National Aeronautics and Space Administration Goddard Space Flight Center and Robert Mallozzi of the University of Alabama in Huntsville have statistically analyzed the observed bursts and report that the weakest, and therefore the most distant, show both a time dilation and a redshift. There are, however, other (controversial) ways to interpret these findings.

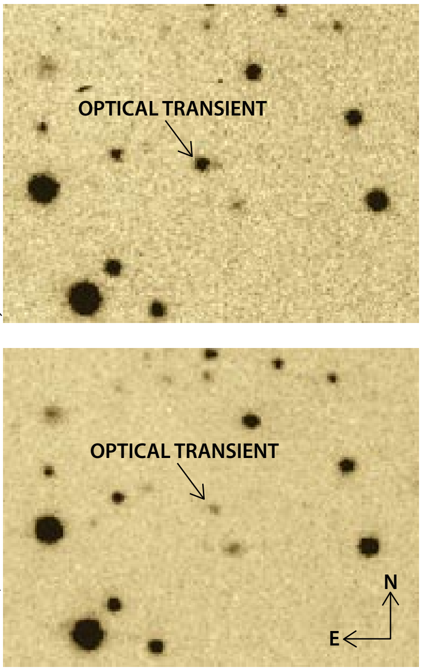
A Cosmic Catastrophe

One feature that makes it difficult to explain the bursts is their great variety. A burst may last from about 30 milliseconds to almost 1,000 seconds—and in one case, 1.6 hours. Some bursts show spasms of intense radiation, with no detectable emission in between, whereas others are smooth. Also complicated are the spectra—essentially, the colors of the radiation, invisible though they are. The bulk of a burst's energy is in radiation of between 100,000 and one million electron volts, implying an exceedingly hot source. (The photons of optical light, the primary radiation from the sun, have energies of a few electron volts.) Some bursts evolve smoothly to lower frequencies such as x-rays as time passes. Although this x-ray tail has less energy, it contains many photons.

X-RAY IMAGE taken by Beppo-SAX on February 28 (*left image*) localized the burst to within a few arc minutes, allowing ground-based telescopes to search for it. On March 3 the source was much fainter (*right image*).



BEPPO-SAX SCIENCE DATA CENTER



PAUL GROOT, TITUS GALAMA AND JAN VAN PARADIJS *University of Amsterdam*

OPTICAL IMAGES of the region of the burst were taken by the William Herschel Telescope on the Canary Islands, on February 28 (*top*) and March 8 (*bottom*). A point of light in the first image has faded away in the second one, indicating a transient afterglow.

If originating at cosmological distances, the bursts must have energies of perhaps 10^{51} ergs. (About 1,000 ergs can lift a gram by one centimeter.) This energy must be emitted within seconds or less from a tiny region of space, a few tens of kilometers across. It would seem we are dealing with a fireball.

The first challenge is to conceive of circumstances that would create a sufficiently energetic fireball. Most theorists favor a scenario in which a binary neutron-star system collapses [see "Binary Neutron Stars," by Tsvi Piran; Scientific American, May 1995]. Such a pair gives off gravitational energy in the form of radiation. Consequently, the stars spiral in toward each other and may ultimately merge to form a black hole. Theoretical models estimate that one such event occurs every 10,000 to one million years in a galaxy. There are about 10 billion galaxies in the volume of space that BATSE observes; that yields up to 1,000 bursts a year in the sky, a number that fits the observations.

Variations on this scenario involve a neutron star, an ordinary star or a white dwarf colliding with a black hole. The details of such mergers are a focus of intense study. Nevertheless, theorists agree that before two neutron stars, say, collapse into a black hole, their death throes release as much as 10^{53} ergs. This energy emerges in the form of neutrinos and antineutrinos, which must somehow be converted into gamma rays. That requires a chain of events: neutrinos collide with antineutrinos to yield electrons and positrons, which then annihilate one another to yield photons. Unfortunately, this process is very inefficient, and recent simulations suggest it may not yield enough photons.

Worse, if too many heavy particles such as protons are in the fireball, they reduce the energy of the gamma rays. Such proton pollution is to be expected, because the collision of two neutron stars must yield a potpourri of particles. But then all the energy ends up in the kinetic energy of the protons, leaving none for radiation. As a way out of this dilemma, Peter Mészáros of Pennsylvania State University and Martin J. Rees of the University of Cambridge have suggested that when the expanding fireball—essentially hot protons—hits surrounding gases, it produces a shock wave. Electrons accelerated by the intense electromagnetic fields in this wave then emit gamma rays.

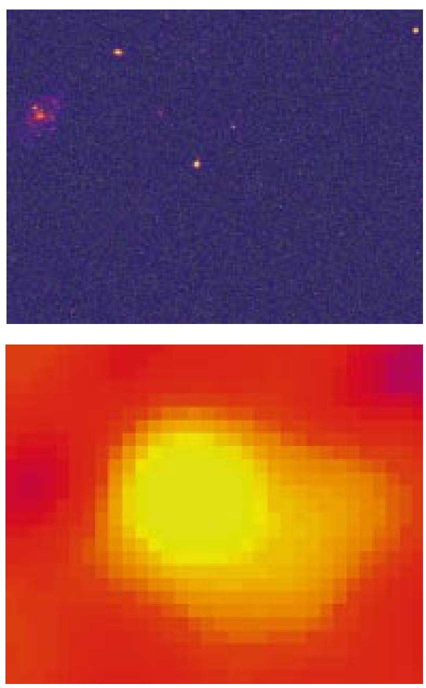
A variation of this scenario involves internal shocks, which occur when different parts of the fireball hit one another at relativistic speeds, also generating gamma rays. Both the shock models imply that gamma-ray bursts should be followed by long afterglows of x-rays and visible light. In particular, Mario Vietri of the Astronomical Observatory of Rome has predicted detectable x-ray afterglows lasting for a month—and also noted that such afterglows do not occur in halo models. GRB 970228 provides the strongest evidence yet for such a tail. There are some problems, however: the binary collapse does not explain some long-lasting bursts. Last year, for instance, BATSE found a burst that endured for 1,100 seconds and possibly repeated two days later.

There are other ways of generating the required gamma rays. Nir Shaviv and Arnon Dar of the Israel Institute of Technology in Haifa start with a fireball of unknown origin that is rich in heavy metals. Hot ions of iron or nickel could then interact with radiation from nearby stars to give off gamma rays. Simulations show that the time profiles of the resulting bursts are quite close to observations, but a fireball consisting entirely of heavy metals seems unrealistic.

Another popular mechanism invokes immensely powerful magnetic engines, similar to the dynamos that churn in the cores of galaxies. Theorists envision that instead of a fireball, a merger of two stars—of whatever kind—could yield a black hole surrounded by a thick, rotating disk of debris. Such a disk would be very short-lived, but the magnetic fields inside it would be astounding, some 10^{15} times those on the earth. Much as an ordinary dynamo does, the fields would extract rotational energy from the system, channeling it into two jets bursting out along the rotation axis.

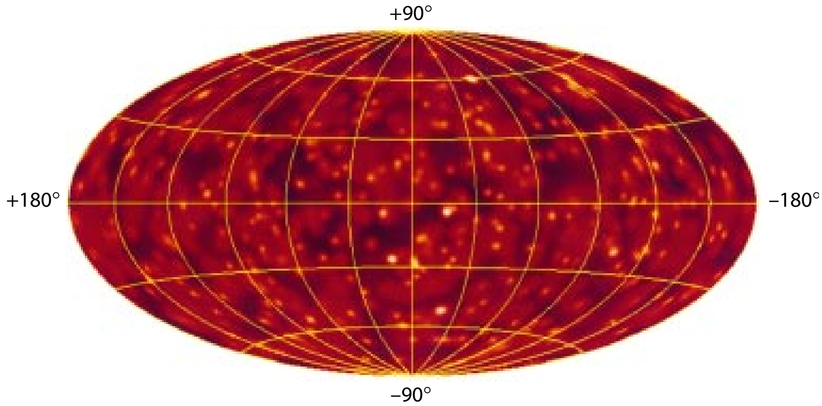
The cores of these jets—the regions closest to the axis—would be free of proton pollution. Relativistic electrons inside them can then generate an intense, focused pulse of gamma rays. Although quite a few of the details remain to be worked out, many such scenarios ensure that mergers are the leading contenders for explaining bursts.

Still, gamma-ray bursts have been the subject of more than 2,500 papers—about one publication per recorded

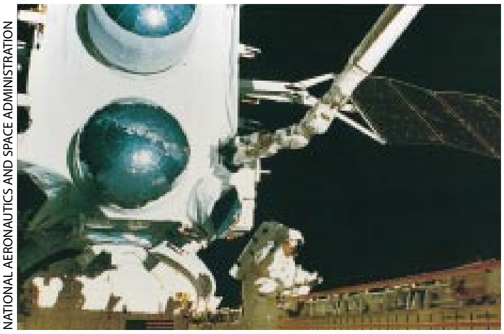


SPACE TELESCOPE SCIENCE INSTITUTE

DEEP EXPOSURE of the optical remnant of GRB 970228 was taken by the Hubble Space Telescope. The afterglow (*near center of top image*), when seen in close-up (*bottom*), has a faint, elongated background glow that may correspond to a galaxy in which the burst occurred.



MAX TEGMARK *Institute for Advanced Study, Princeton*



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

BURST DISTRIBUTION over the sky, measured by the Burst and Transient Source Experiment (BATSE), shows no clustering along the Milky Way (*along equatorial line*). BATSE is located on the Compton Observatory (*right*), here shown being deployed.

burst. Their transience has made them difficult to observe with a variety of instruments, and the resulting paucity of data has allowed for a proliferation of theories.

If one of the satellites detects a lensed burst, astronomers would know for sure that bursts occur at cosmological distances. Such an event might occur if an intervening galaxy or other massive object serves as a gravitational lens to bend the rays from a gamma-ray burst toward the earth. When optical light from a distant star is focused in this manner, it appears as multiple images of the original star, arranged in arcs around the lens. Gamma rays cannot be pinpointed with such accuracy; instead they are currently detected by instruments that have poor directional resolution.

Moreover, bursts are not steady sources like stars. A lensed gamma-ray burst would therefore show up as two bursts coming from roughly the same direction, having identical spectra and time profiles but different intensities and arrival times. The time difference would come from the rays' traversing curved paths of different lengths through the lens.

To further nail down the origins of the underlying explosion, we need data on other kinds of radiation that might accompany a burst. Even better would be to identify the source. Until the fortuitous observation of GRB 970228—we are astonished that its afterglow lasted long enough to be seen—such "counterparts" had proved exceedingly elusive. To find others, we will need to locate the bursts very precisely.

Watching and Waiting

Since the early 1970s, Kevin Hurley of the University of California at Berkeley and Thomas Cline of the NASA Goddard Space Flight Center have worked to establish "interplanetary networks" of burst instruments. They try to put a gamma-ray detector on any spacecraft available or to send aloft dedicated devices. The motive is to derive a location to within arc minutes, by comparing the times at which a burst arrives at spacecraft separated by large distances.

From year to year, the network varies greatly in efficacy, depending on the number of participating instruments and their separation. At present, there are five components: BATSE, Beppo-SAX and the military satellite DMSP, all near the earth; Ulysses, far above the plane of the solar system; and the spacecraft Wind, orbiting the sun. The data from Beppo-SAX, Ulysses and Wind were used to triangulate GRB 970228. (BATSE was in the earth's shadow at the time.) The process, unfortunately, is slow—eight hours at best.

Time is of the essence if we are to direct diverse detectors at a burst while it is glowing. Scott Barthelmy of the Universities Space Research Association at the NASA Goddard Space Flight Center has developed a system called BACODINE (BAtse COordinates DIstribution NEtwork) to transmit within seconds BATSE data on burst locations to ground-based telescopes.

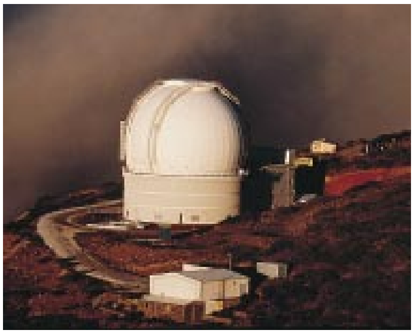
BATSE consists of eight gamma-ray detectors pointing in different directions from eight corners of the Compton satellite; comparing the intensity of a burst at these detectors provides its location to roughly a few degrees but within several seconds. Often BACODINE can locate the burst even while it is in progress. The location is transmitted over the Internet to several dozen sites worldwide. In five more seconds, robotically controlled telescopes at Lawrence Livermore National Laboratory, among others, slew to the location for a look.

Unfortunately, only the fast-moving smaller telescopes, which would miss a faint image, can contribute to the effort. The Livermore devices, for instance, could not have seen the afterglow of GRB 970228 (unless the optical emission immediately after the burst is many times brighter, as some theories suggest). Telescopes that are 100 times more sensitive are required. These mid-size telescopes would also need to be robotically controlled so they can slew very fast, and they must be capable of searching reasonably large regions. If they do find a transient afterglow, they will determine its location rather well, allowing much larger telescopes such as Hubble and Keck to look for a counterpart.

The long-lasting, faint afterglow following GRB 970228 gives new hope for this strategy. The HETE mission, directed by George Ricker of the Massachusetts Institute of Technology, is to be rebuilt and launched in about two years. It will survey the full sky with x-ray detectors that can localize bursts to within several arc minutes. A network of ground-based optical telescopes will

HYE-SOOK PARK *Lawrence Livermore National Laboratory*

ROBOTIC TELESCOPES on a hill near Lawrence Livermore National Laboratory search for a burst within seconds of obtaining its location from BATSE.


VARIETY OF INSTRUMENTS contribute to the study of gamma-ray bursts. The Beppo-SAX satellite (*left*), shown in the process of assembly, has gamma-ray and x-ray detectors that have proved crucial to locating recent bursts. The William Herschel Telescope (*center*) on the Canary Islands photographed the optical transient of GRB 970228. In May the Very Large Array (*right*) of radio telescopes in Socorro, N.M., found radio waves from a burst—for the first time.

left to right: BEPPO-SAX SCIENCE DATA CENTER; ROGER RESSMEYER *Corbis*; NRAO

receive these locations immediately and start searching for transients.

Of course, we do not know what fraction of bursts actually exhibit a detectable afterglow; GRB 970228 could be a rare and fortuitous exception. Moreover, even an observation field as small as arc minutes contains too many faint objects to make a search for counterparts easy. It would be marvelous if we could derive accurate locations within fractions of a second from the gamma rays themselves. Astronomers have proposed new kinds of gamma-ray telescopes that can instantly derive the position of a burst to within arc seconds.

To further constrain the models, we will need to look at radiation of both higher and lower frequency than that currently observed. The Energetic Gamma Ray Experiment Telescope (EGRET), which is also on the Compton satellite, has seen a handful of bursts that emit radiation of up to 10 billion electron volts, sometimes lasting for hours. Better data in this regime, from the Gamma Ray Large Area Space Telescope (GLAST), a satellite being developed by an international team of scientists, will greatly aid theorists. And photons of even higher energy—of about a trillion electron volts—might be captured by special ground-based gamma-ray telescopes. At the other end of the spectrum, soft x-rays, which have energies of up to roughly one kiloelectron volt (keV), are helpful for testing models of bursts and also for getting better fixes on position. In the range of 0.1 to 10 keV, there is a good chance of discovering absorption or emission lines that would tell volumes about the underlying fireball and its magnetic fields. Such lines might also yield a direct measurement of the redshift and, hence, the distance. Sensitive instruments for detecting soft x-rays are being built in various institutions around the world.

Even as we finish this article, we have just learned of another coup. On the night of May 8, Beppo-SAX operators located a 15-second burst. Soon after, Howard E. Bond of the Space Telescope Science Institute in Baltimore photographed the region with the 0.9-meter optical telescope at Kitt Peak; the next night a point of light in the field had actually brightened. Other telescopes confirm that after becoming most brilliant on May 10, the source began to fade. This is the first time that a burst has been observed reaching its optical peak—which, astonishingly, lagged its gamma-ray peak by a few days.

Also for the first time, on May 13 the Very Large Array of radio telescopes in New Mexico detected radio emissions from the burst remnant. Even more exciting, the primarily blue spectrum of this burst, taken on May 11 with the Keck II telescope on Hawaii, showed a few dark lines, apparently caused by iron and magnesium in an intervening cloud. Astronomers at the California Institute of Technology find that the displacement of these absorption lines indicates a distance of more than seven billion light-years. If this interpretation holds up, it will establish once and for all that bursts occur at cosmological distances.

In that case, it may not be too long before we know what catastrophic event was responsible for that burst—and for one that might be flooding the skies even as you read. SA

The Authors

GERALD J. FISHMAN and DIETER H. HARTMANN bring complementary skills to the study of gamma-ray bursts. Fishman is an experimenter—the principal investigator for BATSE and a senior astrophysicist at the National Aeronautics and Space Administration Marshall Space Flight Center in Huntsville, Ala. He has received the NASA Medal for Exceptional Scientific Achievement three times and in 1994 was awarded the Bruno Rossi Prize of the American Astronomical Society. Hartmann is a theoretical astrophysicist at Clemson University in South Carolina; he obtained his Ph.D. in 1989 from the University of California, Santa Cruz. Apart from gamma-ray astronomy, his primary interests are the chemical dynamics and evolution of galaxies and stars.

Further Reading

THE GAMMA-RAY UNIVERSE. D. Kniffen in *American Scientist,* Vol. 81, No. 4, pages 342–350; July 1993.

THE COMPTON GAMMA RAY OBSERVATORY. Neil Gehrels, Carl E. Fichtel, Gerald J. Fishman, James D. Kurfess and Volker Schönfelder in *Scientific American,* Vol. 269, No. 6, pages 68–77; December 1993.

THE GAMMA-RAY BURST MYSTERY. D. H. Hartmann in *The Lives of Neutron Stars*. Edited by A. Alpar, Ü. Kiziloglu and J. van Paradijs. NATO Advanced Studies Institute, Kluwer Academic Publishers, 1994.

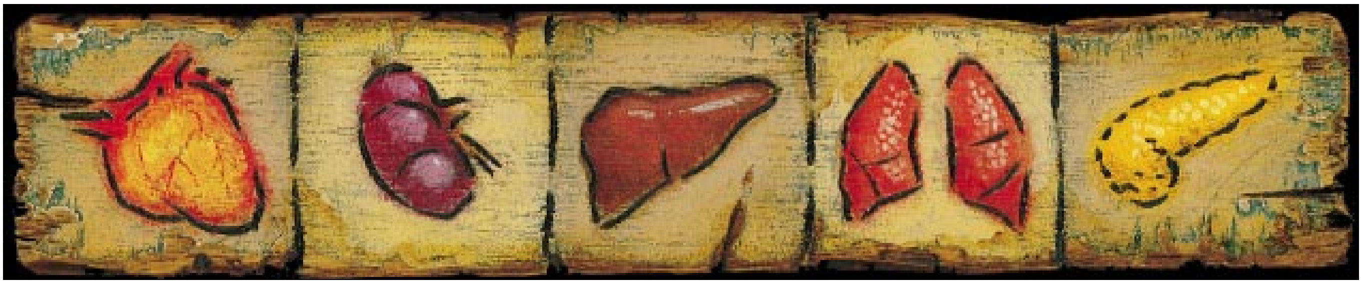
GAMMA RAY BURSTS. G. J. Fishman and C. A. Meegan in *Annual Review of Astronomy and Astrophysics,* Vol. 33, pages 415–458; 1995.

Beppo-SAX Mission home page is available on the World Wide Web at http://www.sdc.asi.it/

Xenotransplantation

After struggling for decades with a shortage of donated organs from cadavers, transplant surgeons may soon have another source to tap

by Robert P. Lanza, David K. C. Cooper and William L. Chick



STEVE JOHNSON AND LOU FANCHER

ORGANS that are now in high demand and in short supply for transplantation include (*from left to right*) the heart, kidney, liver, lungs and pancreas.

Early morning, sometime in the near future. A team of surgeons removes the heart, lungs, liver, kidneys and pancreas from a donor, whereupon a medical technician packs these organs in ice and rushes them to a nearby airport. A few hours later the heart and liver land in one city, the two kidneys in another, and the lungs and pancreas arrive in a third. Speedily conveyed to hospitals in each city, these organs are transplanted into patients who are desperately ill. The replacements function well, and six people receive a new lease on life. Back at the donor center, surgeons repeat the procedure several times, and additional transplants take place at a score of facilities distributed around the country. In all, surgical teams scattered throughout the U.S. conduct more than 100 transplant operations on this day alone.

How could so many organ donors have possibly been found? Easily—by obtaining organs not from human cadavers but from pigs. Although such a medical miracle is not yet possible, we and other researchers are taking definite steps toward it. Our efforts are driven by the knowledge that the supply of human organs will always be insufficient to satisfy demand. Within just the U.S., thousands of patients await transplants of the heart, liver, kidney, lung and pancreas, and millions struggle with diseases that may one day be curable with other kinds of donations. Notably, hemophilia, diabetes and even Alzheimer's and Parkinson's diseases might well be treated using transplanted cells. So the pressure to devise ways to transplant animal cells and organs into patients—"xenotransplantation"—steadily mounts.

Blending Species

The thought of combining parts from different species is not at all new. Greek lore of more than 3,000 years ago featured centaurs—creatures that were half man, half horse—and the Chimera, a combination of lion, goat and serpent. As early as 1682 a Russian physician reportedly repaired the skull of a wounded nobleman using bone from a dog. But it was not until after the turn of the 20th century that doctors attempted with some regularity to graft tissues from animals into humans. For instance, in 1905 a French surgeon inserted slices of rabbit kidney into a child suffering from kidney failure. "The immediate results," he wrote, "were excellent." Nevertheless, the child died about two weeks later.

During the next two decades, several other doctors tried to transplant organs from pigs, goats, lambs and monkeys into various patients. These grafts all soon failed, for reasons that seemed puzzling at the time. Before the pioneering investigations of Nobel laureate Sir Peter Medawar at the University of London during the 1940s, physicians had little inkling of the immunologic basis of rejection.

So, with only failures to show, most doctors lost interest in transplantation. But some medical researchers persevered, and in 1954 Joseph E. Murray and his colleagues at Peter Bent Brigham Hospital in Boston performed the first truly successful kidney transplant. They avoided immunologic rejection by transplanting a kidney between identical twin brothers (whose organs were indistinguishable to their immune systems). Subsequently, Murray and others were able to transplant kidneys from more distantly related siblings and, finally, from unrelated donors, by administering drugs to suppress the recipient's innate immune response.

Medical practice has since grown to include transplantation of the heart, lung, liver and pancreas. But these accomplishments have brought tragedy with them: because of the shortage of donated organs, most people in need cannot be offered treatment. Of the tens of thousands of patients in the U.S. every year deemed good candidates for a transplant, less than half receive a donated organ. The shortfall will become even more dire once doctors perfect methods to treat diabetes by transplanting pancreatic islet cells, which produce insulin. Islet replacement is simpler than transplanting the whole pancreas, but it may require harvesting cells from several donors to treat each patient.

Fortunately, scientists did not entirely abandon the possibility of using animal tissues in patients after human organ transplants came into vogue. During the 1960s, medical researchers continued to investigate exactly why organs transplanted between widely different species fail so rapidly. A major cause, they learned, is that the recipient's blood harbors antibody molecules that bind to the donated tissues. (These antibodies are normally directed against infectious microbes but can also respond to components of transplanted organs.) The attachment of these antibodies then activates special "complement" proteins in the blood, which in turn trigger destruction of the graft.

Such hyperacute rejection of foreign tissue—which begins within minutes or, at most, hours after the surgery—destroys the capillaries in the transplanted organ, causing it to hemorrhage massively. Although this reaction presents an imposing barrier to xenotransplantation, recent experiments suggest that scientists may yet overcome it.

For example, in 1992 David J. G. White and his colleagues at the University of Cambridge managed to create "transgenic" pigs, bearing on the inner walls of their blood vessels proteins that can prevent human complement proteins from doing damage. They did this by introducing into pig embryos a human gene that directs the production of a human complement-inhibiting protein [see "Transgenic Livestock as Drug Factories," by William H. Velander, Henryk Lubon and William N. Drohan; SCIENTIFIC AMERICAN, January]. White and his co-workers have not yet tested how tissues from these pigs fare in a human host, but organs from such genetically engineered pigs have functioned for as long as two months in monkeys, because the pig cells that are in direct contact with the host's immune system are able to quash the first wave of attack.

Other methods may also serve to thwart hyperacute rejection. In 1991 one of us (Cooper), along with several other investigators, identified the specific molecular fragments, or antigens, on

STEVE JOHNSON AND LOU FANCHER

TRANSPLANTS OF TISSUES from animals to humans (xenotransplants) have been attempted experimentally using a variety of donor animals, from frogs to baboons and pigs. Most efforts quickly failed. But doctors may soon perfect ways to transplant organs, such as the heart, from specially bred pigs.

pig tissues that human antibodies target. The cells lining pig vasculature have on their surfaces antigens made up of a particular sugar group. So it may be possible to breed (or indeed to clone) a line of genetically engineered pigs that lack this troublesome sugar group.

One plan would eliminate the enzyme that adds the sugar in the first place. Alternatively, scientists could provide pigs with a gene specifying an enzyme that would replace the problematic sugar with some other carbohydrate structure. For example, they could give pigs the gene for an enzyme that replaced existing antigens with the human type O blood group antigen, which does not elicit an immune response. Or, in principle, the offensive groups could be removed by introducing into a pig the gene for an enzyme that degrades the undesirable sugar.

Yet another strategy to prevent hyperacute rejection would be to alter the recipient's immune system so that it cannot destroy the transplanted tissue. For example, using standard apparatus, doctors can remove from the patient's blood all the antibodies to pig tissue. It is also possible to deplete the complement proteins temporarily or otherwise interfere with their activation. Remarkably, animal studies suggest that if surgeons transplant a pig organ while the patient's immune system is so suppressed, the organ may—for reasons that remain largely mysterious—achieve accommodation, a state that enables it to survive even after the host's antibodies and complement return to normal levels. The transplanted organ then continues to work despite a distinct lack of tolerance from the host's immune system.

Unfortunately, researchers have not yet managed to induce accommodation reliably in animals undergoing xenotransplantation. But Guy Alexandre and his colleagues at the University of Louvain Medical School in Belgium have achieved it in certain patients who received human organs from donors with incompatible blood types—a situation that, like xenotransplantation, normally sparks hyperacute rejection.

Fostering Tolerance

Investigators studying xenotransplantation are optimistic that, with some combination of these methods, immediately harmful immune reactions can be overcome. Yet grafts of animal tissues in patients would still fall prey to more delayed forms of immune rejection, which can take days or weeks to develop. In particular, the so-called cellular immune response to grafts from animals is likely to be at least as strong as the robust attacks that white blood cells of the immune system often mount against organs transplanted from one person to another. Avoiding such delayed reactions might require massive doses of immunosuppressive drugs, such as cyclosporine, to be given indefinitely, and the risks of toxicity, infections and other complications would be excessive.

Newly devised immunosuppressive agents should help, but it would clearly be more desirable if the human body could be induced to accept animal tissues without requiring ongoing drug therapy. That happy condition might seem impossibly difficult to arrange. But hope springs from the observation that long-term organ acceptance, or immunologic tolerance, has occurred spontaneously in a few people who have received human organs. Doctors of these patients were able to reduce, and ultimately eliminate, the normal regimen of immunosuppressive drugs.

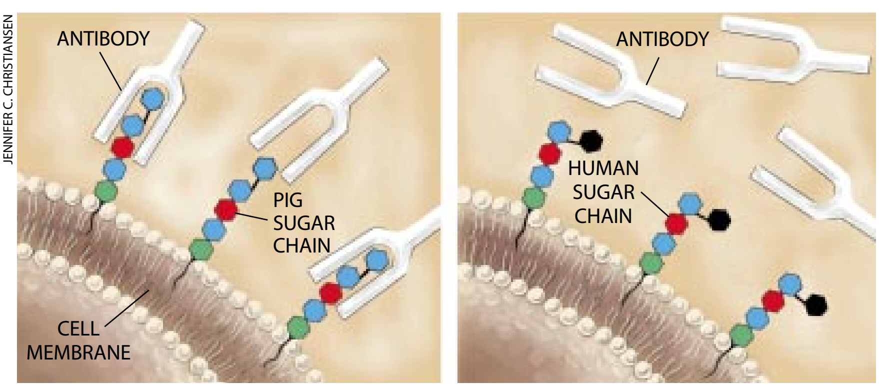
Though still an elusive goal, the induction of immunologic tolerance is an area of vigorous research, and advances are sure to come. Curiously, it may ultimately prove easier to achieve tolerance with xenotransplantation than with traditional organ transplants. Donated human organs need to be procured urgently under emergency conditions, but animal organs would be available on demand. That flexibility might give physicians adequate time to reprogram the immune system of the recipient.

One way to create tolerance involves modifying the immune system of the patient with bone marrow cells from the donor animal. (Bone marrow is the source of all components of the blood, including the white blood cells of the immune system.) Once introduced, the donated cells spread and mature, creating a "chimeric" immune system that is part donor, part recipient. The aim is to alter the patient's immune system so that it does not recognize as foreign either the donated cells or subsequently transplanted tissues from the same animal.

Following this strategy, David H. Sachs and his colleagues at Massachusetts General Hospital injected bone marrow cells from donor pigs (along with substances to stimulate proliferation of the cells) into baboons. These animals had undergone a course of radiation to deplete their immune systems temporarily and prevent rejection of the pig bone marrow cells. The researchers also filtered from the blood of the baboons those antibodies directed against pig tissues and administered a brief course of immunosuppressive drugs. Although the baboons' immune systems eventually killed most of the transplanted cells, some pig DNA survived in one of the baboons for almost a year. What is more, an important component of this chimeric baboon's immune system—the aggressive killer *T* cells—no longer reacted to the pig cells as foreign.

Such research may yield ways to prevent immune rejection of organs transplanted from animals, but truly effective measures are probably still some years away. Another scheme for evading rejection is, however, already undergoing clinical trials: immunoisolation. Following this approach, physicians physically sequester transplanted tissue within a membrane that allows small

HYPERACUTE REJECTION of a pig organ transplanted into a patient would very likely occur in minutes. It ensues after antibodies bind to the linear sugar chains lining pig blood vessels (*left*). But tissues from pigs genetically engineered to carry the angular sugar groups found in people with type O blood should not elicit such reactions (*right*).



Episodes in the History of Xenotransplantation

1682

DAN ERICKSON

ANIMAL TISSUES were transplanted into a person for the first time when a doctor repaired the skull of an injured Russian nobleman using a piece of skull from a dog. The surgery was said to have been successful, but the Russian Church threatened the nobleman with excommunication, prompting him to have the graft removed.

Late 1800s

FROG SKIN was often grafted onto patients' skin in an attempt to heal burns or skin ulcers. One British army surgeon claimed to have performed hundreds of these procedures with good results.

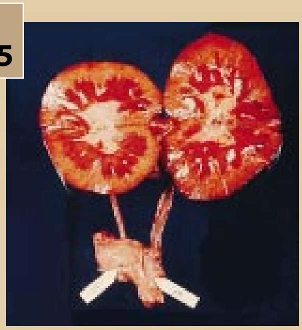
LAURIE CAMPBELL *Tony Stone Images*

1920

CORBIS-BETTMANN

SERGE VORONOFF, an émigré doctor in Paris, began transplanting tissues from the testicles of monkeys into elderly men. He claimed that these sexual rejuvenation treatments instilled new vigor, but experts were skeptical.

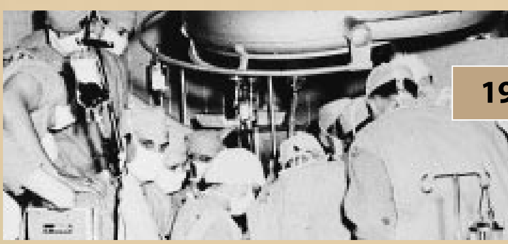
1963 to 1965



COURTESY OF KEITH REEMTSMA

CHIMPANZEE KIDNEYS were transplanted into 13 patients by Keith Reemtsma, a professor of surgery at Tulane University in Louisiana. One of his patients survived for a full nine months after the operation (even returning to her job as a schoolteacher) before succumbing to a severe electrolyte imbalance. Remarkably, the animal kidneys she had received (*photograph*) showed no signs of rejection on inspection at autopsy.

1964



COURTESY OF JAMES D. HARDY

FIRST CARDIAC TRANSPLANT attempted to put a chimpanzee heart into a human. The pioneering effort, conducted by James D. Hardy at the University of Mississippi, failed within two hours because the heart proved too small to support the patient's circulation.

1977

CHRISTIAAN BARNARD (*right*), well known for performing the first successful human heart transplant a decade earlier, tried to use baboon and chimpanzee hearts as temporary backup pumps in two patients with hearts that did not function properly after cardiac surgery. But the animal organs, being too small and subject to rejection, failed to help the patients survive.

WIDE WORLD PHOTOS

1984

LOMA LINDA UNIVERSITY MEDICAL CENTER

BABY FAE, born prematurely with a malformed heart, received a heart from a baboon. Despite the use of the new immunosuppressive drug cyclosporine, the infant lived only 20 more days.

1992

LIVER TRANSPLANTS from baboons to humans, conducted at the University of Pittsburgh, proved a mixed success. One patient survived for more than two months with the animal liver. But the massive immunosuppression necessary to avoid rejection eventually brought on fatal infection.

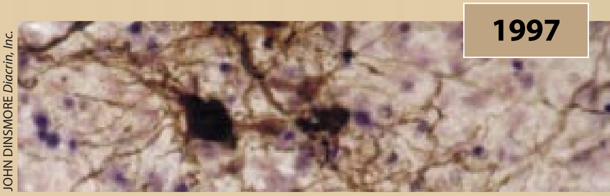
UNIVERSITY OF PITTSBURGH

1995

MARK RICHARDS *Contact Press Images*

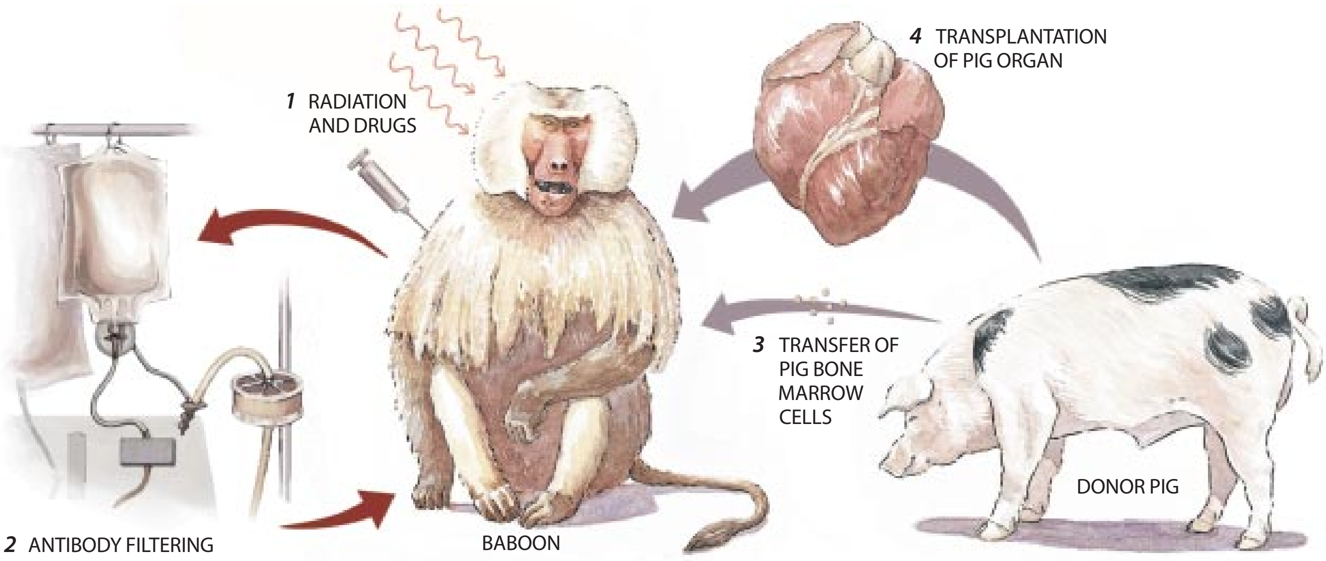
JEFF GETTY received immune cells from a baboon in an attempt to combat his severe AIDS. Although the baboon cells died quickly, his condition mysteriously appeared to improve.

1997



JOHN DINSMORE *Diacrin, Inc.*

CLINICAL TRIAL using pig fetal nerve cells in patients with Parkinson's disease indicated some success. The injected pig cells survived in the brain of at least one person for more than seven months.



RICHARD JONES (*pig, baboon, heart*); JENNIFER C. CHRISTIANSEN

PREVENTING DELAYED REJECTION of cross-species organ transplants might be possible by altering the recipient's immune system so that it includes components from the donor. To test this strategy in animals, a baboon slated to receive bone marrow cells (the source of all immune cells) from a pig was first given radiation and drugs (*1*) to prevent immune rejection of the transplanted cells. The baboon's blood was also filtered (*2*) to remove antibody molecules that would react with pig cells. Finally, the baboon received the bone marrow cells from the donor pig (*3*). Afterward, killer *T* cells isolated from the baboon's immune system did not attack cells from the donor pig. If other components of the recipient's immune system could be equally tamed, organs transplanted from a donor pig (*4*) should be able to survive indefinitely in the new host.

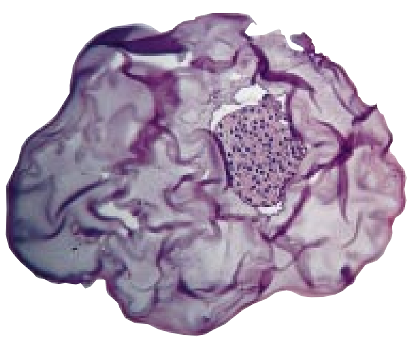
molecules (such as nutrients, oxygen and certain therapeutic agents) to cross it while blocking large molecules (such as antibodies) and white blood cells from reaching the graft. This tactic is feasible only for protecting isolated cells or small packages of tissues, not for whole organs. So it does not address the needs of someone who requires, for example, a new heart or kidney. It should nonetheless be valuable for treating many disorders. And it offers some practical advantages: physicians can manipulate cells or small masses of tissue comparatively easily and can maintain them outside the body for longer periods than are possible when working with intact organs.

Recent attempts at using encapsulated cells from animals to treat liver failure, chronic pain and amyotrophic lateral sclerosis (Lou Gehrig's disease) have all shown promise in clinical trials. Medical researchers may soon try to implant immunoisolated cells from animals to provide the blood-clotting factors hemophiliacs need or to produce nerve growth factors that might help reverse certain neurodegenerative disorders.

Some investigators are especially eager to treat diabetes with isolated pig islet cells. Although one of us (Chick) pioneered the use of "perfused" devices (large sheathed implants connected to a supply of blood) for this purpose, it is easy to see some disadvantages to that particular technique. Most important, the patient requires major surgery, and the device is apt to become clotted. Engineering hollow plastic fibers or chambers unconnected to the bloodstream to isolate cells from the recipient's immune system also has drawbacks: although the surgery needed would be less traumatic than for a perfused device, it is unclear how well a patient could tolerate the plastic materials or having the implant replaced many times—a likely requirement of long-term therapy.

In an effort to overcome these difficulties, two of us (Lanza and Chick), along with colleagues at BioHybrid Technologies, have developed ways to encase cells in small, biodegradable capsules that can be injected under the skin or placed in the abdominal cavity with a syringe. Less than a gram of encapsulated islets from pigs should supply a diabetic patient with normal amounts of insulin. Although a vast number of cells are involved, the total volume required for these implants would be only a few dozen cubic centimeters.

In recent tests, encapsulated islet cells from cows remained alive in dogs for six weeks (the point at which the experiment ended). These results, and others from studies of mice, rats and rabbits, indicate that encapsulated pig islets would most likely survive in patients for anywhere from several months to more than a year. Eventually the tiny packages would degrade, so no surgery would be needed to remove the old capsules when the supply of islet cells needed to be replenished. Clinical trials of this technique should begin within a year.



COURTESY OF ROBERT P. LANZA

ENCAPSULATED ISLET CELLS from the pancreas of a pig may eventually serve to produce insulin in patients afflicted with diabetes. The biodegradable polymer membrane surrounding the islets allows insulin out but protects the islets from attack by immune components.

Troublemaking Hitchhikers

The growing sense that xenotransplantation may be near at hand raises some critical concerns. In particular, many experts worry that animal donors might harbor diseases that, like the

Ebola virus or "mad cow" disease, can harm people. After infecting a transplant patient, such pathogens might spread into the general population and spark an epidemic. Indeed, scientists now believe HIV (the human immunodeficiency virus, which causes AIDS) originated in monkeys and somehow jumped the species barrier to infect humans.

Thus, widespread transplantation of tissues from monkeys or baboons could conceivably put the general health at risk. Fortunately, the threat of such a catastrophe is markedly less with pigs as donors. People have lived in close association with pigs for thousands of years, and yet, except for the possibility of some flu strains, few serious diseases of swine origin appear ever to have arisen in humans.

Pigs could be especially good donors for other reasons as well. They are relatively easy to raise and have organs that are comparable in size and physiology to human organs. Breeds of pigs already exist that are free from certain known pathogens. And, unlike the case with primates, few voice ethical concerns about killing an animal that people routinely slaughter for food.

Still, many questions need to be solved before the transplantation of pig tissues into ailing patients becomes a reality. In addition to the challenge of immune rejection, scientists must also make sure that transplanted pig organs perform properly in their new hosts. Pig hearts and kidneys have functioned adequately in some primates for several weeks, and it seems likely that such organs would work in humans as well. But a pig liver would probably not be able to carry out the myriad functions of a human liver, although the pig organ may be able to sustain life for a short period of time, allowing, for example, the patient's own liver to recover from a temporary shutdown.

It may take many years before physicians can routinely outwit evolution—as some have labeled the goal of xenotransplantation—and replace any failing organ with an animal substitute. But the transplantation of isolated cells and tissues appears poised on the threshold of modern medical practice. And we are optimistic that soon there will be some true successes to report. SA

Dealing with Viral Stowaways

The observation that pigs have passed only a few pathogens to humans despite centuries of close contact assures many people that transplanting organs from these animals would not give rise to any new and dangerous diseases. Still, there are reasons to be cautious.

Certain retroviruses—viruses that incorporate their genetic blueprint directly into the host's DNA—pose a possible threat. Pigs, as well as all other mammals, contain within their genetic stores so-called proviruses—sequences of genetic code that can potentially direct the production of infectious viral particles. (As much as 1 percent of the DNA people carry is made of such viral genes.) These sequences owe their presence in modern animals to past episodes of retroviral infection in their ancestors, when the viruses inserted their genetic code into sperm or egg cells. The offspring of the infected animals retained these viral genes, which were then passed from generation to generation. Over time, most of these vestigial viruses have evolved into forms harmless to their hosts. Yet some remain capable of activity that can cause disease in other species.

So scientists naturally worry about what the proviruses of pigs would do when conveyed into a patient along with tissues transplanted from these animals. Not only does this transfer offer the resulting virus direct access to human cells, it may also present it with a uniquely susceptible victim—one having, for the sake of preserving the transplanted organ, a compromised immune system. Under these circumstances, pig proviruses might be able to give rise to active retroviruses, perhaps causing illness. It is also conceivable that these pig retroviruses could mutate in human hosts or combine with human retroviruses to produce a completely new pathogen. The result might be quite dangerous: unlike the viruses that bring on a short-lived swine flu, certain retroviruses are potentially cancer-causing and produce lifelong infection.

Molecular biologists are working hard to identify troublesome proviruses lurking within pig DNA and eliminate them from breeding herds. The genetic manipulations involved may yet require significant effort, but the results of this work should help quell any remaining fears that xenotransplantation could cause new human diseases. —*R.P.L., D.K.C.C. and W.L.C.*

The Authors

ROBERT P. LANZA, DAVID K. C. COOPER and WILLIAM L. CHICK share a long-standing interest in the transplantation of animal cells and organs. Lanza, who earned his M.D. in 1983 from the University of Pennsylvania, is director of transplantation biology at BioHybrid Technologies in Shrewsbury, Mass. As a student, he studied with heart transplant poineer Christiaan Barnard and Nobel laureate immunologists Gerald Edelman and Rodney Porter. Cooper holds M.D. and Ph.D. degrees from the University of London and is currently an immunologist at Harvard Medical School and Massachusetts General Hospital. He previously worked as a cardiothoracic transplant surgeon and director of research and education at the Oklahoma Transplantation Institute. Chick received his M.D. degree from New York University in 1963. He was formerly a professor of biochemistry and medicine at the University of Massachusetts Medical School, where he served as director of the Diabetes-Endocrinology Research Center. He now serves as the president of BioHybrid Technologies.

Further Reading

BARRIERS TO XENOTRANSPLANTATION. F. H. Bach, S. C. Robson, H. Winkler, C. Ferran, K. M. Stuhlmeier, C. J. Wrighton and W. W. Hancock in *Nature Medicine,* Vol. 1, No. 9, pages 869–873; September 1995.

XENOTRANSPLANTATION AND XENOGENEIC INFECTIONS. L. E. Chapman, T. M. Folks, D. R. Salomon, A. P. Patterson, T. E. Eggerman and P. D. Noguchi in *New England Journal of Medicine,* Vol. 333, No. 22, pages 1498–1501; November 30, 1995.

YEARBOOK OF CELL AND TISSUE TRANSPLANTATION 1996/1997. Edited by Robert P. Lanza and William L. Chick. Kluwer Academic Publishers, 1996.

XENOTRANSPLANTATION: THE TRANSPLANTATION OF ORGANS AND TISSUES BETWEEN SPECIES. Second edition. Edited by D.K.C. Cooper, E. Kemp, J. L. Platt and D.J.G. White. Springer-Verlag, 1997.

Strong Fabrics for Fast Sails

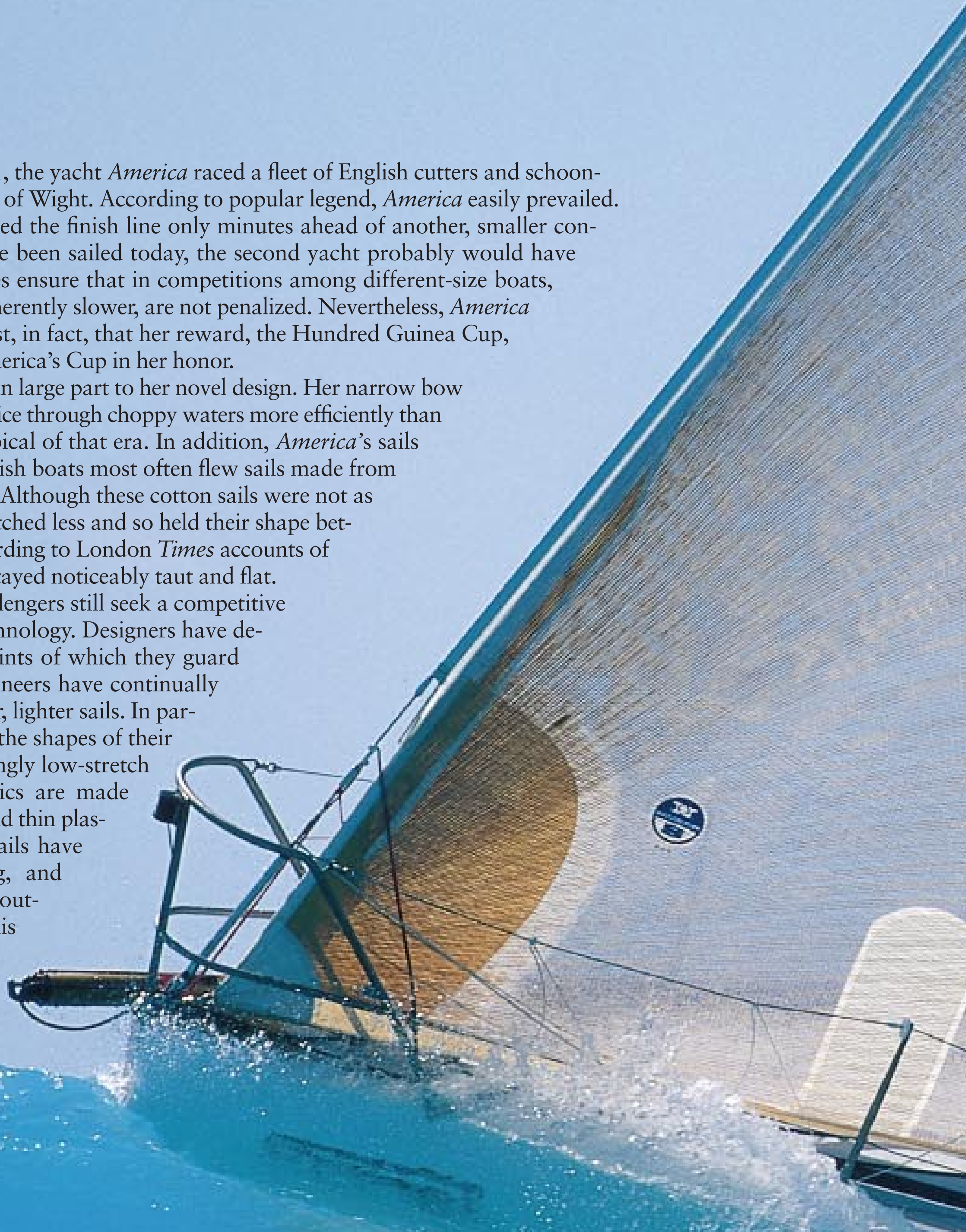
Composite fabrics first developed for the sails of racing yachts may soon find use in parachutes and research balloons

by Brian E. Doyle

On August 22, 1851, the yacht *America* raced a fleet of English cutters and schooners around the Isle of Wight. According to popular legend, *America* easily prevailed. In truth, she crossed the finish line only minutes ahead of another, smaller contender, *Aurora*. Had the race been sailed today, the second yacht probably would have won. Modern handicap rules ensure that in competitions among different-size boats, smaller vessels, which are inherently slower, are not penalized. Nevertheless, *America* was impressively fast—so fast, in fact, that her reward, the Hundred Guinea Cup, came to be known as the America's Cup in her honor.

America owed her victory in large part to her novel design. Her narrow bow and slender hull helped her slice through choppy waters more efficiently than the rounder British ships typical of that era. In addition, *America*'s sails were unusual. Whereas English boats most often flew sails made from flax, *America*'s were cotton. Although these cotton sails were not as strong as flax ones, they stretched less and so held their shape better in the wind. Indeed, according to London *Times* accounts of the regatta, *America*'s sails stayed noticeably taut and flat.

Today America's Cup challengers still seek a competitive edge through innovative technology. Designers have developed faster hulls—blueprints of which they guard with great secrecy. And engineers have continually found ways to make stronger, lighter sails. In particular, they have fine-tuned the shapes of their designs and devised increasingly low-stretch sailcloths. The newest fabrics are made from layers of tough fibers and thin plastic films. These laminated sails have revolutionized yacht racing, and some are now finding uses outside the sailing world. In this



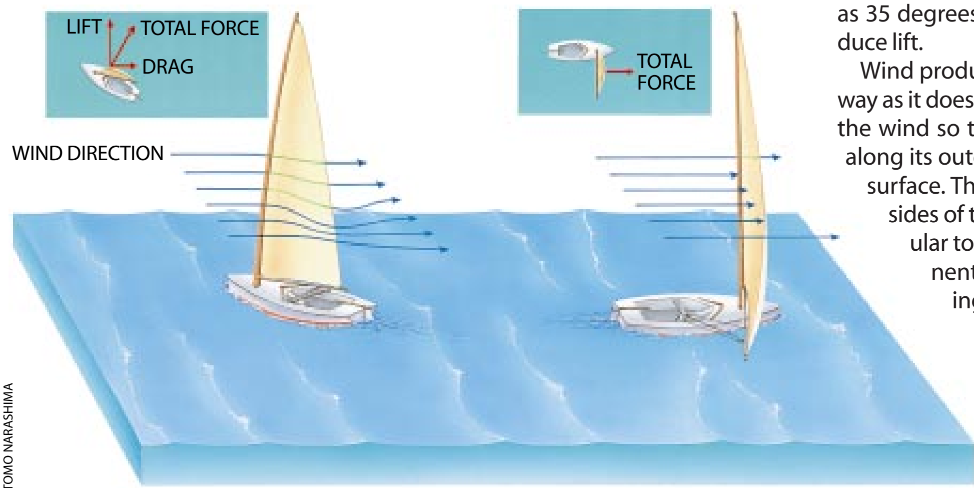
SHARON GREEN

LAMINATED SAILS—made from layers of thin plastic films and tough fibers, such as Kevlar—weigh less and stretch less than traditional cloth sails do. Both features permit yachts to travel at higher speeds: the overall weight of the boat is reduced, and the sail holds its aerodynamic shape better. The so-called three-dimensional laminate, or 3DL, sail shown here bears reinforcing fibers that exactly anticipate the forces acting on the sail when it is in use. As a result, the sail is as light as possible and as strong as needed at every point.


3A

How Sails Work

It is easy to understand how a sailboat moves away from the wind. The available breeze blows into the sail, and this force pushes the boat forward. To produce the most power in this way, sailors set their sails perpendicular to the wind (*drawings at right*). So, too, they adjust the sail shape so that it is as round as possible—for generating maximum drag.



TOMO NARASHIMA

Traveling upwind, though, is a bit more complicated. Left to their own devices, many boats will head into the wind and stay there. In strong winds, they may even become stuck, a condition described as "in irons." A boat cannot move into the wind, because the sails cannot fill. (Pushing them out to either side serves only to drive the boat backward, which is not very useful unless you are in irons and out of options.) But a boat can make passage as close as 35 degrees to the wind if the sails are set to produce lift.

Wind produces lift around a sail much in the same way as it does around a wing. Essentially, the sail turns the wind so that the local static pressure decreases along its outer surface and increases along its inner surface. The pressure difference between the two sides of the sail generates a lift force, perpendicular to the wind (*drawings at left*). The component of this force that keeps the boat moving forward is called thrust.

The wind also creates a drag force on the sail. Drag and lift combined provide the total aerodynamic force acting on the sail. This strong sideways force is counterbalanced by an opposite hydrodynamic force

regard, the brainchild of two Swiss entrepreneurs has gained special attention.

Seven years ago Luc DuBois, a geologist, and Jean-Pierre Baudet, a sail maker, invented a clever manufacturing system for molding laminate sails in one piece. Because the process involves no cutting, the resulting sails are essentially seamless and so less susceptible to stretching. The outer plastic layers of the sail are taped together (these materials come in rolls only about one and a half meters wide) to form a membrane large enough for the mold. And between them, the sailcloth fibers run continuously from one corner to another. These fibers provide the structure's backbone: they are laid in a pattern that exactly anticipates the forces of the wind. As a result, the sails maintain the optimal three-dimensional shape during use. When such three-dimensional laminate (3DL) sails first appeared, they outdid all other sails available. Now aeronautical engineers are exploring the possibility of using these flexible composite membranes for other purposes.

Faster Foils

It is a common misconception that sails stretch into shape. In fact, sail makers depend on the fabric stretching as little as possible. Only by making this assumption can they design sails that will form a specific airfoil when filled with wind: sails must curve and twist in just the right way for air to flow around them and create optimum lift, just as it does with an airplane wing. (To review how sails work, see the box above.)

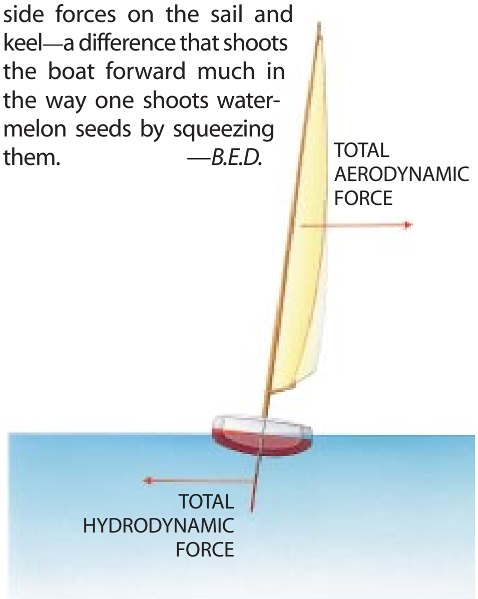
Depending on the circumstances, different sail shapes prove most effective. For moving upwind, flat sails are needed; for sailing away from the wind, fuller sails offer the most power. Similarly, flatter sails provide greater speed in heavy winds, whereas larger, fuller sails perform better in light air. To satisfy these requirements, sail makers create individual sails for a prescribed range of conditions and uses.

For centuries, craftsmen have stitched carefully cut pieces of cloth, called panels, into sails of varying shapes and sizes. Sail makers impart dimension to their creations through techniques known as broad seaming and luff curve. Both involve cutting sail panels with a slight curvature so that when they are either joined to each other or attached to the mast and supporting steel wires (the "rig"), they give depth to the sail.

Among the most important dimensions sail makers consider is a sail's overall amount of curvature, or camber [*see box on page 65*]. In addition, engineers specify just where on the sail its greatest depth, or draft, should be placed. They must also afford the sail a certain amount of twist. Wind typically gains speed and shifts direction with increasing height above the water. So to ensure that the wind hits the sail at a constant angle from top to bottom, some twist is essential.

The central problem designers face in figuring these parameters is that the shape of a sail determines how air flows over it. At the same time, the flow of air itself controls the sail's final shape. Most other types of airfoils have an internal structure that keeps their shape more or less constant. Sails, however, rely only on their physical cut and external forces—

TOMO NARASHIMA (*drawing*) DAN WAGNER (*photograph*) acting on the boat's keel (*drawing below*). The thrust and drag forces on a boat sailing into the wind are small in comparison to the side forces on the sail and keel—a difference that shoots the boat forward much in the way one shoots watermelon seeds by squeezing them. —*B.E.D.*



the wind and the boat's rigging—to give them form. Sail designers have long had to grapple with this challenge of engineering. But the availability of inexpensive workstation-level computing has made the problem considerably easier. Computer programs can predict a sail's shape, given its makeup and some guess as to the distribution of air pressure over it. Next, the computer recalculates the pressure distribution and revises the shape. The calculation and recalculation of pressure and shape continue until a final solution to the problem emerges.

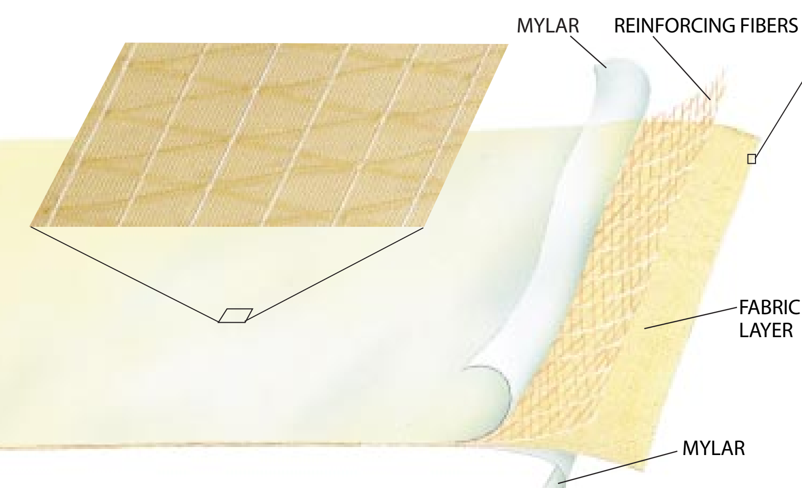
Using computers, designers can also plan how to construct a sail of the desired dimensions using a so-called virtual mold. This computational device helps them determine the proper shape and configuration of the many individual panels of sailcloth. The specialized software also allows them to figure automatically the curvature of the numerous seams between panels. Advanced sail makers with integrated manufacturing systems feed this information directly into computer-driven cutting machines, speeding the process of sail making enormously and improving design accuracy.

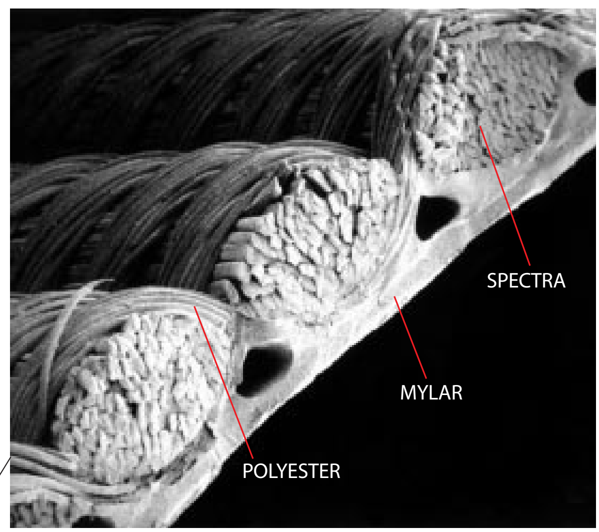
Lighter Fabrics

After deciding how a sail is to be pieced together, a designer must next choose the type of cloth. That decision is determined in part by the desire to limit the weight of the sail, a critical factor governing its overall performance. For instance, burdened by their own weight, some sails lose their shape in light wind. And heavy sails add to a boat's "heeling moment"; to keep the vessel from toppling over, the weight of the sails and mast must be balanced with a lead mass slung below the hull. So lighter sails make it possible to build lighter (and consequently faster) boats. In rough seas, heavier sails also contribute to a boat's "polar moment of inertia," giving rise to a force that drives the bow down into the waves and slows forward progress. Even the sails stored belowdecks can add significant weight to a boat. And crews can handle lighter sails faster and more efficiently without mishap. Despite these many reasons to shed weight, sails cannot be made too light without bringing on a tendency to stretch or break.

Thus, there has been a long-standing search for materials that are at once strong and light. Sail makers used cotton and flax fabrics from long before the time of *America*'s victory in 1851 until shortly after World War II. Then, during the 1950s, they abandoned natural fibers for newly developed synthetic ones, such as polyester and nylon. When durability and low cost are the most important considerations, mainsails and jibs (the smaller sails arrayed ahead of the mast) are still made from tightly wo-

	RELATIVE STRENGTH	RELATIVE MODULUS	GENERIC NAME
POLYESTER	1.0	1.0	
VECTRAN	2.9	6.0	LIQUID CRYSTAL POLYMER
KEVLAR	3.1	9.0	ARAMID
SPECTRA	4.5	11.8	HIGH-MOLECULAR-WEIGHT POLYETHYLENE
CARBON	2.8	15.0	
PBO	5.3	22.0	





COURTESY OF BRIAN E. DOYLE

MODERN SAILCLOTH contains various layers of plastic films, fibers and fabrics (*photograph at left*). Typically layers of oriented polyester, called Mylar, sandwich a fabric layer and a fiber scrim (*drawing at left*). The fabric is specially woven so that yarns running in the warp, or long, direction are perfectly straight on a microscopic scale (*micrograph above*). The main reinforcement fibers are made from high-strength materials such as Kevlar, Spectra or carbon. In making sails from composite cloths, engineers align the panels so that the warp yarns and fibers feel the brunt of the forces on the sail. The secondary fibers, called a gatorback, crisscross over the primary ones; they protect against damage caused by random loads, which occur when the sail flaps during maneuvering.

ven polyester fabrics. Spinnakers, too—the often colorful, parachutelike sails used for sailing downwind—are frequently sewn from lightweight nylon or polyester weaves.

Most modern racing sails, however, are constructed from flexible laminates—which are even lighter still. These laminates contain several layers of fabrics, reinforcing fibers such as Kevlar (the material used in bulletproof vests) and Mylar, a polyester film. (Mylar and Kevlar are registered DuPont trademarks.) Using special techniques, manufacturers weave the fabrics so that the principal threads lie absolutely straight—even on a microscopic scale. Strong reinforcing fibers give the sail further tensile strength, and the Mylar film provides a continuous substrate for bonding and resists shear loading. By carefully choosing the constitution of each layer, sail makers can prescribe the mechanical properties of the resulting composite. The resistance of the fabric to stretching is especially crucial, as is its breaking strength. Also, yield strength, or the load beyond which the material is permanently elongated, is relevant, because even if they do not break, sails can be ruined by deformation.

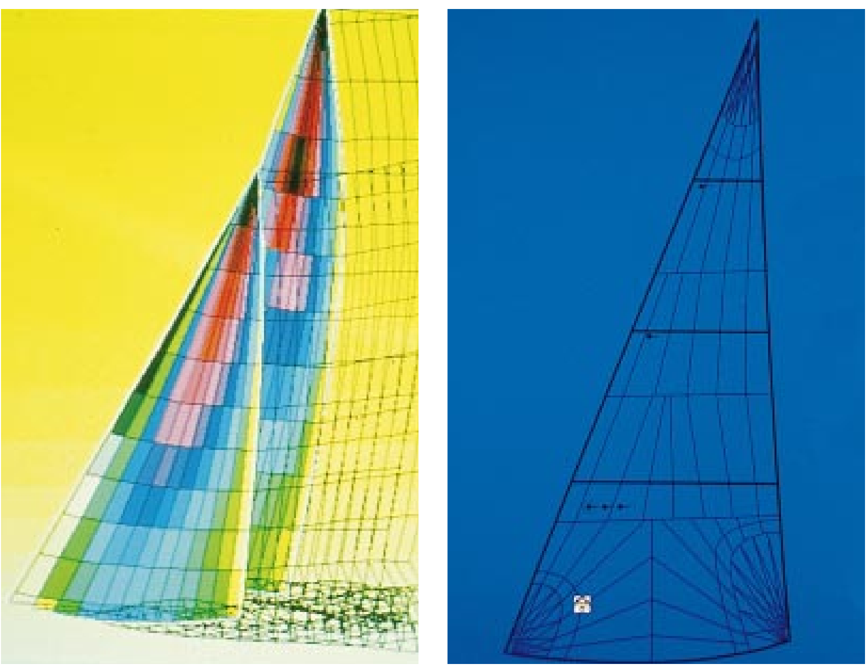
Over the years, designers have used different types of fibers with varying degrees of success. Polyester reinforcements first appeared in the 1970s. Attempts soon after employed Kevlar, which was just then becoming available. These efforts initially flopped because sail makers and sailcloth manufacturers were not accustomed to working with such strong but fundamentally brittle fibers. The weaves they created turned out to be self-abrasive: tension placed on the fabric in one direction tended to crush the fibers that ran in the other. Some early Kevlar-reinforced sails posed problems of a different kind: they were so strong that they could literally break apart a boat's rigging.

Throughout the 1970s and 1980s, designers continued to experiment with Kevlar. To avoid abrasion in all-Kevlar weaves, they turned to other types of reinforcing fibers or special coatings and adhesives. And to compensate for the material's immense strength, sail makers found better ways to distribute the stresses placed on their sails. Boat builders learned, too, to fortify those parts attached to the sail so that they could withstand the higher loads. Eventually, useful Kevlar-reinforced sails emerged. By 1980, for example, the America's Cup was won by a boat with a mainsail made of Kevlar-strengthened laminate. And in 1983 when the U.S. first lost the Cup, the winner, from Australia, used Kevlar laminates for all its mainsails and jibs.

But Kevlar reinforcements were not yet perfected. In 1987 high winds and large waves swept the America's Cup racecourse in Freemantle, Australia. Most designers had expected Kevlar-reinforced laminate sails to work well under these conditions, but instead the $30,000 sails were lasting only a matter of hours. At first, no one could make sense of these failures. After all, the materials making up the sails had sufficiently high yield strengths to sustain the predicted wind loads. Later it became clear that random loads, which no one had considered, were to blame: when the wind filled the sails, they held up fine, but when they fluttered and shook during maneuvering, the wind severely damaged them. To remedy this situation, sailcloth designers now add to composite sails a second layer of reinforcement formed of fibers running across the primary load-bearing direction.

Kevlar remains the most popular fiber for use in racing sails, but many others have found acceptance in niche markets. Spectra fiber, made by Allied Signal Corporation, is a polyethylene material that appeared in the mid-1980s; it is not as brittle as other high-performance materials and so generally lasts longer. Over time, though, it can gradually elongate under load, a tendency that requires heavier fabrics to forestall. For these reasons, Spectra is found more often than not in cruising sails, which sacrifice weight and speed for durability.

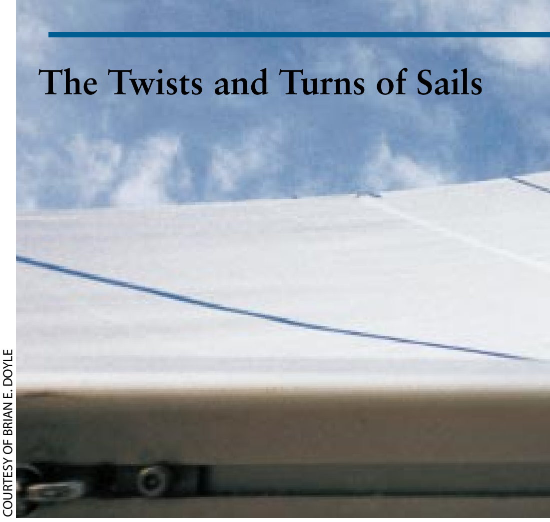
Vectran, a liquid crystal polymer introduced by Hoechst Celanese in the past few years, was initially too expen-



COURTESY OF BRIAN E. DOYLE

COMPUTER-AIDED DESIGN has revolutionized sail making. Some programs calculate an approximate distribution of the air pressure on a sail in use, based on the sail's shape and makeup (*left*). Warmer colors correspond to higher pressures. Taking account of these forces, the software then revises the sail's shape and begins its calculations all over again. Eventually these calculations converge to a single solution. With these answers, computers can further help sail designers determine the cut and alignment of individual panels of fabric, how to put the panels together and how to reinforce them to create the desired airfoil (*right*).

The Twists and Turns of Sails



COURTESY OF BRIAN E. DOYLE

sive for all but the most specialized racing events, but the price has gradually come down, making it more attractive to buyers. Carbon fiber first found use in sailcloth laminates in preparation for the 1992 America's Cup. Carbon weighs only about 60 percent as much as Kevlar for the same strength, but it is exceedingly brittle and difficult to incorporate into sailcloth. In their earliest incarnations, carbon-reinforced sails dusted the boat's deck with a rather disagreeable black soot when they began to wear out. And today carbon's high cost and fragility continue to limit its use to only the most competitive (and well-funded) sailing programs.

Stronger Structures

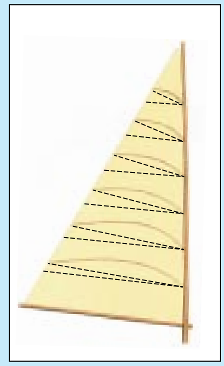
Throughout the 1980s and into the 1990s, laminate sailcloths improved steadily. But sail-making techniques lagged behind. To produce finished sails, manufacturers continued to cut and stitch, or bond, the new fiber-reinforced composite laminates—thereby compromising their potentially great strength with many weak joints. So even as the mechanical performance of the cloth itself improved it became ever more difficult to make seams that would not slip or break. DuBois and Baudet invented their novel 3DL manufacturing technique as a means to maneuver around these very pitfalls. The basic idea was simple: by shaping the sail and forming the composite film on preshaped molds, it would be possible to eliminate seams altogether.

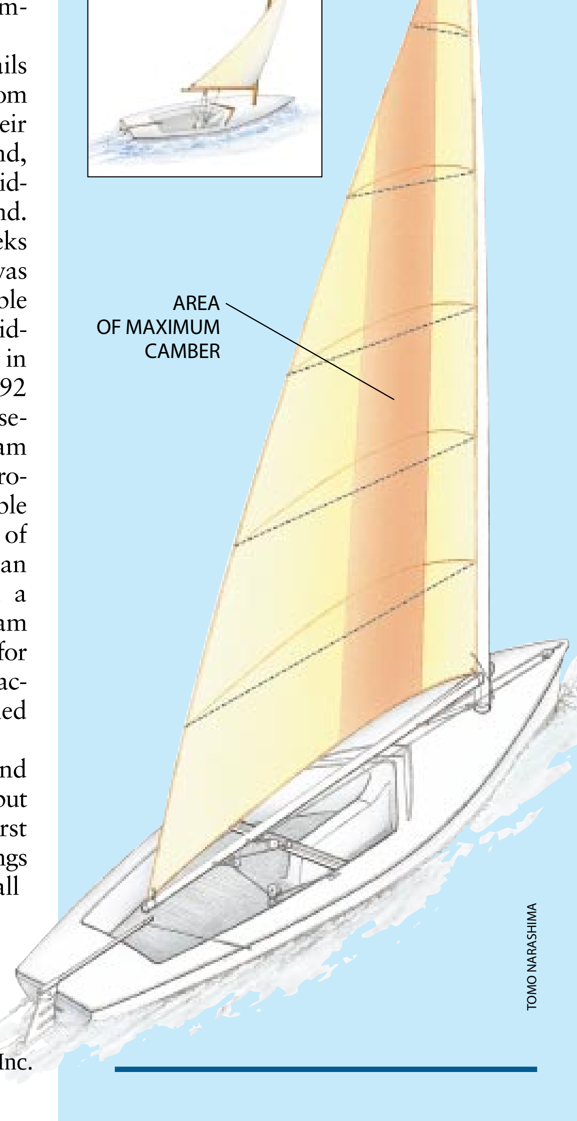
In 1990 the duo presented the concept to North Sails, for whom I worked as a consultant. At this first meeting, it was clear to me that the plan faced many unsolved problems. Because yacht sails are nearly always custom-made, the molds—some of which would have to be enormous—would need to shift shapes quickly and easily. Also, the edges of sails are fixed locations; they must match up with certain attachment points on the rig. Thus, for the depth of the mold to be adjustable, its surface would have to vary in length between these fixed points. In addition, the robotic device used to apply the fibers onto the mold would have to "know" the shape of the mold to avoid collisions with it. Finally, DuBois and Baudet would have to develop adhesive and laminating systems compatible with the rest of the process.

Despite these difficulties, North Sails offered DuBois and Baudet a small room and some funds to demonstrate their idea. They built a plywood mold and, suspended from the ceiling in hang gliding harnesses, put down yarns by hand. Their first sail took almost three weeks to finish. It was worth it. The result was extremely light but far more durable than it looked. Thus, North Sails decided to build the first full-scale facility in hopes of making sails for the 1992 America's Cup. DuBois and Baudet secretly went to work with a small team of engineers and technicians on the prototype factory. For making the flexible mold, the team needed thousands of small motors. But the cost of such an order presented a dilemma. So in a show of great resourcefulness, the team bought up and raided other products for the parts. In the end, the completed factory contained two molds, straddled overhead by a robotic gantry.

Several of us had given advice and watched the project unfold on paper, but we were still surprised when we first visited the plant. Granted, its beginnings were rocky. It was difficult to make all the parts in the process work at once. For example, we repeatedly needed to coordinate the computers that fed information to

How a sail twists and turns helps to define its three-dimensional shape. One vital parameter is curvature, or camber. Sail makers often take photographs looking from the bottom of a sail up to see camber more clearly (*left*). The position of maximum camber—or the part of the sail having the greatest depth—partially governs how much power the sail can produce (*bottom drawing*). Another crucial measure of any individual sail is its built-in twist (*top two drawings*). Wind typically gains speed and shifts directions with increasing height above the water. Twist ensures that the wind hits the sail at a constant angle. —*B.E.D.*





TOMO NARASHIMA

3DL MANUFACTURING (*right*) is more complex than the old cut-and-sew method (*below*). Designers first specify the shape of a sail using computer software. The machine then conveys these parameters to tiny motors under the surface of a giant mold. The motors push the mold into the target shape, and Mylar is laid down. Workers suspended from hang-gliding harnesses check the plastic for defects, such as tears or wrinkles. A gantry then applies the reinforcing fibers in a preestablished pattern that anticipates the loading on the sail. Next, another Mylar layer is added on top, and a vacuum is drawn between the films. Finally, heat activates an adhesive between the films, thereby sealing the laminate.

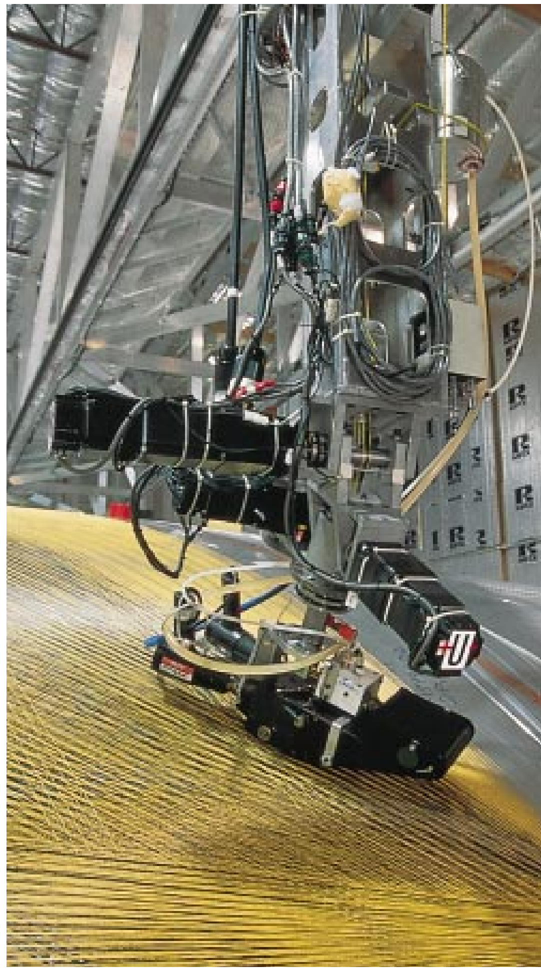
the molds and the gantry. Even when the yarns were laid correctly, the lamination would often fail—ruining an entire sail. The lamination system involved pulling a vacuum between the films to force them together and press out any air bubbles. But pinholes in the Mylar were a constant problem, preventing the vacuum from forming. Eventually, practical sails were produced, but it was too late for the 1992 America's Cup. *Stars and Stripes,* driven by Dennis Connor, tested only one 3DL sail when she raced that year.

Other Uses

Once the prototype plant was in production, Terry Kohler, owner of North Sails, wanted to consolidate the lessons learned and build a new, more efficient facility. This second factory, located in Minden, Nev., has now been making sails for nearly two years. Today operations at Minden run smoothly. To construct a sail, the designer first establishes with the aid of a computer and specialized software the desired shape for the finished product. The computer controls the movement of the motors that adjust the surface of a huge mold—ranging in size from 50 to 150 square feet (4.7 to 14 meters squared)—so that it takes the desired form. Mylar backing is then placed over the mold, in such a way as to conform to the target shape.

Next, a giant gantry lays the reinforcing fibers along a previously established pattern. They are coated with an adhesive as they pay out so that they stay in place. The fibers follow curved trajectories that reflect the distribution of loads anticipated for the sail. Sails can be made in this way using any combination of fibers. Once they are affixed, two additional layers of Mylar are laid down. A vacuum is drawn between the films, and atmospheric pressure pushes them together. Heat activates an adhesive applied to the inner faces of the first and second films. The third film, used only to seal the laminate, is discarded. The first two layers of Mylar then become the two outer surfaces of the finished sail.

3DL sails are not only lighter than those made in the old cut-and-sew method, but they maintain their shape more tenaciously and over a wider range of conditions. So it is not surprising that 3DL sails now dominate many racing events. The advantages of 3DL sails stem in large part from the arrangement of the reinforcing fibers, which follow continuous curves from corner to corner. The density of the fibers varies smoothly throughout the sail to accommodate different amounts of stress, providing the highest strength for the lowest possible weight at every point.



PHOTOGRAPHS COURTESY OF NORTH SAILS

In January 1996, during a conference of the American Institute of Aeronautics and Astronautics, I met several engineers from the National Aeronautics and Space Administration who were working on high-altitude helium balloons. They use these balloons to lift scientific instruments to heights of as much as 150,000 feet (45,720 meters) and plan to conduct such missions for as long as 100 days. Knowing their interest in high-strength fabrics, I invited them to tour the 3DL facility in Minden so they could decide whether sail-making technology might be used to improve the performance of their lighter-than-air craft. Another group working under a NASA contract wants to use 3DL manufacturing techniques to develop ultralight parachute systems. According to their predictions, seamless chutes would weigh a third as much as current nylon canopies. Some scientists have even discussed using 3DL for making the inflatable antennas sent into space.

In the near future, designers have many goals closer to home. For instance, now that seams have been eliminated, there is another obvious way to improve the sail's basic durability: designers hope to make flexible laminated sails equipped with their own built-in hardware. (As things stand, makers stitch and bond elaborate patches to the corners of sails for connecting lines and attaching them to the rig. But these tactics naturally add weight to the sail's structure.) Engineers intend to make 3DL cruising sails that last longer by using new films that better resist exposure to damaging ultraviolet radiation. Manufacturers plan to introduce less exotic, more affordable racing sails for a variety of boats. And 3DL designers are working on stronger, more durable structures woven from hybrid blends of two or more different fibers. Such improvements should help lower the cost of flexible composite fabric sails and bring them into the reach of a broad range of boating enthusiasts. SA

The Author

BRIAN P. DOYLE, a consultant for North Sails, has designed sailcloth for more than 17 years and holds several patents. He is currently developing new working sails for the USS *Constitution,* the world's oldest commissioned warship. "Old Ironsides," as the frigate is more commonly known, celebrates her 200th anniversary this summer and has not sailed under her own power since 1881. Doyle received a bachelor's degree in mechanical engineering from Cornell University in 1970.

Further Reading

AMERICA'S CUP BOOK. John Rousmaniere. W. W. Norton, 1983.

SAIL PERFORMANCE: TECHNIQUES TO MAXIMIZE SAIL POWER. C. A. Marchaj. International Marine, 1990.

ROYCE'S SAILING ILLUSTRATED: THE BEST OF ALL SAILING WORLDS. Patrick M. Royce. Royce Publications, 1993.

THE SAILMAKER'S APPRENTICE: A GUIDE FOR THE SELF-RELIANT SAILOR. Emiliano Marino. Illustrated by Christine Erikson. International Marine, Camden, Me., 1994.

Asbestos Revisited

Once considered safe enough to use in toothpaste, this unique substance has intrigued people for more than 2,000 years

by James E. Alleman and Brooke T. Mossman

The future for asbestos appears downright grim. After two decades of horrendous headlines, this strange fiber probably represents the most feared contaminant on the earth. It is almost certainly the most expensive pollutant in terms of regulation and removal. This year alone, remediation efforts will cost several billion dollars—a staggering outlay, even for an era of enthusiastic environmental activity. Clearly, chaos has come to the world of asbestos. The magnitude of the crisis, however, clouds a crucial irony: the problem with asbestos would never have grown so bad had we not previously thought the material was so remarkably good.

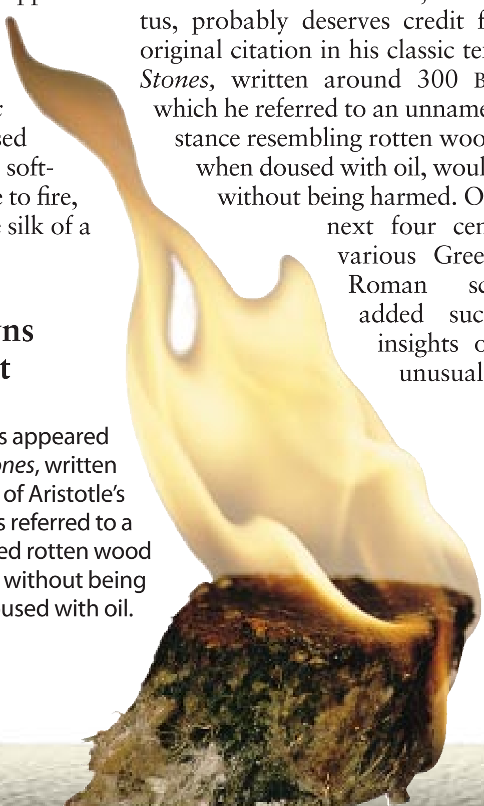
The asbestos label actually applies to a family of silicate minerals, containing silicon and oxygen, that are notable for their fibrous structure [*see box on page 73*]. Seemingly blessed with useful attributes, such as softness, flexibility and resistance to fire, asbestos was once seen as the silk of a magic mineral world. Over the centuries, people have woven asbestos cloaks, tablecloths, theater curtains and flameproof suits for protection against fiery dangers. Asbestos insulation products not only saved energy but also shielded workers from potential burns. Brake shoes and clutch facings improved safety on race cars and school buses; efficient asbestos air filters were used in hospital ventilators, cigarette tips and military gas masks. Indeed, a poignant paradox of the asbestos story stems from its previous image as a guardian of human safety.

The first references to asbestos can be traced to several ancient philosophers. One of Aristotle's students, Theophrastus, probably deserves credit for the original citation in his classic text, *On Stones,* written around 300 B.C., in which he referred to an unnamed substance resembling rotten wood that, when doused with oil, would burn without being harmed. Over the next four centuries, various Greek and Roman scholars added successive insights on this unusual rock and its ever expanding uses. In the first century the geographer Strabo identified the first Greek asbestos quarry on the island of Évvoia, where fibrous stone threads were combed and spun like wool to make an assortment of flame-resistant cloth items.

The Greek physician Dioscorides, in his first-century text *De Materia Medica,* reported that reusable handkerchiefs made of asbestos sold to theater patrons were cleansed and whitened with fire. Dioscorides' work also described an asbestos quarry on Mount Olympus in Cyprus and provided the first mention of the mineral's name: *amiantus,* meaning "undefiled," to reflect its resistance to fire. At least three other authors, including Plutarch, indicated that the eternal flames in the Acropolis were created with asbestos lamp wicks.

The informative account given in Pliny the Elder's first-century manuscript *Natural History* includes one of the most thorough discussions of the stone written in its early history. The mineral's current name can be traced to this text: Pliny referred to *asbestinon,* meaning "unquenchable." According to Pliny, asbestos was used in a number of woven products, from easy-to-clean tablecloths

The Ups and Downs of Asbestos's Past



First mention of asbestos appeared in the Greek text *On Stones,* written by Theophrastus, one of Aristotle's students. Theophrastus referred to a substance that resembled rotten wood and burned (*right*) without being harmed when doused with oil.

Dioscorides' *De Materia Medica,* a first-century medical text, described reusable handkerchiefs made of asbestos that could be cleaned and whitened with fire.

Pliny the Elder referred to the substance *asbestinon* in his book *Natural History*.

DRAWING OF PIPE BY BRYAN CHRISTIE; ASBESTOS SAMPLE COURTESY OF MALCOLM ROSS; JASON GOLTZ (*photograph*) and napkins to shrouds for deceased royalty placed in funeral pyres (the bodies would be incinerated by the heat even though the shrouds did not burn).

Over the next 1,000 years, asbestos continued to attract the attention of kings and chemists from western Europe to China. Even the Vatican laid claim to an asbestos burial gown reportedly found in an ancient Roman sarcophagus. Somewhere along the line, though, the fact that asbestos was a stone seems to have been forgotten.

A considerable amount of fantasy was attached to the possible source of the extraordinary fibers. Medieval alchemists started this trend with a rumor that asbestos grew as hair on fire-resistant salamanders, lending still another name, *salamandra,* to the stone. Works of alchemy frequently incorporated the imagery of an omnipotent salamander surrounded by flames. In the early 16th century France adopted this symbol as a royal emblem on flags, coins and fireplace mantles. (The French first took an interest in asbestos some 700 years earlier, when, according to popular legend, Emperor Charlemagne set an asbestos tablecloth on fire to intimidate his dinner guests.)

The salamander myth was just one of many. Lizard plumes and bird feathers were, for a time, each considered to be the source of asbestos. Attempts to define these fibers led to a bizarre system of nomenclature: several dozen names were eventually assigned to the different forms of asbestos, including "mountain leather," "incombustible linen," "rock floss" and "feathered alum."

Marco Polo serendipitously brought asbestos back to the realm of science. Writing in his diary after visiting a Chinese asbestos mining operation in the late 13th century, he completely debunked the salamander theory and pegged asbestos as a stone. Georgius Agricola, one of the founders of mineralogy, provided a critical boost to the scientific understanding of the substance in the 16th century with his publication *Textbook of Mineralogy.* After carefully reviewing and updating information about the various types of asbestos, its sources and uses, Agricola offered an unusual insight: one of the very few researchers to employ an asbestos taste test, he cautioned his readers that it might "sting the tongue a little."

Asbestos Trade

In 1660, when England chartered the Royal Society, the world's scientific community was becoming increasingly fascinated by asbestos. The society published a series of eight reviews and letters on asbestos over the next 40 years. Later, in 1727, Franz E. Brückmann, a German mineralogist, wrote the first full volume on the topic; similar publications from two other leading scientists of the time, Martin F. Ledermüller and Torbern Bergman, soon followed. Ledermüller's publication was a cutting-edge treatise, depicting each of the known types of fibers with detailed colored engravings.

The range of commercial applications grew with each new publication. Fireproof coats, shirts and sleeve ruffles joined the original group of cloth items; there was also talk of making an indestructible "Book of Eternity," printed with gold on asbestos paper. Credit for another use belongs to a young inventor, Benjamin Franklin. While still a teenager, he carried a small purse woven from asbestos fiber, allegedly hoping that its contents wouldn't burn a proverbial hole in his pocket. During Franklin's first trip to England in 1724, he sold the purse to the British Museum's eventual benefactor, Sir Hans Sloane. (The purse is now in the Natural History Museum's collection.)

Even a group of devious entrepreneurs managed to earn a lucrative living during the late 1700s and early 1800s by exploiting the properties of asbestos. The most successful of these scoundrels were at the same time the most unscrupulous, selling false artifacts to a gullible audience of religious patrons. Cloth and wood relics, presented as miraculous, fire-resistant remnants of Christ's robe or cross but actually made of asbestos, were among the most popular. In a somewhat more innocent practice, a band of traveling stuntmen used fireproof asbestos gloves and capes to mystify audiences during their fiery shows. Another group, known as the Human Salamanders, was particularly famous for roasting handheld steaks while standing inside a bonfire.

In the 1820s a prominent Italian scientist converted this daredevil trick into the first truly successful asbestos business. Giovanni Aldini's ready-to-wear line of fireproof apparel, designed specifically for urban firemen, drew rave reviews and rapidly attracted clients from Paris to Geneva. Shortly thereafter, asbestos proscenium curtains began to

Vestal virgins (*left*) guarded the eternal flame at the shrine of Vesta, goddess of the hearth; the lamp's wick was made of asbestos.

Around the year 800, Charlemagne threw an asbestos tablecloth into the fire and pulled it out again unharmed in an attempt to impress some of his dinner guests.

TOMO NARASHIMA

COURTESY OF THE BRITISH LIBRARY

The hairs of fire-resistant salamanders (*left*) were considered to be the source of asbestos fibers by some medieval alchemists.

Marco Polo visited an asbestos mine in China during the latter half of the 13th century. He concluded that asbestos was a stone, not the hair of a woolly lizard.

100

1000

1850

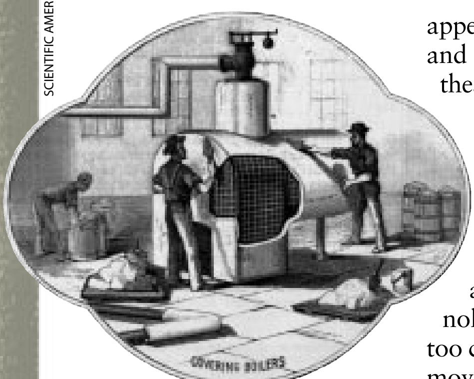
1828: First known U.S. patent for asbestos, issued for insulating material in steam engines
1834: U.K. patent for use of asbestos in safes
1853: U.K. patent for asbestos in lubricants used for bearings

SCIENTIFIC AMERICAN

Roofing felt made of asbestos

1859: U.K. patent for asbestos-lined fireboxes
1865: U.K. patent for asbestos insulating material for electrical wires
1868: U.S. patent for roofing felt made of asbestos

1820



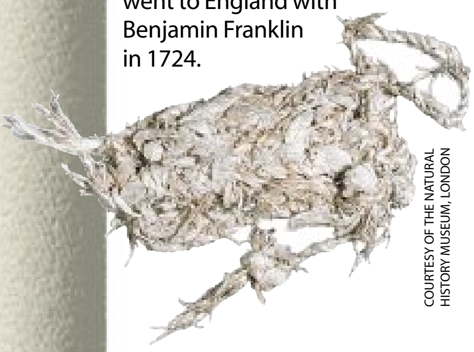
SCIENTIFIC AMERICAN

Asbestos used as insulating material

1800

Fireproof apparel and theater curtains began to appear across Europe in the early part of the 19th century.

Purse made of asbestos (*below*) went to England with Benjamin Franklin in 1724.


COURTESY OF THE NATURAL HISTORY MUSEUM, LONDON

Royal Society, founded in England in 1660, published some of the first scientific papers about asbestos in the journal *Philosophical Transactions*.

Textbook of Mineralogy, written by Georgius Agricola in the 16th century, included a lengthy description of the properties of asbestos and where it could be found in places such as Greece, India and Egypt.

1500

appear, installed to enhance stage safety and credited with saving many lives in theater fires.

It was the steam engine, though, that made asbestos a superstar stone. These massive machines had been steadily pushed to their physical limits; further improvements in safety and efficiency awaited some breakthrough in technology. Asbestos alone tended to be too coarse and abrasive for the engine's moving parts. But mixed with rubber, it offered just the right combination, allowing workers to make more resilient internal components, such as steam gaskets and packings.

By the 1860s the use of asbestos had literally hit the roof. After dabbling in fireproof paint mixtures, a young New York building contractor, Henry Ward Johns, developed a flame-resistant tar paper tailor-made for an era all too frequently plagued by building fires. This roofing material, which blended asbestos fibers into a tar, burlap and manila paper sandwich, paved the way for an immense industry in asbestos-based construction products.

Mixtures of asbestos and cement were first used in building materials shortly after the turn of the century, beginning with a lightweight, high-strength construction panel invented by an Austrian engineer, Ludwig Hatschek. Once again, because of the intense concern about fire protection, Hatschek's invention created an overnight sensation. Other workers soon derived several related products from Hatschek's basic formula, including synthetic slate roof shingles, corrugated wall and roof panels, and decorative wall and ceiling moldings.

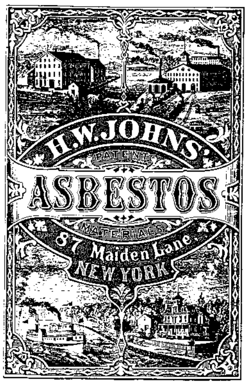
Dozens of products introduced in the first half of this century incorporated asbestos. Fireproof ships were constructed out of boards of asbestos and cement. Blends of plastic and asbestos were used in buttons, telephones and electrical panels. Indeed, from its start, the plastics industry relied on the combination of plastic and asbestos; the fibers strengthened the mix, reduced weight and improved thermal resistance. Even after more advanced polymer materials began to dominate the market, asbestos remained an important binder and strengthening agent. Vinyl-asbestos tile, for instance, became a mainstay of the flooring industry. To this day, automobile brake shoes that contain asbestos are sold in repair shops around the country by mechanics unconvinced that a perfect replacement has been found.

Asbestos Man

By 1939 the public's perception of asbestos could hardly have been more positive. That year the New York World's Fair included a prominent display from the company Johns-Manville that proudly celebrated the mineral's "service to humanity." A giant Asbestos Man greeted visitors to the company's pavilion and offered a thorough indoctrination about the extraordinary traits of asbestos. The fair itself was literally draped with asbestos, from rooftop coverings to underground pipelines.

After this wave of popularity just before World War II, the demand for asbestos was on the verge of surpassing the global supply. Lacking adequate domestic reserves, the world's military superpowers found themselves heavily reliant on foreign imports. The Germans attempted to amass an adequate stockpile, covertly shipping supplies from South Africa. For a time, the Allies feared that Germany had devised a chemical substitute, although subsequent top-secret Central Intelligence Agency studies disproved these rumors.

1880



UNIVERSITY OF DELAWARE LIBRARY, NEWARK, DEL.

Advertisement for asbestos from the 1870s

1884: U.K. patent for asbestos construction boards
1885: U.K. patent for asbestos membranes used to filter substances such as juices

BASS PHOTO COMPANY COLLECTION, INDIANA HISTORICAL SOCIETY LIBRARY

The Indiana State Capitol (*left*) was mentioned in an 1894 advertising booklet for uses of asbestos entitled "Heat Insulation and Fire Protection in Prominent Buildings."

In this country, foreign sources of asbestos—such as the exchange program set up between the U.S. and the Soviet Union by the American entrepreneur Armand Hammer and the Soviet leader Vladimir Lenin—were considered dangerously vulnerable. While Canadian mining operations tried valiantly to meet American demands, the government imposed severe nationwide restrictions on nonessential applications. Several hundred tons had to be supplied every day for uses ranging from ships' engines to auto parts for army jeeps. Parachute flares, bazooka shells and torpedoes all carried asbestos; battlefield medics even used it as an easily sterilized surgical dressing.

The global boom in construction after World War II triggered the next, and probably last, asbestos rush. Structural engineers clearly valued the strength, durability and fireproof nature of asbestos-cement products and liberally worked them into their designs. High-rise buildings became a reality in part because of an innovative spray-on asbestos coating that protected steel structures against fire-induced buckling.

The unusual properties of asbestos led to an absolutely startling range of uses. The U.S. Postal Service had it woven into fireproof mailbags. Fruit juice, wine and sugar producers purified their goods with asbestos filters. Heart surgeons used it for thread, and a toothpaste was

What Is Asbestos?

Six distinct types of asbestos have been identified: actinolite, amosite, anthophyllite, crocidolite, tremolite and chrysotile. All contain long chains of silicon and oxygen that give rise to the fibrous nature of the mineral. Yet each is decidedly different in physical and chemical properties, depending on the other components of the rock, such as calcium, magnesium or iron.

The fireproof threads of asbestos are stronger than steel and quite resilient, making the stone appealing for a wide range of industrial applications. Yet the strength and resilience of asbestos also make it dangerous to human health. Asbestos fibers can penetrate bodily tissue, particularly the lungs, eventually causing tumors to develop.

The first five versions listed above (the so-called amphibolic versions) are by far the strongest and stiffest—thus making them the most dangerous. The two most common amphibolic types, amosite and crocidolite (often referred to as "brown" and "blue" asbestos, respectively), originate in remote South African mines and were once mixed with insulation and cement until regulations were enacted prohibiting the use of amphibolic asbestos. The remaining amphibolic versions—anthophyllite, tremolite and actinolite—were never commercially significant.

CHRYSOTILE

The sixth type of asbestos, chrysotile, once accounted for more than 95 percent of the asbestos used worldwide. Chrysotile differs significantly in texture, composition and behavior from the other forms of the mineral. Its crystal structure is snakelike (hence its alternate name, "serpentine"), and it is noticeably softer and more flexible than the other kinds. Because chrysotile is softer and can be broken down by the body more easily than the other forms, it does not damage tissue as extensively as the five amphibolic varieties.

An estimated 20 percent of buildings in the U.S. still contain products such as shingles, cement pipes and insulation made from chrysotile asbestos. Yet well-maintained asbestos in buildings will not spontaneously shed fibers into the air. Instead decay, renovation or demolition of the structures can lead to the release of fibers. Furthermore, most studies indicate that airborne levels of asbestos in buildings—even those in which the original asbestos has been disturbed—are significantly lower than current health standards set by the U.S. government to protect asbestos workers.

—J.E.A. and B.T.M.

CROCIDOLITE

AMOSITE

JOHN A. UNDERWOOD *Purdue University*

1900

Lady Asbestos, from an early 20th-century advertising booklet

Telephones and various other household items were fabricated from a blend of asbestos and plastic.

Automobile brake shoes were made of asbestos.

1920

Asbestos Industry Regulations were passed in England in 1931 to address concerns that exposure to asbestos led to lung damage, particularly among textile factory workers.

Asbestos Man (*right*), from 1939 World's Fair

SMITHSONIAN INSTITUTION LIBRARIES (*Lady Asbestos*); SUPERSTOCK (*telephone*); CORBIS-BETTMANN (*car*); MUSEUM OF THE CITY OF NEW YORK (*Asbestos Man*); THE KOBAL COLLECTION (*Wicked Witch*); UPI/CORBIS-BETTMANN (*fireproof suit*); SUPERSTOCK (*housing construction*); JOHN CHIASSON *Gamma-Liaison* (*asbestos removal*); NASA (*space shuttle*)

made with its fibers. Modeling clays and artificial snow contained asbestos. Hollywood even gave the mineral a couple of bit parts, in the Wicked Witch of the West's burning broomstick in *The Wizard of Oz* and the man-made spider webs that hung across the reanimated ancient Egyptian's cave in *The Mummy.*

Escalating Health Concerns

By the time the U.S. Environmental Protection Agency opened its doors in 1970, the commercial world of asbestos had expanded into thousands of products. Annual use in this country continued to climb for another three years, hitting an all-time high in 1973 of nearly a million tons. But shortly thereafter, the history of asbestos took a negative turn, driven by escalating concerns about human health.

Problems stemming from the inhalation of exceedingly high levels of asbestos in milling and manufacturing plants had actually been observed since the turn of the century. Reports of fibrotic lung damage, known as asbestosis, in Britain's dusty textile factories led to that country's enactment of the Asbestos Industry Regulations of 1931. Over the next several decades, however, the topic drew relatively little attention from the emerging industrial health field, despite the fact that medical investigators had also uncovered a worrisome link between asbestos and lung cancer, especially in smokers.

This mood started to change during the mid-1960s as it became apparent that even low levels of asbestos posed significant health hazards; this finding implied that much larger numbers of people, including thousands of World War II–era ship insulators, might be at risk for lung damage. Disturbing results from around the world fingered the class of asbestos known as amphiboles as the principal culprits for inducing mesothelioma, a tumor found in the chest or gut. In response to these revelations, most industrial countries imposed regulations that limited exposure to just the amphiboles. But faced with increasing pressure from labor unions and ominous projections of a million-plus victims, the U.S. government chose to regulate the asbestos family as a whole.

Although the EPA's ban on all forms of asbestos was lifted in 1991, the political and legal climate for asbestos use in the U.S. is still troubled. Few people can recall this mineral's prior glory, and fewer still would ever dream of continuing its widespread use. Past generations may have considered asbestos to be an invaluable resource, but the present concern about its possible risk to human health obscures these memories.

To suggest that asbestos might still hold any redeeming qualities appears foolhardy. To qualify the mineral as a vital commodity of strategic global significance seems completely ridiculous. And yet this is precisely the case. The type of asbestos known as chrysotile (which is softer and less dangerous than the amphiboles), for example, remains an essential mineral for many crucial technologies, with the U.S. government holding military stockpiles to this day.

A prominent demonstration of this lingering importance can be found in the nation's space shuttle program. Each of the ship's solid-fuel boosters carries asbestos-impregnated rubber liners to protect the steel casings from the heat of takeoff. (The use of asbestos in aerospace applications began during the late 19th century, with the efforts to develop a fireproof hot-air balloon. A replica of an early rocket, coated in asbestos to guard against catastrophic structural failure, can be seen today on the main floor of the Smithsonian Institution's Air and Space Museum, openly defiant of the current pressures to remove all asbestos from public areas.)

Asbestos also plays a vital role in the operation of the U.S. Navy's submarine forces. These underwater vessels could not operate without some means of self-contained oxygen production; fibrous mats woven out of asbestos represent a key component in the onboard electrolytic cells that split oxygen from water molecules.

Asbestos can also be found closer to home. At least 75 percent of the chlorine used today for bleach, cleansers and disinfectants comes from chemical industries whose manufacturing processes depend on asbestos products. In fact, the very water we drink might well have been processed with asbestos-treated chlorine as well as piped through an asbestos-cement conduit on its way to our houses. Enough of the asbestos-cement pipe has been used in all 50 states since 1930 to circle the earth eight times over and still run to the moon and back.

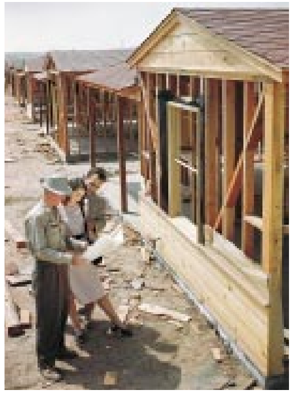
A Rational Perspective

Admittedly, all these present-day applications (which rely mainly on the safer chrysotile form) do not require huge amounts of asbestos. Indeed, the consumption of asbestos in the U.S. has fallen by about 95 percent from the 1973 peak. Beyond our country's borders, though, many nations still consider chrysotile asbestos to be an important resource. In 1997 over two million tons of the substance will be processed

1940

Wicked Witch of the West appeared in the 1939 movie *The Wizard of Oz* with a broom made of asbestos.

Postwar construction projects relied heavily on asbestos.



Wartime paraphernalia—including fireproof suits (*left*) and parachute flares—contained asbestos.

Health concerns began to surface in the U.S. during the 1960s, after studies revealed that low levels of asbestos exposure could be more dangerous than previously thought.

1970

Asbestos use reached an all-time high in the U.S. in 1973.

Removal of asbestos (*above*) from schools, houses and public buildings has been ongoing.

1980

The solid-fuel boosters on the space shuttle (*below*) are insulated with asbestos—one of many current applications of the mineral.

1990

throughout the world, mostly blended into asbestos-cement construction products for use in Asian, eastern European and developing countries.

The public's view of asbestos will probably never return to its previous enthusiasm. Hindsight, however, suggests that efforts to eradicate asbestos might have been somewhat misjudged and mishandled. The predicted rates of future mortality caused by both indoor and outdoor exposure to asbestos fiber now appear minuscule when compared with the risks associated with tobacco smoking and drug and alcohol abuse. The widely espoused and emotionally volatile premise that "one fiber can kill" arguably overstepped the bounds of scientific reality, triggering a purge of asbestos from schools and other buildings with dubious benefit in far too many instances.

Hoping to secure a rational perspective on the asbestos controversy, in 1988 the EPA joined Congress and a variety of concerned private institutions in asking a respected nonprofit organization, the Health Effects Institute, for an independent evaluation of the dilemma. The institute's report attempted to educate the public about the fallacies and economic consequences of rampant asbestos removal. In 1991 the American Medical Association published a second report that reached similar conclusions. These two documents emphasized that current contamination is extremely low compared with the unregulated workplace levels that originally gave rise to asbestos-related lung disease.

The global future for asbestos may hinge on supply as much as safety. Just as the ancient Greek asbestos mines eventually hit rock bottom, today's reserves are being depleted. Chemists have long searched for suitable substitutes, but a perfect solution has not yet been found. The original irony of asbestos has thus come full circle, to a present position where a substance so apparently evil could still be considered good, despite its tarnished image—quite fitting for this unquenchable stone. SA

The Authors

JAMES E. ALLEMAN and BROOKE T. MOSSMAN share an interest in the study of asbestos. Alleman, a professor at Purdue University's School of Civil Engineering, pursues the practical applications and history of the mineral. Mossman, a professor at the College of Medicine at the University of Vermont, investigates the medical effects of asbestos.

Further Reading

ASBESTOS: SCIENTIFIC DEVELOPMENTS AND IMPLICATIONS FOR PUBLIC POLICY. B. T. Mossman, J. Bignon, M. Corn, A. Seaton and J.B.L. Gee in *Science*, Vol. 247, pages 294–300; January 19, 1990.

ASBESTOS: A CHRONOLOGY OF ITS ORIGINS AND HEALTH EFFECTS. R. Murray in *British Journal of Industrial Medicine*, Vol. 47, No. 6, pages 361–365; June 1990.

THE SCHOOLROOM ASBESTOS ABATEMENT PROGRAM: A PUBLIC POLICY DEBACLE. M. Ross in *Environmental Geology*, Vol. 26, No. 3, pages 182–188; October 1995.

Global Population and the Nitrogen Cycle

Feeding humankind now demands so much nitrogen-based fertilizer that the distribution of nitrogen on the earth has been changed in dramatic, and sometimes dangerous, ways

by Vaclav Smil

During the 20th century, humanity has almost quadrupled its numbers. Although many factors have fostered this unprecedented expansion, its continuation during the past generation would not have been at all possible without a widespread—yet generally unappreciated—activity: the synthesis of ammonia. The ready availability of ammonia, and other nitrogen-rich fertilizers derived from it, has effectively done away with what for ages had been a fundamental restriction on food production. The world's population now has enough to eat (on the average) because of numerous advances in modern agricultural practices. But human society has one key chemical industry to thank for that abundance—the producers of nitrogen fertilizer.

Why is nitrogen so important? Compared with carbon, hydrogen and oxygen, nitrogen is only a minor constituent of living matter. But whereas the three major elements can move readily from their huge natural reservoirs through the food and water people consume to become a part of their tissues, nitrogen remains largely locked in the atmosphere. Only a puny fraction of this resource exists in a form that can be absorbed by growing plants, animals and, ultimately, human beings.

Yet nitrogen is of decisive importance. This element is needed for DNA and RNA, the molecules that store and transfer genetic information. It is also required to make proteins, those indispensable messengers, receptors, catalysts and structural components of all plant and animal cells. Humans, like other higher animals, cannot synthesize these molecules using the nitrogen found in the air and have to acquire nitrogen compounds from food. There is no substitute for this intake, because a minimum quantity (consumed as animal or plant protein) is needed for proper nutrition. Yet getting nitrogen from the atmosphere to crops is not an easy matter.

The relative scarcity of usable nitrogen can be blamed on that element's peculiar chemistry. Paired nitrogen atoms make up 78 percent of the atmosphere,

but they are too stable to transform easily into a reactive form that plants can take up. Lightning can cleave these strongly bonded molecules; however, most natural nitrogen "fixation" (the splitting of paired nitrogen molecules and subsequent incorporation of the element into the chemically reactive compound ammonia) is done by certain bacteria. The most important nitrogen-fixing bacteria are of the genus *Rhizobium,* symbionts that create nodules on the roots of leguminous plants, such as beans or acacia trees. To a lesser extent, cyanobacteria (living either freely or in association with certain plants) also fix nitrogen.

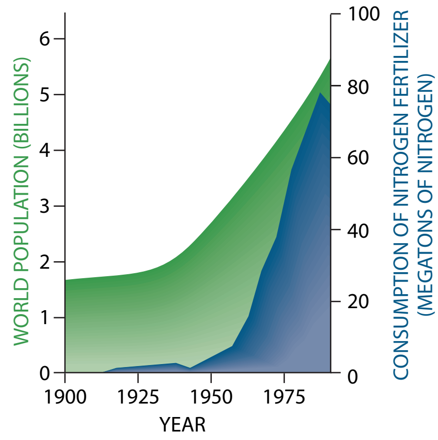
A Long-standing Problem

Because withdrawals caused by the growth of crops and various natural losses continually remove fixed nitrogen from the soil, that element is regularly in short supply. Traditional farmers (those in preindustrial societies) typically replaced the nitrogen lost or taken up in their harvests by enriching their fields with crop residues or with animal and human wastes. But these materials contain low concentrations of nitrogen, and so farmers had to apply massive amounts to provide a sufficient quantity.

Traditional farmers also raised peas, beans, lentils and other pulses along with cereals and some additional crops. The nitrogen-fixing bacteria living in the roots of these plants helped to enrich the fields with nitrogen. In some cases, farmers grew legumes (or, in Asia, *Azolla* ferns, which harbor nitrogen-fixing cyanobacteria) strictly for the fertilization provided. They then plowed these crops into the soil as so-called green manures without harvesting food from them at all. Organic farming of this kind during the early part of the 20th century was most intense in the lowlands of Java, across the Nile Delta, in northwestern Europe (particularly on Dutch farms) and in many regions of Japan and China.

The combination of recycling human and animal wastes along with planting green manures can, in principle, provide annually up to around 200 kilograms of nitrogen per hectare of arable land. The resulting 200 to 250 kilograms of plant protein that can be produced in this way sets the theoretical limit on population density: a hectare of farmland in places with good soil, adequate moisture and a mild climate that allows continuous cultivation throughout the year should be able to support as many as 15 people.

In practice, however, the population densities for nations dependent on organic farming were invariably much lower. China's average was between five and six people per hectare of arable area during the early part of this century. During the last decades of purely organic farming in Japan (which occurred about the same time), the population density there was slightly higher than in China,



BRYAN CHRISTIE

SUDDEN GROWTH in the global consumption of nitrogen fertilizer during the 20th century has been matched by a parallel increase in world population.

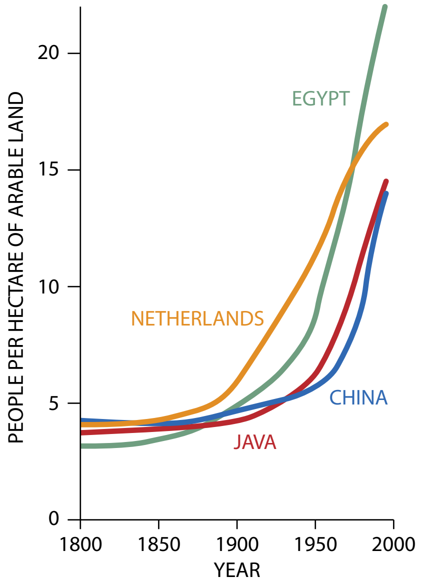
but the Japanese reliance on fish protein from the sea complicates the comparison between these two nations. A population density of about five people per hectare was also typical for fertile farming regions in northwestern Europe during the 19th century, when those farmers still relied entirely on traditional methods.

The practical limit of about five people per hectare of farmland arose for many reasons, including environmental stresses (caused above all by severe weather and pests) and the need to raise crops that were not used for food—those that provided medicines or fibers, for example. The essential difficulty came

INTENSIVE AGRICULTURE, such as that practiced in these Scottish fields, relies on the industrial production of nitrogen fertilizer, using a technique that was first engineered in the second decade of this century. That same process is now implemented at scores of ammonia factories (*inset*) situated throughout the world.

JASON HAWKES *Julian Cotton Photo Library*

ERIC FREEDMAN *Bruce Coleman Inc.*



BRYAN CHRISTIE

POPULATION DENSITY increased substantially in countries with intensive agriculture only after the use of nitrogen fertilizer became common.

from the closed nitrogen cycle. Traditional farming faced a fundamental problem that was especially acute in land-scarce countries with no uncultivated areas available for grazing or for the expansion of agriculture. In such places, the only way for farmers to break the constraints of the local nitrogen cycle and increase harvests was by planting more green manures. That strategy preempted the cultivation of a food crop. Rotation of staple cereals with leguminous food grains was thus a more fitting choice. Yet even this practice, so common in traditional farming, had its limits. Legumes have lower yields, they are often difficult to digest, and they cannot be made easily into bread or noodles. Consequently, few crops grown using the age-old methods ever had an adequate supply of nitrogen.

A Fertile Place for Science

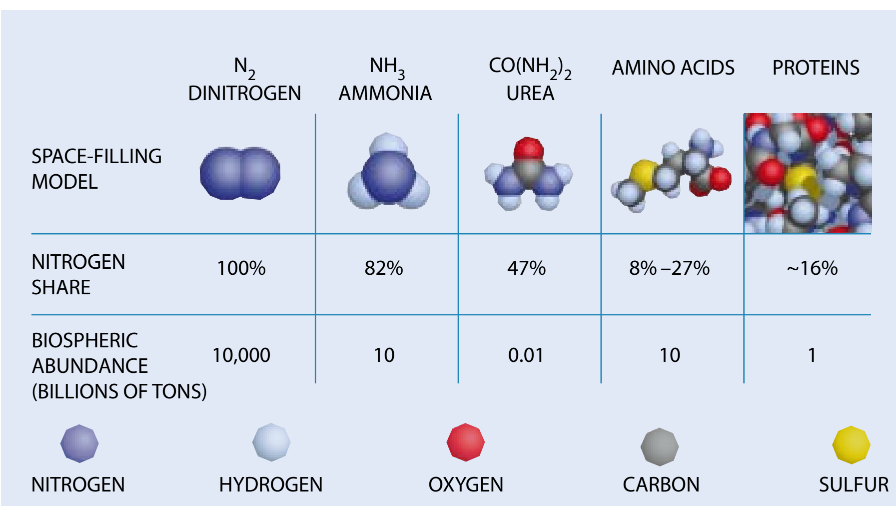
As their knowledge of chemistry expanded, 19th-century scientists began to understand the critical role of nitrogen in food production and the scarcity of its usable forms. They learned that the other two key nutrients—potassium and phosphorus—were limiting agricultural yields much less frequently and that any shortages of these two elements were also much easier to rectify. It was a straightforward matter to mine potash deposits for potassium fertilizer, and phosphorus enrichment required only that acid be added to phosphate-rich rocks to convert them into more soluble compounds that would be taken up when the roots absorbed water. No comparably simple procedures were available for nitrogen, and by the late 1890s there were feelings of urgency and unease among the agronomists and chemists who were aware that increasingly intensive farming faced a looming nitrogen crisis.

As a result, technologists of the era made several attempts to break through the nitrogen barrier. The use of soluble inorganic nitrates (from rock deposits found in Chilean deserts) and organic guano (from the excrement left by birds on Peru's rainless Chincha Islands) provided a temporary reprieve for some farmers. Recovery of ammonium sulfate from ovens used to transform coal to metallurgical coke also made a short-lived contribution to agricultural nitrogen supplies. This cyanamide process—whereby coke reacts with lime and pure nitrogen to produce a compound that contains calcium, carbon and nitrogen—was commercialized in Germany in 1898, but its energy requirements were too high to be practical. Producing nitrogen oxides by blowing the mixture of the two elements through an electric spark demanded extraordinary energy as well. Only Norway, with its cheap hydroelectricity, started making nitrogen fertilizer with this process in 1903, but total output remained small.

The real breakthrough came with the invention of ammonia synthesis. Carl Bosch began the development of this process in 1899 at BASF, Germany's leading chemical concern. But it was Fritz Haber, from the technical university in Karlsruhe, Germany, who devised a workable scheme to synthesize ammonia from nitrogen and hydrogen. He combined these gases at a pressure of 200 atmospheres and a temperature of 500 degrees Celsius in the presence of solid osmium and uranium catalysts.

Haber's approach worked well, but converting this bench reaction to an engineering reality was an immense undertaking. Bosch eventually solved the greatest design problem: the deterioration of the interior of the steel reaction chamber at high temperatures and pressures. His work led directly to the first commercial ammonia factory in Oppau, Germany, in 1913. Its design capacity was soon doubled to 60,000 tons a year—enough to make Germany self-sufficient in the nitrogen compounds it used for the production of explosives during World War I.

Commercialization of the Haber-Bosch synthesis process was slowed by the economic difficulties that prevailed



NITROGEN COMPOUNDS permeate the biosphere. The most abundant form (N_2), which makes up 78 percent of the atmosphere, is so strongly bonded that it does not engage in most chemical reactions. Plants need reactive nitrogen compounds, such as ammonia (NH_3) and urea ($CO(NH_2)_2$), which are much more scarce. (The abundance estimates shown are valid to within a factor of 10.) Plants use these substances to fashion amino acids, the building blocks of proteins, which serve myriad functions in living cells.

BIOGRAFX

a

DAN GURAVICH *Photo Researchers, Inc.*

b

JEREMY BURGESS SPL/*Photo Researchers, Inc.*

c

KENNETH W. FINK *Bruce Coleman Inc.*

NITROGEN-FIXING BACTERIA, the microbes that convert atmospheric nitrogen into reactive compounds, live in root nodules of leguminous plants, such as soybeans (*a*). They can also be found in *Azolla* ferns (*b*) and inside sugarcane plants (*c*).

between wars, and global ammonia production remained below five million tons until the late 1940s. During the 1950s, the use of nitrogen fertilizer gradually rose to 10 million tons; then technical innovations introduced during the 1960s cut the use of electricity in the synthesis by more than 90 percent and led to larger, more economical facilities for the production of ammonia. The subsequent exponential growth in demand increased global production of this compound eightfold by the late 1980s.

This surge was accompanied by a relatively rapid shift in nitrogen use between high- and low-income countries. During the early 1960s, affluent nations accounted for over 90 percent of all fertilizer consumption, but by 1980 their share was down below 70 percent. The developed and developing worlds drew level in 1988. At present, developing countries use more than 60 percent of the global output of nitrogen fertilizer.

Just how dependent has humanity become on the production of synthetic nitrogen fertilizer? The question is difficult to answer because knowledge remains imprecise about the passage of nitrogen into and out of cultivated fields around the globe. Nevertheless, careful assessment of the various inputs indicates that around 175 million tons of nitrogen flow into the world's croplands every year, and about half this total becomes incorporated into cultivated plants. Synthetic fertilizers provide about 40 percent of all the nitrogen taken up by these crops. Because they furnish—directly as plants and indirectly as animal foods—about 75 percent of all nitrogen in consumed proteins (the rest comes from fish and from meat and dairy foodstuffs produced by grazing), about one third of the protein in humanity's diet depends on synthetic nitrogen fertilizer.

This revelation is in some ways an overestimate of the importance of the Haber-Bosch process. In Europe and North America nitrogen fertilizer has not been needed to ensure survival or even adequate nutrition. The intense use of synthetic fertilizer in such well-developed regions results from the desire to grow feed for livestock to satisfy the widespread preference for high-protein animal foods. Even if the average amount of protein consumed in these places were nearly halved (for example, by persuading people to eat less meat), North Americans and Europeans would still enjoy adequate nutrition.

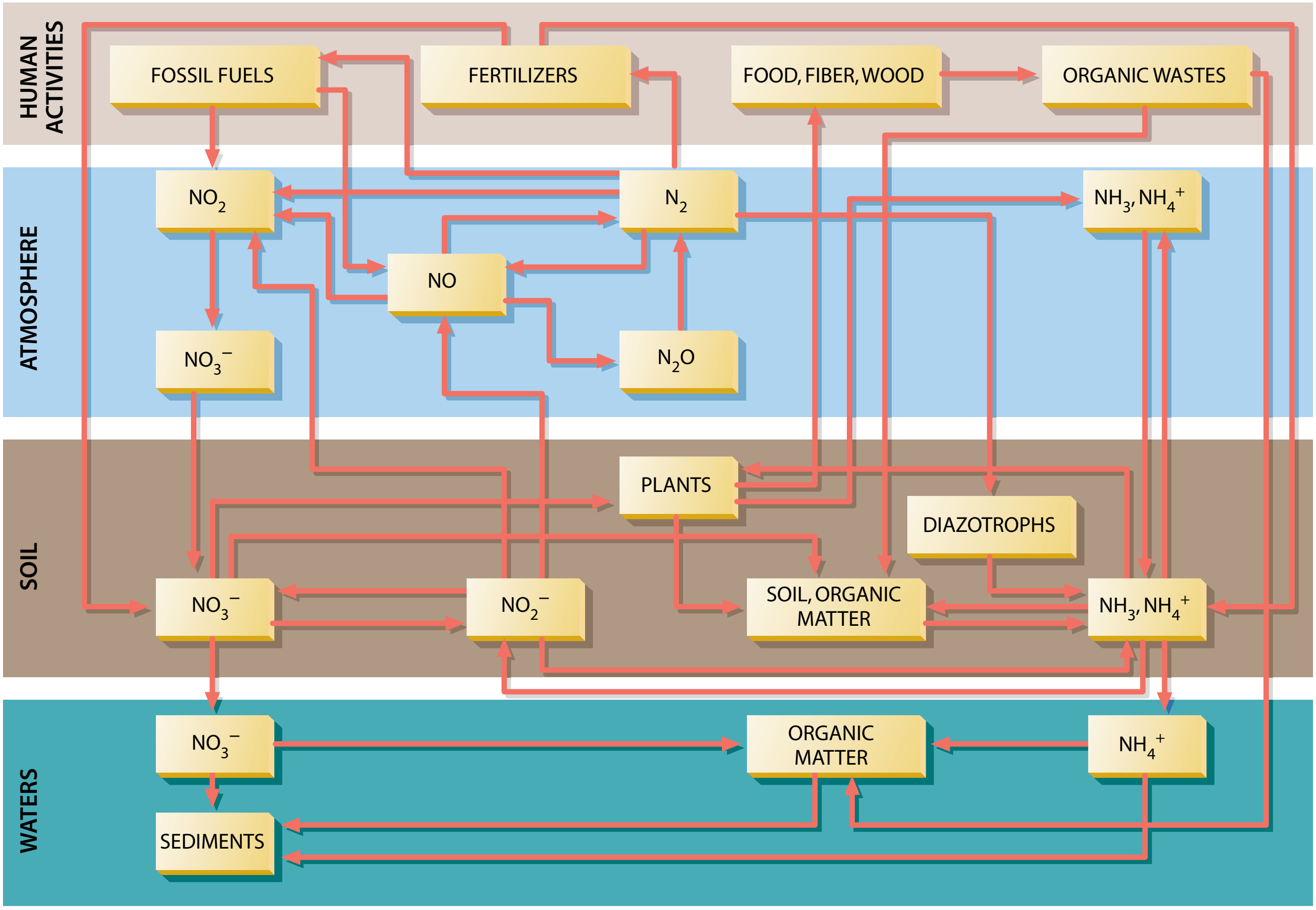
Yet the statement that one third of the protein nourishing humankind depends on synthetic fertilizer also underestimates the importance of these chemicals. A number of land-scarce countries with high population density depend on synthetic fertilizer for their very existence. As they exhaust new areas to cultivate, and as traditional agricultural practices reach their limits, people in these countries must turn to ever greater applications of nitrogen fertilizer—even if their diets contain comparatively little meat. Every nation producing annually in excess of about 100 kilograms of protein per hectare falls in this category. Examples include China, Egypt, Indonesia, Bangladesh, Pakistan and the Philippines.

Too Much of a Good Thing

Massive introduction of reactive nitrogen into soils and waters has many deleterious consequences for the environment. Problems range from local health to global changes and, quite literally, extend from deep underground to high in the stratosphere. High nitrate levels can cause life-threatening methemoglobinemia ("blue baby" disease) in infants, and they have also been linked epidemiologically to some cancers. Leaching of highly soluble nitrates, which can seriously contaminate both ground and surface waters in places undergoing heavy fertilization, has been disturbing farming regions for some 30 years. A dangerous accumulation of nitrates is commonly found in water wells in the American corn belt and in groundwater in many parts of western Europe. Concentrations of nitrates that exceed widely accepted legal limits occur not only in the many smaller streams that drain farmed areas but also in such major rivers as the Mississippi and the Rhine.

Fertilizer nitrogen that escapes to ponds, lakes or ocean bays often causes eutrophication, the enrichment of waters by a previously scarce nutrient. As a result, algae and cyanobacteria can grow with little restraint; their subsequent decomposition robs other creatures of oxygen and reduces (or eliminates) fish and crustacean species. Eutrophication plagues such nitrogen-laden bodies as New York State's Long Island Sound and California's San Francisco Bay, and it has altered large parts of the Baltic Sea. Fertilizer runoff from the fields of Queensland also threatens parts of Australia's Great Barrier Reef with algal overgrowth.

Whereas the problems of eutrophication arise because dissolved nitrates can travel great distances, the persistence of nitrogen-based compounds is also troublesome, because it contributes to the acidity of many arable soils. (Soils are



BRYAN CHRISTIE

NITROGEN RESERVOIRS of many different kinds exist within the earth's waters, soil, atmosphere and biological mantle. Nitrogen moving between these temporary resting spots takes diverse forms. The advent of large-scale fertilizer production modifies natural flows of this element enormously, unbalancing the nitrogen cycle in sometimes troubling ways.

also acidified by sulfur compounds that form during combustion and later settle out of the atmosphere.) Where people do not counteract this tendency by adding lime, excess acidification could lead to increased loss of trace nutrients and to the release of heavy metals from the ground into drinking supplies.

Excess fertilizer does not just disturb soil and water. The increasing use of nitrogen fertilizers has also sent more nitrous oxide into the atmosphere. Concentrations of this gas, generated by the action of bacteria on nitrates in the soil, are still relatively low, but the compound takes part in two worrisome processes. Reactions of nitrous oxide with excited oxygen contribute to the destruction of ozone in the stratosphere (where these molecules serve to screen out dangerous ultraviolet light); lower, in the troposphere, nitrous oxide promotes excessive greenhouse warming. The atmospheric lifetime of nitrous oxide is longer than a century, and every one of its molecules absorbs roughly 200 times more outgoing radiation than does a single carbon dioxide molecule.

Yet another unwelcome atmospheric change is exacerbated by the nitric oxide released from microbes that act on fertilizer nitrogen. This compound (which is produced in even greater quantities by combustion) reacts in the presence of sunlight with other pollutants to produce photochemical smog. And whereas the deposition of nitrogen compounds from the atmosphere can have beneficial fertilizing effects on some grasslands or forests, higher doses may overload sensitive ecosystems.

When people began to take advantage of synthetic nitrogen fertilizers, they could not foresee any of these insults to the environment. Even now, these disturbances receive surprisingly little attention, especially in comparison to the buildup of carbon dioxide in the atmosphere. Yet the massive introduction of reactive nitrogen, like the release of car-

ADRIENNE T. GIBSON *Earth Scenes*

EUTROPHICATION arises in fertilizer-laden waters because excess nitrogen spurs the growth of algae.

bon dioxide from fossil fuels, also amounts to an immense—and dangerous—geochemical experiment.

From Habit to Addiction

Emissions of carbon dioxide, and the accompanying threat of global warming, can be reduced through a combination of economic and technical solutions. Indeed, a transition away from the use of fossil fuels must eventually happen, even without the motivation to avoid global climate change, because these finite resources will inevitably grow scarcer and more expensive. Still, there are no means available to grow crops—and human bodies—without nitrogen, and there are no waiting substitutes to replace the Haber-Bosch synthesis.

Genetic engineers may ultimately succeed in creating symbiotic *Rhizobium* bacteria that can supply nitrogen to cereals or in endowing these grains directly with nitrogen-fixing capability. These solutions would be ideal, but neither appears imminent. Without them, human reliance on nitrogen fertilizer must further increase in order to feed the additional billions of people yet to be born before the global population finally levels off.

An early stabilization of population and the universal adoption of largely vegetarian diets could curtail nitrogen needs. But neither development is particularly likely. The best hope for reducing the growth in nitrogen use is in finding more efficient ways to fertilize crops. Impressive results are possible when farmers monitor the amount of usable nitrogen in the soil so as to optimize the timing of applications. But several worldwide trends may negate any gains in efficiency brought about in this way. In particular, meat output has been rising rapidly in Latin America and Asia, and this growth will demand yet more nitrogen fertilizer, as it takes three to four units of feed protein to produce one unit of meat protein.

Understanding these realities allows a clearer appraisal of prospects for organic farming. Crop rotations, legume cultivation, soil conservation (which keeps more nitrogen in the soil) and the recycling of organic wastes are all desirable techniques to employ. Yet these measures will not obviate the need for more fertilizer nitrogen in land-short, populous nations. If all farmers attempted to return to purely organic farming, they would quickly find that traditional practices could not feed today's population. There is simply not enough recyclable nitrogen to produce food for six billion people.

When the Swedish Academy of Sciences awarded a Nobel Prize for Chemistry to Fritz Haber in 1919, it noted that he created "an exceedingly important means of improving the standards of agriculture and the well-being of mankind." Even such an effusive description now seems insufficient. Currently at least two billion people are alive because the proteins in their bodies are built with nitrogen that came—via plant and animal foods—from a factory using his process.

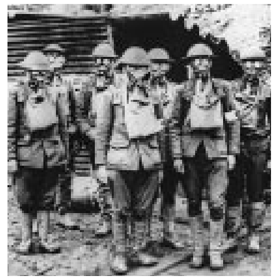
Barring some surprising advances in bioengineering, virtually all the protein needed for the growth of another two billion people to be born during the next two generations will come from the same source—the Haber-Bosch synthesis of ammonia. In just one lifetime, humanity has indeed developed a profound chemical dependence. SA

The Curious Fate of Fritz Haber


UPI/CORBIS-BETTMANN

FRITZ HABER received the Nobel Prize for Chemistry after being labeled a war criminal.

Although he was awarded the Nobel Prize in 1919 for ammonia synthesis, Fritz Haber led an essentially tragic life. As the director of the Kaiser Wilhelm Institute for Physical Chemistry during World War I, he developed the use of chlorine gas for the German general staff. Haber believed this gruesome weapon would help bring a swift victory and thus limit overall suffering. Others took a dimmer view. On the eve of the first use of the gas against Allied troops in 1915, Haber's wife committed suicide, tormented by her husband's horrific contribution to the war. And after the Armistice, the Allies considered Haber a war criminal. Haber was demoralized, but he continued to conduct research. Later, with the rise of Nazi-inspired anti-Semitism in Germany, this Jewish scientist fled and took up residence in England. Haber died in 1934 in Basel, Switzerland. —*V.S.*


CORBIS-BETTMANN

GAS ATTACKS during World War I caused enormous Allied casualties.

The Author

VACLAV SMIL was educated at the Carolinum University in Prague in the Czech Republic and at Pennsylvania State University. He is currently a professor in the department of geography at the University of Manitoba in Canada. Smil's interdisciplinary research covers interactions between the environment, energy, food, population, economic forces and public policy.

Further Reading

Population Growth and Nitrogen: An Exploration of a Critical Existential Link. Vaclav Smil in *Population and Development Review*, Vol. 17, No. 4, pages 569–601; December 1991.

Nitrogen Fixation: Anthropogenic Enhancement—Environmental Response. James N. Galloway, William H. Schlesinger, Hiram Levy II, Anthony Michaels and Jerald L. Schnoor in *Global Biogeochemical Cycles*, Vol. 9, No. 2, pages 235–252; June 1995.

Nitrogen Pollution in the European Union: Origins and Proposed Solutions. Ester van der Voet, Rene Kleijn and Udo de Haes in *Environmental Conservation*, Vol. 23, No. 2, pages 120–132; 1996.

Cycles of Life: Civilization and the Biosphere. Vaclav Smil. Scientific American Library, W. H. Freeman and Company, 1997.

Taking Computers to Task

by W. Wayt Gibbs, *staff writer*

At a grand Silicon Valley expo convened in March by the Association for Computing Machinery, a handful of chief technologists from industry and academia rose before a rapt audience of 2,000 to forecast how computers will evolve over the next 50 years. The exercise, as most of the gurus admitted, was specious—even the clearest crystal ball clouds hopelessly beyond a decade or so. But in the process of extrapolating a distant future, they tipped their hands to reveal what wonders they believe lie just around the bend.

Computers exchanging video calls as commonly as e-mail. Three-dimensional windows that open into virtual worlds instead of virtual scrolls. Machines that speak and respond to human languages as well as their own. Personal "agent" programs that haggle for concert tickets, arrange blind dates and winnow useful information from the chaff of daily news. And everything, from our medical records to our office files to the contents of our refrigerators, hypertextually linked via the great global network.

These transformations in the way we interact with software—its so-called user interface—have begun to graduate from idle speculation to working prototypes and even a few shipped products. It is widely expected that before long they will replace the flat windows, icons, menus and pointers that for 12 years have dominated personal computer interfaces. In demos, the new technologies are inarguably cool, and as Nathan Myhrvold, Microsoft's vice president of applications and content, observed during his turn at the dais, "'Cool' is a powerful reason to spend money."

But in the computer industry and in the media that cover it, it has become common to tout with almost millennial fervor that the changing face of computers will make them not just more enjoyable but also dramatically more useful. Historian (and *Scientific American* columnist) James Burke spoke for many at the conference when he asserted that "we stand today on the threshold of an explosion in information technology, the social and economic consequences of which will make everything that came before look like slow motion."

In fact, the explosion is well under way, and its economic blessings so far appear decidedly mixed. For all the useful things computers do, they do not seem, on balance, to have made us much richer by enabling us to do more work, of increasing value, in less time. Compared with the big economic bangs delivered by water-, steam- and electricity-powered machines, productivity growth in the information age has been a mere whimper.

Anyone who has whiled away an afternoon upgrading a word processor, taken a break at work to download box scores from ESPN.com or watched in horror as a system crash obliterated several hours' work can attest to part of the problem. Recent studies of computer use in offices reveal that much of the time saved by automation is frittered away by software that is unnecessarily difficult, unpredictable and inefficient. Design experts warn that current industry trends toward increasingly complex programs and new, untested ways of presenting information could do more harm than good—and will almost certainly do less good than advertised. The road to improved productivity, they argue, heads in a very different direction.

The Productivity Puzzle

Which direction businesses follow is important because productivity growth is "at the crux of economic success," says Stephen S. Roach, chief economist at Morgan Stanley. "It is the only way a nation can increasingly generate higher lifestyles for its households and separate itself competitively from its peers." That much economists agree on. But the past decade has seen vigorous debate over the seemingly poor payoff from industrial nations' 25-year bet on information technology (IT) as an engine of economic growth.

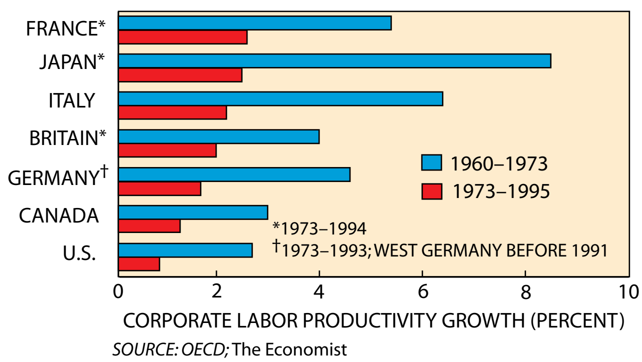
The stakes continue to mount. Despite a doubling every 18 months in the processing power a dollar buys, corporations have been pouring more and more dollars into computers. In the U.S., Roach reports, companies last year spent 43 percent of their capital budgets—$213 billion—on hardware alone. That is more than they invested in factories, vehicles or any other type of durable equipment. Adding in software, networks and the people needed for computer support and training brings the total IT bill for 1996 to about $500 billion in the U.S. and more than $1 trillion worldwide, according to Paul A. Strassmann, chairman of Method Software and a former chief information officer for Xerox and the Pentagon. Polls indicate that executives intend to spend even more next year.

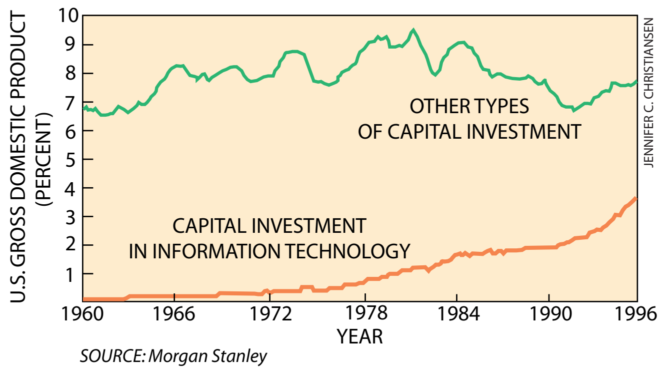
Businesses buy computers for many reasons but most ultimately aim for two goals: lowering the labor and overhead needed to make their product, and raising the number and price of products they sell. In both cases, IT investments should boost national productivity, corporate profits and standards of living. What puzzles economists is that productivity growth measured in the seven richest nations has instead fallen precipitously in the past 30 years, from an average of 4.5 percent a year during the 1960s to a rate of 1.5 percent in recent years. The slowdown has hit the biggest IT spenders—service-sector industries, especially in the U.S.—hardest. Most of the economic growth of the 1990s can be explained by increased employment, trade and production capacity. Computers' contributions, in contrast, nearly vanish in the noise.

There have been a few notable exceptions. Telecommunications companies extracted almost 7 percent more work

Coming generations of computers will be more fun and engaging to use. But will they earn their keep in the workplace?

WORKING HARD OR HARDLY WORKING? Computers can now tune into Internet "channels," make video calls, recognize speech and navigate 3-D worlds. But few of these innovations demonstrably boost productivity.





LABOR PRODUCTIVITY—the average amount of output produced by an hour's work—has grown more slowly in the seven largest economies since the 1960s (*left*), despite increasing investments in office automation (*right*). Computer and telecommunications equipment now consume the largest single share (43 percent) of American industry's capital budgets.

per hour from their employees each year between 1973 and 1983, for example. "They had many highly routine tasks that were relative easy to automate," observes Tom Landauer, a former Bellcore cognitive scientist now at the University of Colorado. That, Roach says, is typical. "What IT payback we've seen has been confined largely to low value, transaction-processing functions: moving trades, clearing checks, processing orders." In the larger occupations where most economic activity happens—sales, management, professional work—"productivity gains have been limited and disappointing," he says.

Economists have proposed four plausible explanations for the puzzle. One is that the slowdown is a mirage created by outdated measuring tools. Computers allow companies to offer speedier, more personal services and a wider variety of goods, advocates argue, and those benefits often escape the standard economic statistics. In education, finance and a few other IT-intensive industries, output is inherently hard to measure. Perhaps the payoff is real, just hard to quantify.

"There may be some legitimate measurement problems of output," Roach concedes. "But I would argue that there are more compelling biases in the labor input because of the enormous volume of unreported work time in the U.S." Cellular phones, laptops and networks, he adds, "all allow knowledge workers to work longer than ever before." Unlike their productivity, however, employees' time has definite limits.

In his 1995 book, *The Trouble with Computers,* Landauer points out that if mismeasurement is the answer, it must be mismeasurement on an implausibly colossal scale. For if productivity growth

Beyond the Desktop

Over the past decade computer hardware has grown orders of magnitude in speed and capacity. Software has evolved more slowly. "We're still stuck in the valley of 1984," when graphical user interfaces first hit the mass market, says designer Bruce Tognazzini. "It's time to get on with it." But interface experts have their doubts about whether the technologies most often extolled as successors to the current model will significantly improve many kinds of work.

3-D Virtual Environments

"Certainly there are niche applications where virtual environments are helpful," says Ben Schneiderman of the University of Maryland. Scientists use them to explore molecular structures, architects to walk clients through their designs. Ford Motor Company uses virtual reality to teach forge hammer operators how to stamp out connecting rods (*right*). Ford's pilot studies suggest the simulator could cut training times in half.


PETER YATES SABA

But the low resolution of computer displays blurs distant objects in 3-D scenes and makes oblique text difficult to read, Tognazzini points out. Immersive head-mounted displays can cause nausea and headaches. And "people tend to get lost more easily in virtual spaces," notes Fred Brooks of the University of North Carolina at Chapel Hill.

"It is very easy to be swayed by a 3-D demo," cautions Jakob Nielsen, distinguished engineer of strategic technology at Sun Microsystems. "But it is misguided to think that for work 3-D will be tremendously useful." Dan M. Russell, a research manager at Apple, concurs: "Stuart Card and I used to build 3-D stuff at Xerox that looked really cool. But it was useless."

Autonomous Software Agents

The growing Internet has also sparked research into so-called intelligent agents, programs that automatically adapt to their users' preferences and make decisions on their behalf. Pattie Maes of M.I.T.'s Media Lab offers several examples: a refrigerator that alerts you when you need milk; a program called Yenta that intuits your interests from your e-mail and suggests other people you might want to meet; an agent that will find items you want to buy and will haggle for a good price.

Although these prototypes are fun, Schneiderman questions their utility in the workplace. "Human behavior is so rich and complex that it is very hard to predict what people like and want," he says. "In a business situation, will people accept recommendations that are wrong 10 percent of the time?"

was in fact just 1.25 percentage points higher than the economists have measured since the 1960s, then by 1995 official statistics understated the U.S. gross national product by roughly $1 trillion, an error of about $10,000 per household per year.

A second explanation is that U.S. industries have so far purchased only enough computer hardware to account for 2 to 5 percent of their capital stock. Roach, though critical of IT's contributions so far, claims that "you just can't expect such a small slice to transform the performance of the corporate sector." But computers are mere doorstops without their software. Adding the cost of programs, telecommunications and other office equipment brings the total to almost 12 percent, according to Daniel E. Sichel of the Federal Reserve Board. That still excludes the cost of support staff and maintenance. Railroads energized the economy when they accounted, at their peak, for just 12 percent of capital stock, editor Pam Woodall pointed out in *The Economist* last September. Why not computers?

Paul A. David, a Stanford University economist, suggested a third possibility in 1990. Electric motors, he observed, did not boost productivity growth appreciably until more than 40 years after Edison installed the first dynamo in 1881. It wasn't until 1919 that half of American plants were wired for power. And it was later still before factories reorganized their production lines to exploit the new technology fully. By analogy, now that about half of American jobs involve some form of computer and companies are deploying IT more strategically, perhaps the big productivity gains are just beginning.

"An information revolution that transforms work overnight is just not likely," argues Erik Brynjolfsson of the Massachusetts Institute of Technology's

Speech Recognition and Understanding

Researchers at M.I.T. have built a state-of-the-art system called GALAXY that can understand and answer spoken questions about weather, airline flights and the city of Boston. Even on such relatively simple, focused tasks, however, the system often makes mistakes. Like most other speech-driven programs, it is not yet clearly faster than old-fashioned methods, such as consulting travel agents or newspapers.

"People rarely speak in grammatically correct sentences," observes Tom Landauer of the University of Colorado. "So when you put the best speaker-independent systems in real-world situations, at most they can recognize 10,000 words—about a sixth of what we use in day-to-day life—and they get at least one quarter of the words wrong."

Despite more than 25 years of research on the subject, says cognitive scientist Donald Norman, "language understanding by machines remains decades and decades away. And on top of that," he adds, "anyone who has ever struggled to communicate with an assistant knows that this isn't the answer."

The World Wide Web

"The Internet has a lot of potential to help productivity" by eliminating middlemen and improving customer service, Nielsen allows. "But the Web is enormously mismanaged in most corporations," he asserts. "Marketing, communications and information management departments are taking simplistic tactical views of this technology." Tognazzini rails as well against the poor design of most sites: "On the Web there are a million ways to do something differently; 999,000 of them are hideously stupid. There are no rules here. This is exactly the way it was in the early days of PCs, when each program was a new adventure."

Moving beyond animated envelopes and spinning logos to work-saving applications is difficult, Tognazzini reports. He recently designed a Web-based benefits administration program for medical insurers that could replace reams of paperwork. "It was 10 times harder to design than anything I ever built on the Mac," he says. "About 80 percent of our work went into overcoming the defects and limitations of the Web browsers." In the end, some employees found the Web pages too difficult to use.

"We're all enthralled with the Web because it does cool things that we couldn't do before," Landauer comments. "We know it's popular. What we don't know is whether on balance it is having beneficial or bad effects in workplaces."

TIM BROWN *Tony Stone Images*

Videoconferencing

As millions of computers link up via the Internet, video calls might seem an attractive replacement for business travel (*above*), with potentially huge savings. "I spend a lot of time in videoconferences," Norman reports, "and it is better than just a telephone call. But it's hard to do real work with it. I don't believe it will replace the need for business trips."

Like speakerphones, Nielsen argues, video—even at television quality—fails to capture subtle but crucial aspects of human communication. Meeting participants thus tend to ignore the person on the box. "If you want to save on plane fare," Tognazzini concludes, "you need full-size images that are better quality than high-definition TV," a goal still many years distant.

Sloan School of Management. “But I think productivity may grow disproportionately in recent years as companies reorganize.” IT advocates have widely touted Brynjolfsson’s 1993 analysis of 367 large firms, which calculated an average gross return of 81 percent on computer purchases—more than 13 times the gross return on other kinds of capital investments.

That sounds impressive, but Roach complains that the study attributed all the success of firms to the variations in their computer investments, ignoring other important factors. Brynjolfsson disputes that assertion but acknowledges that computers’ rapid depreciation and many hidden costs undoubtedly cut net returns considerably. Indeed, in a study last year using similar data, Sanjeev Dewan of the University of California at Irvine confirmed high gross payoffs but found little evidence that IT performs significantly better than other kinds of equipment it tends to displace. Sichel, in a book published in June, concludes that “the contribution of computing services to growth is unlikely to rise substantially in coming years, as long as [IT] earns the same net return as other capital.”

Strassmann and others have suggested a fourth explanation. Perhaps computers, despite the enthusiastic claims made for them, are still mediocre tools for improving the efficiency and quality of most information work. Maybe the productivity boom of the 1950s and 1960s, and the rise in living standards it purchased, was a fluke, the result of an unsustainable postwar boom. After all, the languid productivity growth of recent years is right in line with that of the first half of this century.

Substantial evidence supports the unpleasant conclusion that much of the $1-trillion annual IT bet is poorly wagered. According to the Standish Group on Cape Cod, Mass., 31 percent of the computer systems that corporations build for their employees are either canceled or rejected as unfit for duty. When they are installed, Strassmann says, “computers often create pathologies and increased costs.” Consider U.S. hospitals, he suggests in his new book, *The Squandered Computer.* In 1968 they employed 435,000 administrative staff and served 1.4 million patients at a time. Although the average daily patient population dropped to 853,000 by 1992, administrative employment actually rose to 1.2 million—in large part because in-

Four Innovations That (Might) Improve Work

Better Displays

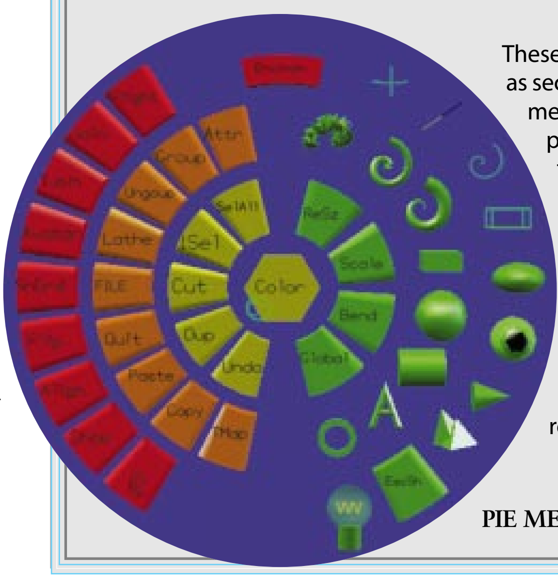
“Screens eight times their present size and four times their resolution might improve some kinds of work efficiency by 30 percent,” Landauer says. Two recent inventions might make such displays more affordable. Microvision in Seattle has produced thumb-size devices that rapidly scan a color image directly onto a viewer’s retina. Current versions produce images of size and resolution comparable to conventional monitors, but the company’s director of engineering claims that the technology should scale easily to larger, more detailed displays. At M.I.T., Joseph Jacobson has formulated an ink that, coated onto paper, turns the sheet into an electronically controlled display. Plugged into a computer, the paper can then produce black-and-white images of 100 dots per inch that remain stable even when power is removed. The sheets can later be erased and rewritten. Jacobson is working on color versions.

AP/WIDE WORLD PHOTOS

RETINAL PROJECTION of a toucan appears beside Microvision vice president Todd MacIntyre.

Pie Menus

These arrange command options as sectors in a circle instead of segments on a bar. “They are 30 percent faster and have half the error rates of menu bars,” Schneiderman says. “We remember angles much better than distances,” explains Ted Selker of the IBM Almaden Research Center in San Jose, Calif. “So pie menus allow you to make choices much more rapidly, relying on muscle memory.”



MICHAEL F. DEERING *Sun Microsystems*

PIE MENUS are more efficient.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

ELECTRONIC INK turns paper into a digital display.

formation processing consumed an increasing amount of staff time.

Many industries that made strategic investments in technology to become more flexible and responsive to changing markets, Roach says, have in fact accomplished quite the reverse. “Here’s the rub,” he explains, “About 85 percent of these outlays over the years have gone into banks, securities firms, insurance companies, airlines, retail and the like. It used to be that these companies’ main assets were people.” During recessions, they could lay off workers and remain competitive. “But now they have this massive infrastructure of installed IT” whose expenses are fixed, he points out, adding that in the next recession, “there could be an extraordinary crunch on their bottom line. So there is a real downside here to the information age.”

Still, there is clear upside potential. If companies can find more effective ways, if not to automate, then at least to augment their higher functions, computers and networks might produce as strong a productivity kick as the generations of machines that preceded them. To do that, firms will need to pay closer attention to what IT actually costs and truly delivers.

PC Pathologies

A typical desktop PC carries a price tag of about $3,000 in the U.S.—or about $1,000 a year over the average life span of an office machine. But research by the Gartner Group in Stamford, Conn., reveals that in corporate practice, the average annual bill is more like $13,000. Most corporate PCs are linked to a network and contain a few standard programs: that adds $1,730 a year. Because computers are often hard to use, companies have to provide about $3,510 worth of technical support for every user. Then there are the technicians needed to keep the network humming, who add $1,170 to the check.

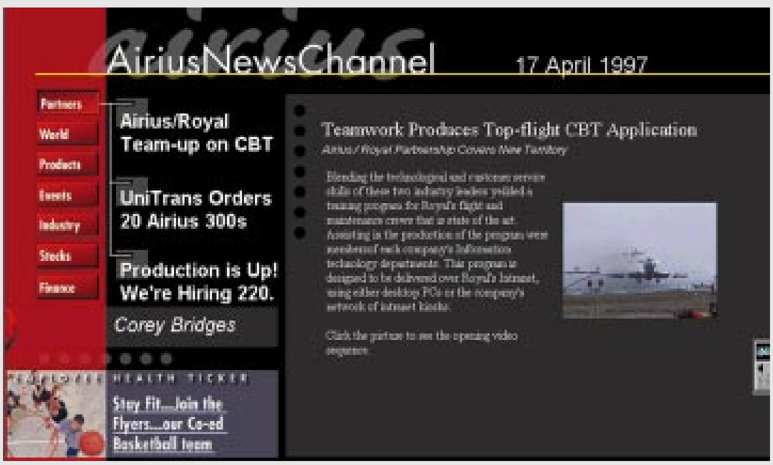
The largest notch in Gartner’s tally, however, is for the time that employees waste “futzing” with their computers rather than working on them. That costs employers another $5,590 per computer each year, the group estimates. Its guess may be low. SBT Accounting Systems in San Rafael, Calif., found in a 6,000-person survey that office workers futz with their machines an average of 5.1 hours—more than half a workday—each week. One fifth of that time was wasted waiting for programs to run or for help to arrive. Double-checking printouts for accuracy and format ran a close second. Lots of time goes into rearranging disk files. And then there are games; Microsoft Windows comes with four preinstalled. All told, SBT estimates, futzing costs American businesses on the order of $100 billion a year in lost productivity.

There may be little that companies can do to reduce hardware and futzing costs. Boeing removed Windows’s solitaire game from all its machines, Landauer notes. Sun Microsystems reportedly banned its managers from using presentation software to create fancy slides for meetings.

Of course, businesses could lower their IT budgets considerably by holding on to their computers and software for more than three or four years. But few do. “My guess is that 80 to 90 percent of that $213 billion [U.S. investment] goes to replace obsolete IT each year,” Roach says.

The software industry frustrates long-term investments by producing ever larger, slower programs that require ever larger, faster machines. At the March conference, Myhrvold modestly proposed “Nathan’s First Law”: “Software is a gas,” he said. “It expands to fill its container.” In fact, that is more of a policy than a necessity. “After all,” he observed later with a laugh, “if we hadn’t brought your processor to its knees, why else would you get a new one?”

But when it comes to software, new is not necessarily improved. Behavioral studies have shown that “creeping featurism” is often counterproductive. Software developers know this. “The biggest single problem we see users having



NETSCAPE COMMUNICATIONS CORPORATION

CUSTOMIZED OFFICE INTERFACES could be constructed for employees.

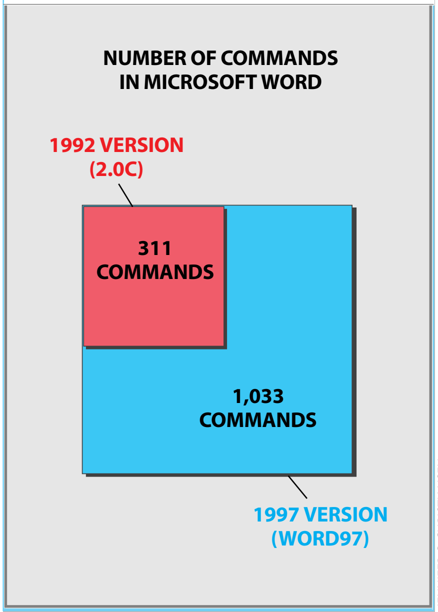
Specialized Software

Norman argues that “the answer is to simplify the technology, have it do less.” Netscape claims its new Netcaster software allows companies to easily build interfaces customized for their employees. “The idea behind Netcaster is the ability to take any Web page and have it become the primary user interface for your computer,” hiding the operating system beneath, explains Mike McCue, Netscape’s director of advanced technology. “The administrator can create a single environment that looks and works the same for everybody, regardless of the kind of computer they use. This should really reduce training and support costs.”

User-Centered Design

These are all impressive ideas, but, as Nielsen points out, “experience shows that if we just take our best visions and implement them, they will fail.” The reason, Landauer elaborates, is that “the average interface has 40 defects in need of repair. Two usability evaluations or user tests will usually find half the flaws; six will find almost 90 percent. This only takes a day or two.” Repeated testing, it seems, is perhaps the most potent technique of all.

Creeping Featurism



JENNIFER C. CHRISTIANSEN

is mapping their goal to the function in the program that will perform it," says Ken Dye, Microsoft's usability manager for desktop applications. "Adding features that have less and less utility has made it more difficult for people to do that, because there is a larger set to choose from." So why do this year's Microsoft programs have hundreds more features than the previous versions? Dye blames it on trade press reviewers who evaluate products with checklists.

If increasingly feature-laden interfaces are a business necessity for software companies, it may be because their customers underestimate the price of hard-to-use software. Four years of surveys by Margaret Hurley, director of research for the Nolan Norton Institute in Melbourne, Australia, show that nontechnical employees take 4 to 10 percent of their time to help co-workers solve computer problems. That huge reservoir of hidden support, Hurley calculates, lofts the total annual cost for a PC from $13,000 to about $23,500. "The factor most closely linked to support costs," she says, "was the extent to which the user interface matched the way users thought and worked."

Designing software that is both efficient and easy to use is hard, says Jakob Nielsen, an interface expert at Sun Microsystems. "User interfaces only work if every detail works. If you get one button wrong, people can easily waste half an hour recovering from a mistake." Because most interfaces are designed by technically savvy programmers and are rarely tested on typical users, he says, more often than not they contain dozens of significant flaws.

The Microsoft team in charge of designing the user interface for Windows 95 studied people using the previous version, which was the most common PC operating system for three years. Almost all users, the team reported at the CHI '96 conference on computer-human interaction, had trouble managing the software's overlapping windows. Nearly half avoided running more than one program at a time because doing so confused them. A large fraction were bewildered by the filing system, which places folders within folders within folders, unlike the real world. Many had trouble double-clicking the mouse. The average beginner took 10 minutes to open a program if it was not already visible. Many of these basic problems also bedevil Apple Macintosh and UNIX users; custom-built software is often worse.

"It's time to get angry about the quality of user interfaces," exclaims Ben Schneiderman, head of the Human-Computer Interaction Laboratory at the University of Maryland. "The public doesn't understand what they could have had by now," agrees Bruce Tognazzini, a designer who helped to develop the original Macintosh interface. They and others argue that applying human-factors research to existing software technology could make workplace computer systems dramatically more productive, easier to use and cheaper to support.

An NYSE Model

The New York Stock Exchange (NYSE) took this approach four years ago when it hired Mauro/Mauro/Design to help upgrade the four primary computer systems used on its trading floor. Stock specialists, each trading just a few companies, were using vintage 1987 software and millions of paper cards to record quotes and sales. But the market's growth was crowding more traders into very limited space. "In two weeks we now process as many shares as we handled each year in the late 1970s," explains William A. Bautz, the exchange's senior vice president for technology. The volume threatened to choke the system.

The NYSE needed its upgrade soon, but instead of jumping into programming, "we spent the first six months observing traders on the floor, modeling their cognitive work flow," recalls Charles Mauro, president of the design firm. "Then we would develop a prototype, test a piece, expand the functions, test again—we went through 30 iterations of testing." The software engineers hated this approach, he says, because the specifications kept changing.

But the results were impressive. The upgrade took just two years to complete; previous revisions had taken six. Wireless handheld computers replaced the paper cards and readers, saving $1 million a year, according to Mauro. As the system has been rolled out, Bautz reports, specialists' productivity has risen dramatically. "We think we can now get over two billion shares a day through the system," he says. Error rates have fallen by a factor of 10 since 1987 even as workloads more than doubled.

Bautz figures that despite the fees of two design firms, the upgrade cost no more than it would have using a traditional development process. "I'm firmly convinced that within 20 years, this methodology will be the prime factor in

NEW YORK STOCK EXCHANGE

PORTER GIFFORD *Gamma-Liaison*

NEW YORK STOCK EXCHANGE redesigned the computer interfaces on its trading floor, replacing millions of paper cards (*top*) with handheld devices (*bottom*). Traders now handle many more shares per day yet make fewer mistakes.

increasing productivity in the information age," Mauro testifies.

He is not alone in his enthusiasm. Sarah A. Bloomer, director of the Hiser Group, reports that when her firm reformatted a grant administration system to reflect the way workers at Australia's health and family services agency approach their jobs, employees were able to shave five minutes off each task, on average—equivalent to an annual savings of $3.5 million. After American Express redesigned its computer interface for bank authorizations, training times reportedly fell from 12 hours to two, and task times dropped from 17 minutes to four—a 325 percent efficiency improvement.

Unfortunately, few of the futuristic technologies that so excite academic and industrial researchers have demonstrated such utility. "There is no evidence yet that any of these putative replacements for the standard graphical user interfaces are any better," Landauer says. "It's people's pipe dreams at this point."

Indeed, researchers presented at least 83 novel interfaces at the CHI '97 conference. Many do truly nifty things. One program takes dictation with 97 percent accuracy from radiologists. Another allows users to walk through virtual-reality supermarkets. A "HyperMirror" both reflects users' images and projects video of distant collaborators. A Web-surfing agent automatically races ahead on the Net and brings back pages that it calculates will interest its owner.

But only nine of those 83 projects compared workers' performance on real tasks using the new interface with their current way of doing things. Four offered no gains at all. Radiologists completed their reports faster without the computer. Video offered no improvement over audio for collaborative writing or design. Only three new interfaces—an interactive blueprint program, the combination of a keyboard joystick with a mouse for two-handed input, and a "wearable" computer—sped work significantly.

That last device is worth noting, for it exemplifies what some argue is the direction most likely to lead to strong productivity growth. Developed at Carnegie Mellon University, the VuMan3 computer straps onto a belt; a wire connects it to a small display worn over one eye. Although meant to be used for three-dimensional tasks where both hands must be free, the device does not use 3-D graphics or speech recognition. It has simple controls: a large dial and three oversized buttons. Yet in field tests at a military maintenance depot, the device cut the time needed to inspect amphibious vehicles by 40 percent and trimmed another 30 percent off paperwork. Like the stock traders' handheld pads and the Australian bureaucrats' grant forms, its interface is specialized for a single task.

ENGINEERING DESIGN RESEARCH CENTER, ICES, CARNEGIE MELLON UNIVERSITY

WEARABLE COMPUTERS developed at Carnegie Mellon University, such as this one worn on the belt and with an eyepiece display, use simple interfaces specialized for single tasks. In field tests, the systems doubled vehicle inspection efficiency and reduced aircraft inspection times from 40 hours to 31.

Toward Useful Tools

Specialization, suggests Donald Norman, former vice president of research for Apple, can help provide a "better match between people's software and their jobs." He proposes abandoning giant, general-purpose application suites for simpler tools designed to do just one function well. Some, he suggests, should be separate "information appliances" outside the PC but linked to it by a network. The much heralded convergence of PCs, televisions and telephones "is totally wrong," concurs William Buxton, chief scientist for Silicon Graphics. "We need to diverge."

Apple tried last year to introduce interchangeable software components with its OpenDoc system. OpenDoc found few takers, but the industry appears ready to try again. Several groups have proposed competing standards that would allow tools to work together, regardless of who made them.

Once compromise is reached, the Internet will allow anyone to sell the software equivalent of a better mousetrap; the Web has lowered software distribution costs to virtually nil. Many companies hope the Net will similarly slash their distribution, transaction and marketing expenses. The path toward that grail is filled with dragons, however. As firms push their employees and internal communications onto the network, futzing opportunities multiply. Software that Netscape plans to release later this year will enable a company to create Web "channels" that serve as the default interface on its employees' computers. Workers can subscribe to other channels (such as ABC and ESPN) as well: "We have the most powerful media companies in the world working to take over the desktop," grins Mike McCue, Netscape's director of advanced technology.

Given such software and the proliferation of corporate-wide networks, "every company suddenly has its own user-interface design project," Nielsen points out. "If they don't do it right, they are going to face immense productivity loss." On the other hand, if businesses seize the opportunity to study what their workers do, to test software carefully and to demand provable payoffs from their information technology, Landauer's rough calculations suggest that productivity growth in the U.S. could rise back above the 4.5 percent mark of the 1960s.

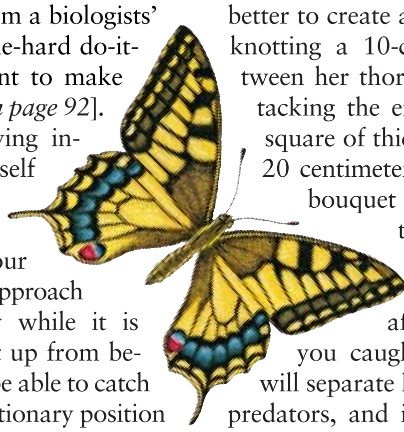
Perhaps, but nations might do well to hedge their bets. Even if user-centered design becomes the rule rather than the exception, Roach of Morgan Stanley warns against expecting macroeconomic miracles. "Productivity is a trend that moves glacially," he says. "You cannot expect instant payback from any input factor, whether it is increased employment, better training, new technology or more capital. It's just not going to happen overnight." SA by Shawn Carlson

How-To's of Butterfly Rookeries

Some of my earliest adventures in science came while I was a small boy hunting insects in my mother's flower garden. She loved her garden for its explosions of yellow, lavender and violet blossoms, but I was much more interested in stalking the ostentatious visitors they attracted. My mother's flowers served as sugary ports of call for butterflies so dazzling that spring still finds me netting and occasionally raising these delightful insects.

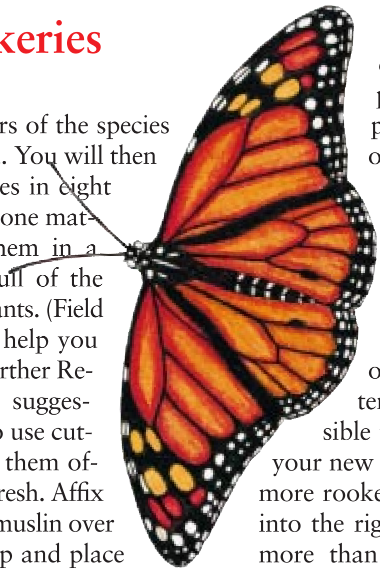
Lepidoptera (a term that includes butterflies, moths and skippers) is perhaps the most widely studied order of insects. Yet with only modest equipment, the amateur lepidopterist can find almost endless diversion and even do original research. Populations can respond dramatically to changing habitats, and each specimen tells a story.

The first requirement for a butterfly hunter is, of course, a deep gauze net. You can buy one from a biologists' supply house, but die-hard do-it-yourselfers may want to make their own [*see box on page* 92].



Never chase a flying insect. You'll run yourself into the dirt in half an hour with nothing to show for your exhaustion. Instead approach your quarry slowly while it is feeding and scoop it up from behind. You may also be able to catch butterflies from a stationary position as they flutter past. Always let the net overtake them rather than swooping it toward them head-on. Make sure to jerk the net closed with a quick 90-degree twist at the end of your swing to keep your prey from escaping.

If you want to assemble a butterfly collection, you should raise your own specimens—they will be free of the parasites that can mar wild exemplars, and they are fascinating to study. Luckily, butterflies are easy to rear. The sex of members of many species can be determined by the patterns of spots on their wings. If you are uncertain, catch at least four members of the species you wish to breed. You will then have seven chances in eight of having at least one mating pair. Place them in a glass terrarium full of the butterfly's food plants. (Field observations will help you here, or see the Further Resources box for suggestions.) It's okay to use cuttings, but replace them often to keep them fresh. Affix cotton netting or muslin over the terrarium's top and place it outside and out of direct sunlight.



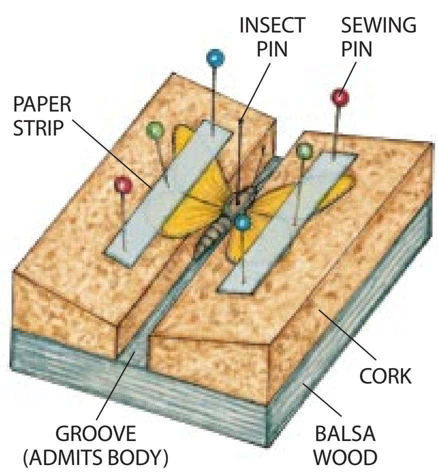
A female can also lure her own males for mating. But please don't, as some entomologists suggest, tack one of the female's wings to a tree to immobilize her. Her agonized fluttering will very likely injure her severely and attract more predators than suitors. It is much better to create a short leash by gently knotting a 10-centimeter thread between her thorax and abdomen and tacking the end to the center of a square of thick poster board about 20 centimeters on a side. Secure a bouquet of her favorite flowers to the square and hang the assembly horizontally in the late afternoon near where you caught her. This platform will separate her from tree-dwelling predators, and its swaying will scare away most birds.

In the early morning, transfer your hopeful mother to a net-lined enclosure surrounding a plant on which her species' caterpillars can feed. Caterpillars can be picky, so some butterflies will lay eggs only on particular kinds of plants. If you don't know which plant to use, secure cuttings from several kinds near where the female was caught. The eggs might be sterile, but if they hatch, keep track of which caterpillars do best.

Plastic two-liter soda containers make ideal caterpillar rookeries. Cut off the top and tape a layer of muslin over it, then place the eggs and your caterpillar's favorite food plant (or cuttings from the plant the female laid her eggs on) inside. A smidgen of petroleum jelly on the inner lip will keep the hatchlings from climbing up the side and fouling themselves in the netting.

Keep your caterpillars outdoors with sunlight and temperature as close as possible to their normal habitat. As your new family matures, you'll need more rookeries. A caterpillar must get into the right position to pupate, and more than about five siblings often means too few places in a small container. Arrange twigs in the containers to provide suitable niches. If you rear too many caterpillars for your needs, release the excess creatures on live food plants in their native environment. Transfer any chrysalides or cocoons that develop to your outdoor terrarium and record their daily progress in your field notebook. If all goes well, they will ultimately become magnificent adults.

Select only the best specimens for mounting. Traditionally, two are chosen—one mounted face down and the



PATRICIA J. WYNNE (*butterflies and mounting assembly*)

MOUNTING A BUTTERFLY **(above).** ***Butterflies pictured are*** **(clockwise from top right)** ***female monarch*** **(Danaus plexippus);** ***male monarch; swallowtail*** **(Papilio machaon); Lycaeides melissa samuelis.**

other face up to display both sides of the wings. Place cotton balls soaked in either a commercial insecticide or fingernail polish remover into a tea strainer. Hang the strainer with a thread near the top of an airtight jar and place a few layers of paper towel on the jar's bottom. Stun the insect with a firm (yet careful) pinch on the underside of its thorax, drop it into the jar and secure the lid. Return in about 30 minutes to remove your specimen from the jar.

If you can't mount the specimen immediately, store it in a triangularly folded piece of blotting paper. Keep stored butterflies in a sealed container in the freezer until you can mount them. Make sure the specimens have returned to room temperature before you proceed.

The illustration on the opposite page shows the procedure for mounting butterflies. Cork or balsa wood make good surfaces for pinning. These should be slightly angled as shown, to compensate for the wings' tendency to droop. Begin by inserting an insect pin through the right dorsal side of the thorax. (Never

Further Resources

Books:

The Amateur Naturalist. Gerald Durrell. Alfred Knopf, 1982.

Butterflies East of the Great Plains. Paul A. Opler and George O. Krizek. Johns Hopkins University Press, 1984.

The Butterflies of North America. James A. Scott. Stanford University Press, 1986.

The Practical Entomologist. Rick Imes. Simon & Schuster, 1992.

Biological Supplies:

BioQuip Products. 17803 LaSalle Ave., Gardena, CA 90248. Telephone: (310) 324-0620. E-mail: bioquip@aol.com

Butterfly World. Tradewinds Park, 3600 West Sample Rd., Coconut Creek, FL 33073. Telephone: (954) 977-4400.

Organizations for Butterfly Enthusiasts:

Sonoran Arthropod Studies Institute. P.O. Box 5624, Tucson, AZ 85703-0624. Telephone: (520) 883-3945. E-mail: arthrostud@aol.com

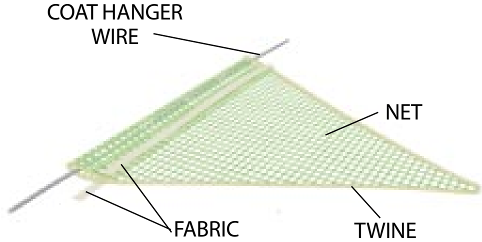
Young Entomologists' Society. Gary and Dianna Dunn, 1915 Peggy Place, Lansing, MI 48910-2553. Telephone: (517) 887-0499. E-mail: yesbug@aol.com

Lepidoptera Research Foundation. 9620 Heather Rd., Beverly Hills, CA 90210. Telephone: (310) 274-1052. E-mail: Mattoni@ucla.edu

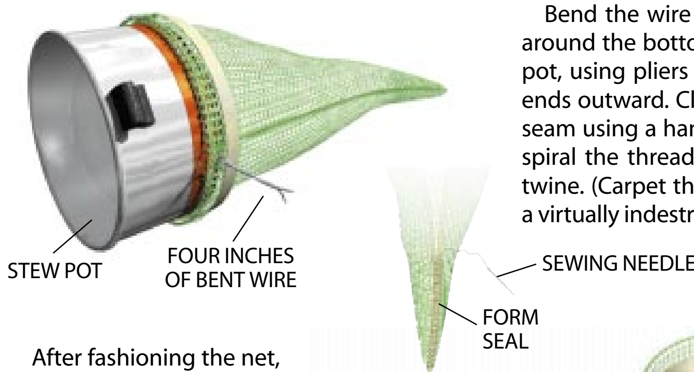
Lepidopterists' Society. Membership: 1900 John St., Manhattan Beach, CA 90266-2608. Telephone: (310) 545-9415.

Constructing a Butterfly Net

The scoop must be fashioned from soft fine-mesh cotton netting and be at least two feet deep. Use a sewing machine to embed a length of twine along the edge that will become the side seam; this reinforcement will keep the seam from unraveling. Stitch fabric reinforcement onto the edge that will become the opening and then sew the net and fabric around a length of coat hanger wire.



Bend the wire into a circle around the bottom of a stew pot, using pliers to bend the ends outward. Close the side seam using a hand needle to spiral the thread around the twine. (Carpet thread creates a virtually indestructible seal.)



After fashioning the net, make two four-inch-deep crossing cuts with a coping saw along a broomstick's axis. Insert the ends of the net's wire frame and pour a generous helping of 24-hour epoxy into the slots. Finally, tightly wrap the assembly with a layer of cotton clothesline. My first homemade net survived more than 10 years of vigorous use.

BRYAN CHRISTIE

substitute sewing pins for insect pins; they are too thick and will rust.) Spread and secure the wings and then attach the insect to the center of the mounting board. Keep the abdomen from sagging by crossing two pins directly underneath it. Let the specimen dry out for at least a week before transferring it to a permanent case.

Look out for minuscule mounds of dust beneath your specimens that tip off the activity of tiny insect pests that may be slowly devouring your collection. Make sure each case is tightly sealed with a few mothballs inside to control these marauders.

Serious collectors should connect with their nearest natural history museum. Many museums continually collect local species to monitor the changes in these populations. Collecting for an institution is a great way to advance science and give conservationists the raw data they need to help protect the environment. SA

For more information about this and other amateur science projects, check out the Society for Amateur Scientists's World Wide Web page at http://www.thesphere.com/SAS/ You may call them at (800) 873-8767 or (619) 239-8807 or write them at Society for Amateur Scientists, 4735 Clairemont Square, Suite 179, San Diego, CA 92117.

I gratefully acknowledge informative conversations with David Faulkner.

by Ian Stewart

Squaring the Square

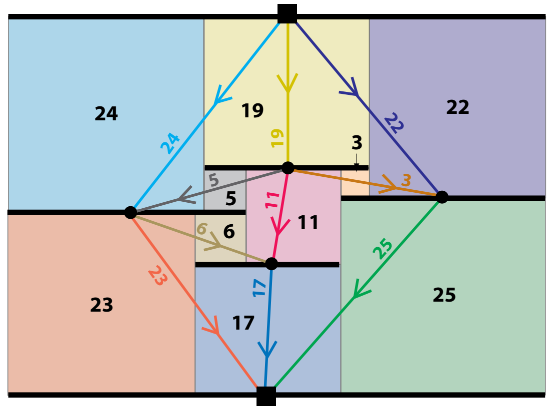
The problem of squaring the circle goes back to the ancient Greeks, but that of squaring the square is more recent. Can you tile a square using square tiles? Easy, you might say—consider a chessboard, where 64 small squares tile one big one. There's an extra condition, however: all the tiles must be of different sizes.

In 1903 Max Dehn proved that if a rectangle is tiled by squares, then the sizes of the tiles, and of the rectangle itself, are commensurable—integer multiples of a single number. So if we choose a suitable unit of measurement, all sides are integers. This theorem has since been proved in at least a dozen different ways, all of them fairly cunning.

Say that a rectangle or square is squared if it can be tiled by distinct square tiles. In 1909 Z. Morón discovered the first squared 33 × 32 rectangle, using nine square tiles of sides 1, 4, 7, 8, 9, 10, 14, 15 and 18. You might like to make up a set of tiles and try this puzzle; for the answer, see *Unsolved Problems in Geometry,* by Hallard T. Croft, Kenneth J. Falconer and Richard K. Guy (Springer-Verlag, New York, 1991). Morón also managed to tile a 65 × 47 rectangle with 10 square tiles [*see illustration at right*].

In 1939 R. Sprague solved the "squared square" problem with a tiling that employed 55 different tiles. Unfortunately, it lacked elegance in one respect: it contained a smaller squared rectangle. Tilings that do not include any squared rectangles are said to be "simple" and are harder to find.

By 1940 R. L. Brooks, C.A.B. Smith, A. H. Stone and W. T. Tutte had discovered the first simple squared square. Martin Gardner has described their method entertainingly in *More Mathematical Puzzles and Diversions* (Penguin Books, London, 1977). The team started by representing the structure of any squared rectangle by a network, known as its Smith diagram. Every horizontal line in the squared rectangle corresponds to a node of the network, and each component tile corresponds to an edge. This edge links the two nodes corresponding to the horizontal lines that meet the top and bottom of the tile, and the edges are labeled with the size of this tile.

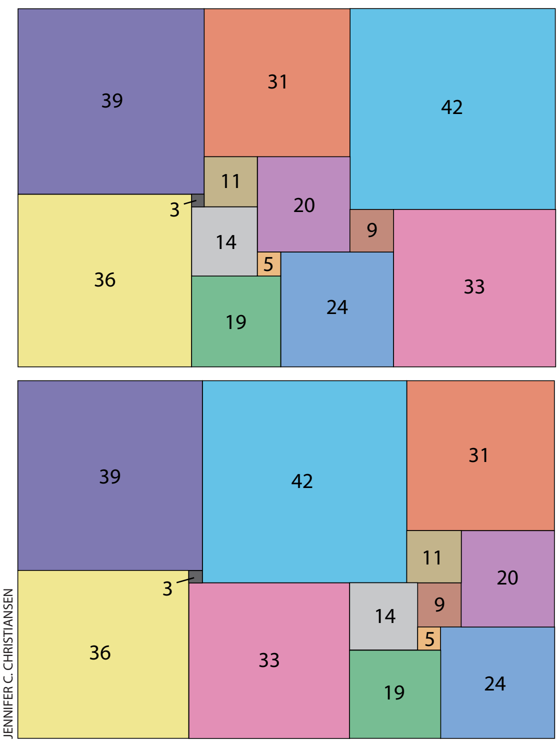


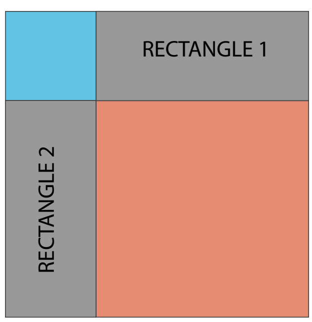
SQUARED RECTANGLE can be represented as an electrical circuit. Each horizontal line corresponds to a node. Current flows into the top node and out of the bottom one; the amount of it through each wire equals the side of the square represented.

Remarkably, if each edge of the Smith diagram is assumed to be a wire of unit resistance, and the numerical labels are interpreted as electric currents flowing through the wires (measured in amperes, say), then the whole diagram forms an electrical circuit that obeys the usual "Kirchhoff's laws" of electrical engineering. If we assign opposite signs to currents that flow in opposite directions, the laws are:

1. The total current flowing into any terminal is zero, except for those nodes where it enters and leaves the circuit.
2. The sum of the currents around any closed loop is zero.

That these laws fit our problem follows easily from the geometry of the tiling. For instance, the second law implies that the sum of the sides of squares running along the left vertical edge equals the sum of the sides of those along the right edge—an obvious result. By using principles from electrical circuit theory, the four mathematicians developed systematic methods for constructing and analyzing squared rectangles, with the eventual objective of finding a simple squared square.





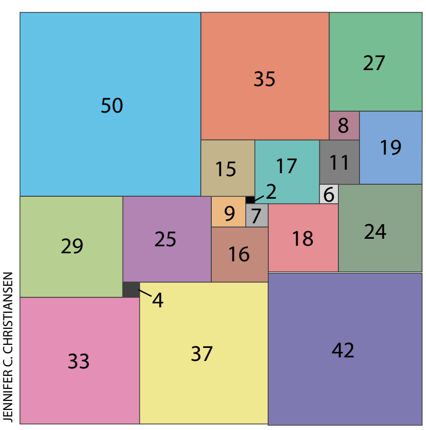
TILES OF THE SAME SIZE CAN SQUARE a 112 × 75 rectangle in two ways (left). *If squared with different tiles, however, two rectangles can be combined with squares to create a larger squared square* (right).

The first breakthrough came from an unexpected quarter. Brooks had found a 112×75 squared rectangle with 13 tiles, and he built a jigsaw puzzle out of them. His mother had a go at the puzzle and succeeded in solving it as well—but her solution was different. The mathematicians had never come across such a phenomenon before: a set of square tiles that tiled the same rectangle in two different ways. But they had been hoping for some time to find two squared rectangles of the same size that had no common tile sizes, because then it would be easy to fit them together, with two extra squares, to make a squared square. It would be a compound square, but it would be a start.

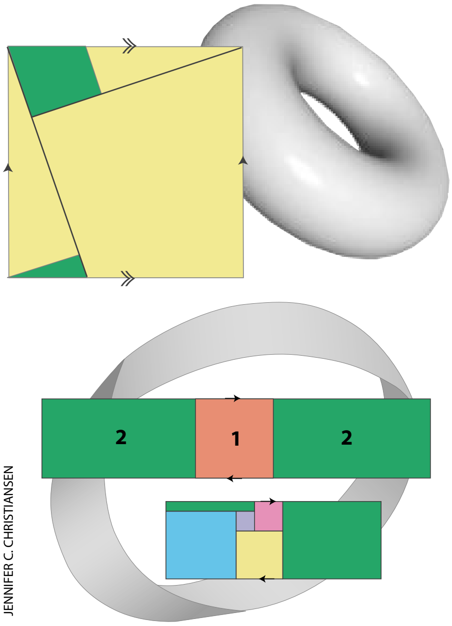
Brooks's rectangle would not lead to a squared square, because the same set of tiles was used twice. But on looking at the Smith diagrams of the two tilings, the mathematicians realized that on short-circuiting two nodes of one diagram by putting them on top of each other, they could obtain the other diagram. The two points thus "identified"—mathematical jargon for shorted—were at the same electrical potential, so that the flow of electricity was not affected.

From this clue they developed other ways to tinker with Smith diagrams. Eventually this approach paid off, leading them to a simple squared square formed from 69 tiles. With further effort, Brooks reduced the number of tiles to 39.

In 1948 T. H. Willcocks found a squared square with only 24 tiles. But his square was not simple. Meanwhile J. W. Bouwkamp and his colleagues were



UNIQUE SQUARED SQUARE with the fewest tiles.



JENNIFER C. CHRISTIANSEN

TORUS* (top) *and Möbius strip* (bottom) *can be tiled in special ways. The edges marked with similar arrows must be glued so that the arrows line up. Then the green areas combine into square tiles.

cataloguing all possible squared rectangles with up to 15 tiles—finding a total of 3,663. In 1962 A.W.J. Duivestijn proved that any simple squared square must contain at least 21 tiles; by 1978 he had found such a square and proved that it was the only one. In 1992 Bouwkamp and Duivestijn published 207 simple squared squares with between 21 and 25 tiles—all such squares, in fact.

Although these results pretty much polish off the squared square problem, there are innumerable variants. What about squared dominos—rectangles with one side twice as long as the other? There is a trivial way to square such a rectangle: start with a squared square and add one additional square tile, the size of the entire squared square, next to it. But are there nontrivial ways?

Another extension is to tile surfaces other than rectangles, an option discussed by David Gale in his "Mathematical Entertainments" column in the *Mathematical Intelligencer*. Topologists know that several interesting surfaces can be constructed by identifying opposite edges of rectangles—gluing them together, at least in the imagination. Take a rectangle and glue two opposite edges: you get a cylinder. Give the rectangle a half twist before gluing, and you get a Möbius strip. Glue both pairs of opposite edges together, with no twists, and the result is a torus—a doughnut-shaped surface, hole and all. Glue both pairs of opposite edges together, giving one pair a half-twist, and you get a Klein bottle—a famous one-sided surface that cannot be formed in three-dimensional space without crossing itself. Give both pairs a half-twist, and you get a projective plane—also one-sided and impossible to represent in three dimensions.

Clearly, any tiling of the rectangle carries over to a tiling of the resulting surface. But the surface may possess additional tilings, because its tiles can cut across the glued edges. For example, the lower figure at the left shows a Möbius strip tiled with just two squares, of side 1 and 2, respectively. The arrows indicate the sides to be glued. Although one square in the picture seems to be cut into two rectangles, those pieces join up when the edges are glued. This tiling of the Möbius strip has a rather nasty feature, unfortunately: the small tile has a common boundary with itself. Its top and bottom edges get glued—so really it is a Möbius strip itself, not a square. In 1993 S. J. Chapman found a tiling of the Möbius strip without this awkward feature, using five tiles (*lower strip*). No such tiling exists with fewer tiles.

A cylinder can be squared as well, but with at least nine tiles—just as for rectangles. "Trivial" squarings simply take Morón's rectangles and join up suitable edges, but there are also two nontrivial nine-tile squarings. Their tiles are the same sizes as Morón's.

For the cylinder and Möbius strip, the edges of the tiles have to be parallel to those of the surface. But the torus, Klein bottle and projective plane do not have any edges, so tiles could conceivably be set at an angle. In fact, if this is done, a torus can be tiled with just two squares, provided we allow two edges of the same tile to meet. (As a bonus, there is a proof of the Pythagorean theorem hidden in this picture; can you see why?)

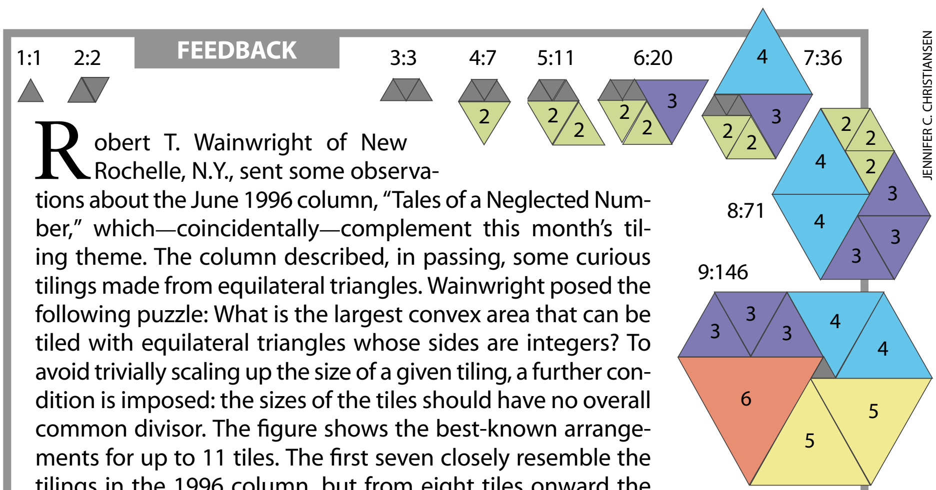
Not much seems to be known about tilings of the Klein bottle. Every tiling of a Möbius strip can be glued along its edge (there is only one) to give a tiling of the Klein bottle, and there are no other ways to tile the Klein bottle with six or fewer square tiles. Nobody knows whether this remains true for seven or eight tiles—but it is false for nine.

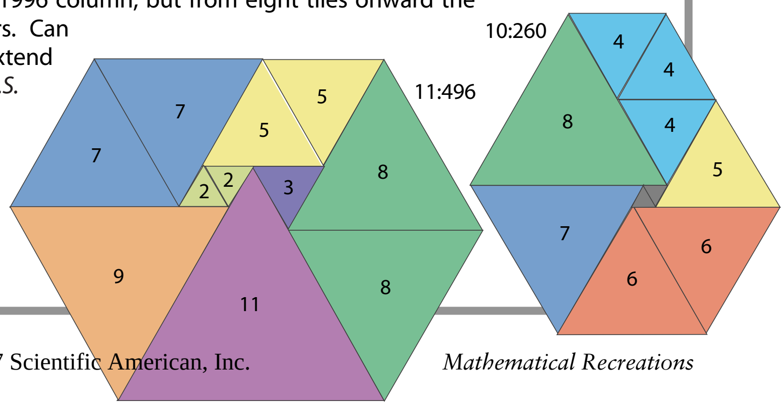
Virtually nothing is known about tilings of the projective plane. And what about tiling, say, the surface of a cube? The field is wide open—and I eagerly await your Feedback. SA

Answers to the factoring problem from June: 777,923 = 881 × 883; 603,181 = 641 × 941; 21,720,551 = 211 × 311 × 331

FEEDBACK

Robert T. Wainwright of New Rochelle, N.Y., sent some observations about the June 1996 column, "Tales of a Neglected Number," which—coincidentally—complement this month's tiling theme. The column described, in passing, some curious tilings made from equilateral triangles. Wainwright posed the following puzzle: What is the largest convex area that can be tiled with equilateral triangles whose sides are integers? To avoid trivially scaling up the size of a given tiling, a further condition is imposed: the sizes of the tiles should have no overall common divisor. The figure shows the best-known arrangements for up to 11 tiles. The first seven closely resemble the tilings in the 1996 column, but from eight tiles onward the pattern differs. Can any readers extend the list? —*I.S.*





CURIOUS TILINGS made of equilateral triangles.

JENNIFER C. CHRISTIANSEN

SEX AND COMPLEXITY

Review by Tim Beardsley

Arcadia
BY TOM STOPPARD
Faber and Faber, London, 1995 ($9.95)


STAN BAROUH

TOM STOPPARD'S ARCADIA
links ideas from the Victorian (left) *and modern* (right) *worlds.*

"I can't think of anything more trivial than the speed of light. Quarks, quasars, big bangs, black holes—who gives a s--t?" demands Bernard Nightingale in Tom Stoppard's play, shortly before his sensational literary theory that the poet Lord Byron killed a rival in a duel is decisively disproved by botanical evidence. The obnoxious professor's comeuppance is emblematic of the tension between poetry and science that pulls at the characters in *Arcadia,* just as that mythic landscape strains to reconcile bucolic leisure and natural fecundity.

Stoppard's play, first published in the U.K. four years ago, is poised to reach a much larger audience now that general production rights are available in the U.S. (This review is based in part on a performance at the Arena Stage in Washington, D.C.) *Arcadia* deserves a tip of the hat from every rationalist who has fumed at Hollywood's two-dimensional scientific noncharacters, such as the chaos theorist Ian Malcolm, who stumbles through *Jurassic Park.* The verbal virtuosity in *Arcadia* rests on a respectful, even sympathetic, examination of the way modern science looks at the world.

The play revolves around a 13-year-old math prodigy, Thomasina Coverly, who baffles her tutor, Septimus Hodge, by asking if God is a Newtonian. Thomasina, who sharpens her skills with attempts to prove Fermat's last theorem, goes on to invent—in 1809!—the technique that would later become known as fractal geometry. She teasingly writes in the margin of her lesson book that she has discovered a "truly wonderful method whereby all the forms of nature must give up their numerical secrets," adding that "this margin being too mean for my purpose, the reader must look elsewhere"—a sly reference to Fermat's nearly identical jottings.

Thomasina recognizes (slightly anachronistically) that Sadi Carnot's account of the physics of steam engines represents "bad news from Paris," even as a Newcomen steam pump helps to remodel the garden of her parents' Derbyshire country house in the "picturesque" style that aims to outnature Nature. Carnot's thermodynamic equation, Thomasina perceives, "goes only one way" in time, unlike Isaac Newton's equations of motion. The consequence is that the universe must run down, arriving eventually at a state of "heat death" in which matter and energy are evenly dispersed. Her tutor is not cheered by the news.

One hundred and eighty-odd years later, a parallel story unfolds. A mathematical biologist and a social historian, now living in the same house, try to reconstruct the dwelling's earlier times. The biologist, Valentine, uses shooting records to model the chaotically fluctuating populations of game birds on the grounds, whereas Hannah, the historian, is absorbed by the garden.

Their predictable romantic equilibrium is predictably destroyed when a third body arrives—the aforementioned Nightingale, hot on the trail of Byron, who was a visitor to the cottage in Hodge and Thomasina's day. Nightingale's libidinous drive disrupts the tenuous social order, yielding chaos in the 1990s intriguingly similar to that produced two centuries earlier by the analogous drives of Hodge, Byron and the other philanderers of their period. Sex, one participant speculates, is the attraction that Newton left out of his formulations.

That attraction draws Thomasina—by a misfortune as unpredictable as the flap of a butterfly's wings—to her own kind of heat death, and Hodge to a life of melancholia. Whether Thomasina's insight into our dismal fate is correct is a question that science still cannot answer: thermodynamics says yes, but, just perhaps, complexity (in physics and in physicality) can forestall a dark and dreary end.

Stoppard, long known as one of England's most inventive playwrights, weaves these deep ideas seamlessly into scintillating dialogue about seduction and landscape architecture. Scientists tired of being represented either as Faust figures or as clowns should applaud the value of this achievement.

TIM BEARDSLEY is a staff writer for SCIENTIFIC AMERICAN.

EXPLORING THE OCEAN IN DEPTH

Review by David Schneider

The Universe Below: Discovering the Secrets of the Deep Sea
BY WILLIAM J. BROAD
Simon & Schuster, New York, 1997 ($30)

It might be taken for granted that journalists attempting to chronicle any complex scientific or technical enterprise must immerse themselves in their chosen subject matter. What comes as a surprise while reading William J. Broad's *The Universe Below* is that its author was able to fulfill that obligation quite so literally. Among the many fascinating tales of deep-sea exploration recounted, Broad includes several narratives of his own underwater exploits—donning scuba gear to investigate sunken shipwrecks off the Azores or diving to the bottom of the Pacific stuffed into the cabin of a tiny research submarine.

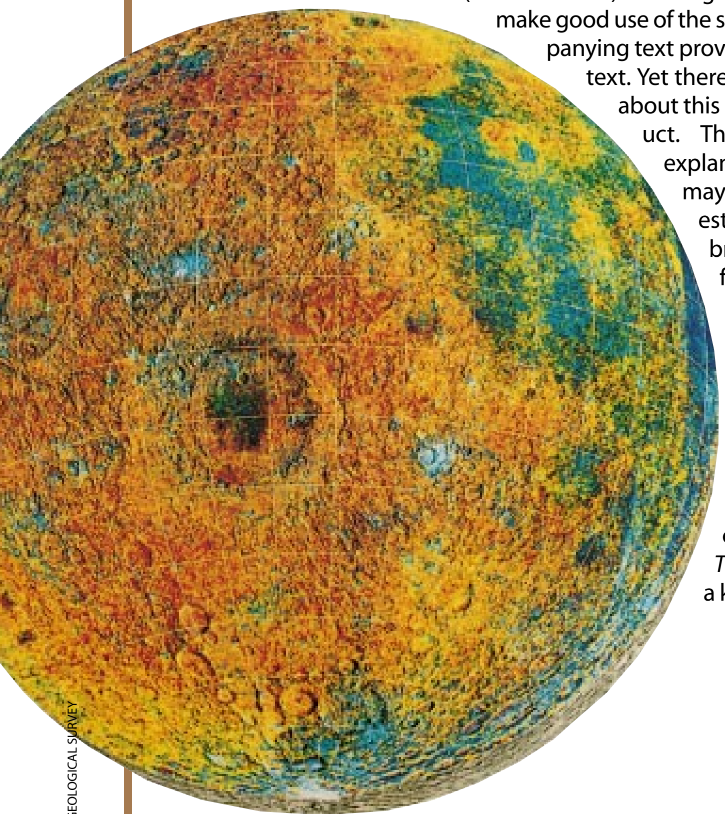
But *The Universe Below* is not simply a colorful underwater travelogue. Rather it weaves into a unified whole descriptions of many seemingly disparate efforts to explore and exploit the undersea realm. Beginning with early mariners' attempts to overcome their fear of the deep (and the monstrous creatures it was presumed to harbor), Broad traces the steady advance of scientific understanding as increasingly sophisticated methods were brought to the task of exploring the deep sea. As he begins the

THE ILLUSTRATED PAGE

The NASA Atlas of the Solar System
BY RONALD GREELEY AND RAYMOND BATSON
Cambridge University Press, New York, 1997 ($150)

With the space age only four decades old, spacecraft have already scrutinized 30 of the solar system's major bodies, including the moon (*below*) and every planet save Pluto. The magnitude of that triumph is paralleled by the magnitude of the atlas that illustrates it—each page measures 45 x 30 centimeters (18 x 12 inches). Dazzling color images and maps make good use of the space, while the accompanying text provides some helpful context. Yet there is something quixotic about this lavish, expensive product. Those who need the explanatory background may not have much interest in a mineralogical breakdown of the surface of the moon, and vice versa. And publishing is changing: many of the images (though not the maps) are now available for free on the Internet. As a grand synthesis of planetary cartography, however, *The NASA Atlas* is one of a kind.

—Corey S. Powell



U.S. GEOLOGICAL SURVEY

BRIEFLY NOTED

BILLIONS AND BILLIONS: THOUGHTS ON LIFE AND DEATH AT THE BRINK OF THE MILLENNIUM, *by Carl Sagan. Random House, New York, 1997 ($24).*
Completed shortly before Carl Sagan's untimely death this past February, these essays touch on many of his trademark themes. The title chapter, in which he gently mocks his tendency to pontificate about "billions" of this and that, falls flat. His exhortations on the perils of global warming and the folly of militarism, in contrast, argue powerfully against creeping complacency. Sagan concludes with an account of the rare bone disease that ultimately took his life, remaining resolutely rational to the end.

WHY WE AGE: WHAT SCIENCE IS DISCOVERING ABOUT THE BODY'S JOURNEY THROUGH LIFE, *by Steven N. Austad. John Wiley & Sons, New York, 1997 ($24.95).*
Aging occurs because any gene whose activity manifests late in life is immune from the forces of natural selection, so harmful mutations can collect over thousands of generations. Someday, genetic engineering may counteract the inevitable decline. But the author doubts whether the modern elixirs—vitamin E, exercise, melatonin, caloric restriction—can provide even limited help in lengthening life span.

RELATIVITY SIMPLY EXPLAINED, *by Martin Gardner. Dover Publications, Mineola, N.Y., 1997 ($11.95).*
THE LARGE, THE SMALL AND THE HUMAN MIND, *by Roger Penrose, with Abner Shimony, Nancy Cartwright and Stephen Hawking. Cambridge University Press, New York, 1997 ($19.95).*
Those struggling with Albert Einstein's theories of relativity will find Martin Gardner's 1962 text, now available in paperback reissue, a model of elucidation. Gardner softens the hard sciences with touches of humor and a relentless intellectual honesty. A fresh postscript brings the book up to date.

Following Einstein's lead, Roger Penrose seeks the common threads connecting the realms of relativity, quantum physics and consciousness. His attempts to link mind and quanta still look suspect, but one could hardly ask for a shrewder or more enthusiastic tour guide to the extremes of physics.

Continued on page 101

narrative, Broad describes not only those pioneering explorations of much renown, such as the research expedition of the HMS *Challenger* in 1873, but also illuminates the contribution of many less appreciated events and motivations. For example, he aptly points out a significant but often forgotten driving force in Victorian-era probing of the deep: the desire to test Charles Darwin's theories of evolution by looking for living fossils—ocean dwellers that having suffered little change in their watery abode over the ages should have evolved more sluggishly than land creatures.

Yet the historical context of deep-sea exploration becomes most important, and perhaps most engaging to read about, once Broad's narrative arrives at the age of undersea warfare. Of particular interest are his excellent descriptions of various cold war machinations on the seabed. Broad recounts, for instance, how in 1965 the U.S. Navy outfitted one of its submarines with an internal hangar and retractable doors so that spy equipment could be lowered into the ocean depths. The crew of the sub could then secretly examine key military hardware, such as the warheads from ballistic missiles, that the Soviets had lost at sea. In a particularly stealthy move, navy salvage experts apparently recovered a lost piece of Soviet equipment from the seafloor and—just to be sure that their operation remained undetected—carefully replaced it with a mock-up that was identical in appearance to the original.

Yet Broad does not linger unduly on underwater military intrigues. It is in fact the author's thesis that the demise of cold war anxieties truly opened up civilian exploration of the deep sea, as technology formerly reserved for the military was turned to other purposes. He cites the discovery of the wreck of the liner *Titanic* in 1985 and the gold-laden paddlewheel steamer *Central America* in 1988. Descriptions of the ongoing collaboration between the U.S. Navy and various scientific researchers bolster that argument, but one wonders whether the connection is not somewhat overstated. After all, no fantastically new form of undersea instrumentation revealed the resting place of the *Titanic* or the *Central America;* instead these finds were made possible by the perseverance of their discoverers—and, of course, by the money to keep survey ships crisscrossing the Atlantic for weeks on end.

The link between the spread of undersea technology from the military and the discovery of historic shipwrecks seems stronger when Broad describes the search for *I-52*. This World War II vintage Japanese submarine was thought to have gone to the bottom in 1944 while carrying supplies intended to aid the German military (228 tons of tin, molybdenum and tungsten, 54 tons of rubber and, interestingly, two tons of gold bars). For half a century no one knew for sure the fate of that vessel. The key to locating the wreck—accomplished by a privately funded venture in 1995—was the availability of special software for refining navigational information, calculations that had been developed originally for the U.S. military. Broad's account of the discovery of this lost sub is captivating. It can be faulted only for being too brief, in that he never fully explains how the formerly classified system of navigation analysis actually works.


DIMITRY SCHIDLOVSKY

HIDDEN WORLD
of the deep sea is entertainingly revealed.

In the discussion of *I-52* and in other parts of the same chapter dealing with more ancient shipwrecks, the conflict between mere treasure hunting and legitimate marine archaeology recurs. Yet Broad handles his protagonists all too gingerly, declining to critique the relative merit of their arguments. Perhaps his lack of a firm stance in this regard reflects the realization that many of the people and motivations involved are truly complex. But one worries that another concern is lurking beneath the surface of his writing: Broad may be reluctant to alienate some of his subjects.

Indeed, my only disappointment with this book is the suspicion it raises about Broad's objectivity when it comes time to lavish praise or target criticism. Curiously, he seems to gush over those people who can provide him with what he so obviously enjoys—a ticket into the world of deep-sea exploration. His observations surrounding a virtual trip to the deep Pacific made using a remotely operated vehicle belonging to Monterey Bay Aquarium Research Institute provide a case in point. In this chapter, he joins Bruce H. Robison, a marine biologist who studies the amazing creatures that inhabit the middle depths of the ocean. Robison is an accomplished scientist and an active presence in the ocean research community. There are ample ways to describe this investigator without resorting to the fawning language Broad offers: "Visually, he is a man of rugged good looks, deeply tanned, broad-shouldered, his hair longish, his beard gray. He could easily win a Hemingway look-alike contest and probably break a few hearts along the way."

Many of the characters Broad comes across in his travels are portrayed in ways that seem excessively flattering. He even makes a point to praise his anonymous sources in the military as "patriots" for discussing military secrets with him. The only villains Broad finds easily are the Russians: he casts scorn on them for damaging with their two research submersibles the remains of the *Titanic* during various dives on the wreck. He further attacks the Soviet and Russian government for continuing to dump nuclear wastes at sea long after other nations ceased that practice. So Broad is clearly willing to take sides in some debates (even though, contrary to intuition, the danger posed by nuclear wastes left on the seabed remains debatable for some scientists). But readers might be left wondering why his criticism seems so muted when it comes to those who have given the author inside information or a ride somewhere interesting.

Broad's descriptions ultimately lose the sharp edge of journalistic objectivity. (By the end of the book he freely uses "we" and "our" to describe the work of scientists exploring the ocean.) Still, his propensity to become a participant rather than a detached observer does little to detract from the overall quality of the book. *The Universe Below* remains a fine vehicle for exploring the ocean and the curious characters who have been involved in that adventure.

DAVID SCHNEIDER is a staff writer for SCIENTIFIC AMERICAN.

ON THE SCREEN

A Healthy Baby Girl
DIRECTED BY JUDITH HELFAND
Judith Helfand Productions/ITVS, 1996. Airing June 17 on P.O.V. Series/PBS
Available on video from Women Make Movies; telephone: (212) 925-0606

During the middle of this century, millions of pregnant women were prescribed diethylstilbestrol (DES), a synthetic estrogen said to help prevent miscarriage. Its actual effects were far more sinister: deformation of the child's sexual organs and various health risks, most notably increased incidence of cancer of the vagina and cervix. Judith Helfand (*seen as a baby at right*) was diagnosed with DES-related cancer at age 25. Seven years later she has distilled her experience into an unflinching yet surprisingly humane look at the effects of the drug on her and her family. Helfand's story is also a plea for more research into the long-term consequences of DES and a reminder that medical science is not always as cautious or certain as one might like to think.

—*Corey S. Powell*

COURTESY OF JUDITH HELFAND

BRIEFLY NOTED

Continued from page 99

THE SCIENCE OF JURASSIC PARK AND THE LOST WORLD, *by Rob DeSalle and David Lindley. BasicBooks, New York, 1997 ($18).*

DINOSAUR LIVES: UNEARTHING AN EVOLUTIONARY SAGA, *by John R. Horner and Edwin Dobb. HarperCollins, New York, 1997 ($24).*

There is some real science in Steven Spielberg's (and Michael Crichton's) noisy dinosaur epics; there is also a lot of nonsense. Rob DeSalle and David

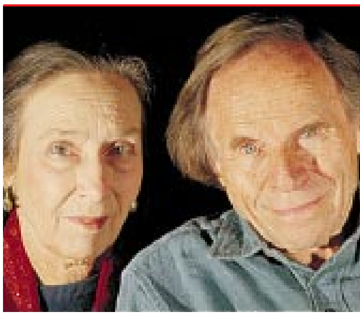
MICK ELLISON

Lindley breeze through the key question, Is it really possible to clone dinosaurs? (In short, not now and probably not ever.) John R. Horner—a consultant for the film *Jurassic Park*—and Edwin Dobb serve up a much more substantial overview of the metaphorical ways in which paleontologists bring dinosaurs back to life. Neither book lists references or further readings, and *Dinosaur Lives* does not even have an index.

PLUTONIUM AND HIGHLY ENRICHED URANIUM 1996: WORLD INVENTORIES, CAPABILITIES AND POLICIES, *by David Albright, Frans Berkhout and William Walker. SIPRI and Oxford University Press, New York, 1997 ($80).*

As the U.S. and Russia take the first, small steps toward reducing their nuclear arsenals, the two countries face an unprecedented challenge: disposing of the estimated 1,600 metric tons of plutonium and highly enriched uranium that both sides now agree are superfluous. Efforts to protect and account for the dangerous fissile material, to place it under international controls or to "blend it down" for use in power reactors are all either stymied or proceeding at an extremely slow pace. International controls are in effect on less than 1 percent of the materials—a proportion that must be drastically increased to reduce the threat of diversion and theft.

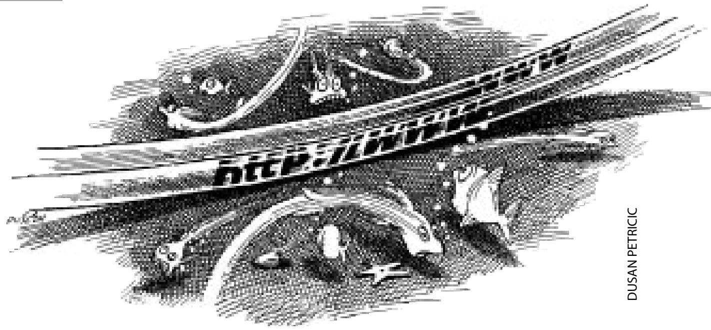
COMMENTARY



WONDERS

by Philip and Phylis Morrison

Bandwidth Galore



DUSAN PETRICIC

These days long-haul digital signals travel confined within fiber-optic cables—witness the busy dry-land "backbones" of the Internet. Down in the seven seas more optical cables carry the major share of ocean-crossing traffic, and they are multiplying fast. Amazingly, Victorian glories such as Lord Kelvin's Atlantic cable and Isambard Kingdom Brunel's paddle-wheel leviathan, the *Great Eastern,* are still evoked by today's hot news. The third-generation, all-optical cable linking London and Tokyo—ready by late 1997—starts out westward from England, to enter the sea across the same beach in the craggy Cornish coastline where once ran the first cable to the antipodes, opened in 1872.

This billion-dollar cable is a little hyped as FLAG, a "fiber-optic link around the globe." It holds two two-way pairs of hair-thin optical fibers within its diameter of a centimeter, wherever it is not specially armored against careless trawlers and hungry sharks. FLAG has eight segments between landfalls. First it passes the Straits of Gibraltar to touch Spain, then eastward past Scylla and Charybdis to Egypt, down the Red Sea to Bombay to curve wide around the tip of India, then across the narrow isthmus in Thailand, achieving its terminal in Japan via Hong Kong and Korea. Strong branches go off to the United Arab Emirates, Malaysia and China. Nor is FLAG alone. Optical cables encage the globe; eight of them now traverse the North Atlantic, another half a dozen the Pacific. By the year 2000, 100 countries will be hooked up to submerged fiber optics, the real superhighway to www.anywhere.

It was physicist John Tyndall in 1854 who first admired the guiding of light by curved jets of water. The effect was at once recognized as an extension of total internal reflection: light is turned back without loss whenever it seeks to pass at low angles from a dense refracting medium to one less so, as from water into air. Today's fibers guide perfectly. They are precisely layered cylinders of very pure silica, a tiny core clad by a coating of slightly lower refraction.

The first task in the long development of optical fiber was to give it an incredible clarity. Fiber size and composition were chosen to favor a single, simple coherent wave front. It is atomic disorder that scatters light, especially when a region of higher or lower density locally matches the size of the light wave. Because random fluctuations of only a few atoms are more likely than those of many atoms, the dominant scattering is at the smallest wavelengths. Scattering in fibers diminishes strongly and steadily as the color of the light is varied from violet to infrared, a behavior quite parallel to that of the blue sky. Minimum scatter is found at an infrared wavelength about double that of the deepest visible reds. The losses of these photons through one kilometer of fiber are little more than those over a kilometer of pure air, even though silica is a couple of thousand times denser.

Submerged fiber optics—the real superhighway to www.anywhere.

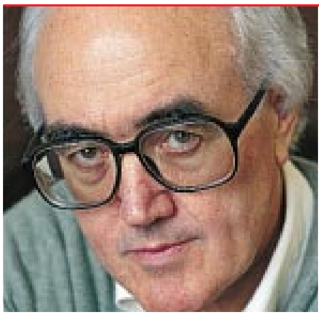
So far ours is a physicist's summary. A chemist would quite understandably talk more of the insight that has brought us fibers clear as the heavens. Metallic atomic impurities, not the randomness of pure silica, are the sources of most scattering, just as it is droplets and dust that make gray skies. To produce this fiber, microscopic silica particles are deposited onto glass from high-purity vapor reactants. The material is heated gently and drawn down under exquisite control to uniform hairlike diameter. The best fibers of 25 years ago lost 50 times more light to impurities than modern quality fiber does. Just as blue haze obscures faraway mountains, the residual scattering in fiber still prevents a message pulse from spanning a whole ocean at one bound. At first the only remedy was to fit the cable with many complex electronic amplifiers, inserted where needed to refresh the fading pulses. That worked, but electronics is too slow to match the promise of infrared bandwidth.

The brilliant solution now at hand is the use of all-optical light amplifiers. Each one is an infrared laser that is but a 10- or 20-meter length of artfully doped fiber. Between 1985 and the early 1990s, physicists and engineers at the University of Southampton in the U.K. and at Bell Labs made such fiber lasers faster—by two orders of magnitude—than their electronic predecessors.

To understand this amazing amplifier, think of doping the regular fiber with a rare-earth ion that has an unpaired electron. Not many dopant ions are needed, just a few for every thousand atoms in silica. A number of sharp new quantum states, either absorbing or emitting energy, consequently appear in the fiber. One particular dopant, trivalent erbium, has a state that corresponds to a wavelength of 1.55 microns, just about at the scattering minimum. Now pump up the ions by sending in plenty of photons from a solid-state laser, all at a wavelength (1.45 microns) chosen to resonate with a second erbium state at a little higher energy. Those excited ions rapidly decay to their lower state, ready to radiate after a short rest. In this laser-pumped state, an ion is poised to radiate a 1.55-micron-wavelength photon whenever another photon of the same reso-

Continued on page 104

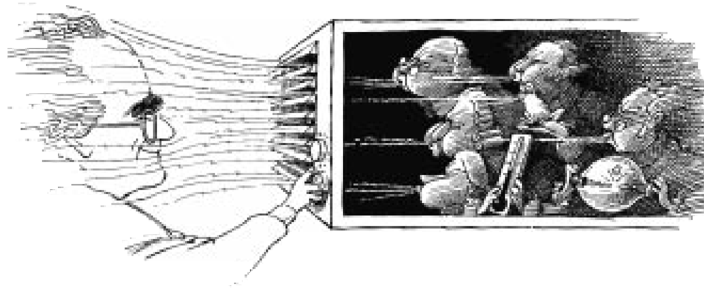
COMMENTARY



CONNECTIONS

by James Burke

Cool Stuff



DUSAN PETRICIC

I was fiddling with the controls of an air-conditioning unit in a hot American hotel room recently and wondering how Celsians (that is, everybody else) manage with the Fahrenheit scale. Mind you, the man himself didn't have it much easier. By the time Daniel Gabriel Fahrenheit was making his mercury thermometers in 1714 or so, there was a high degree of confusion about what was hot and what was not. Some contemporary thermometers had as many as 12 different scales marked on a large wooden board behind the instrument! When Fahrenheit settled for male-armpit heat as 98.6 degrees and melting ice as 32 degrees, life got a bit simpler all around. His system was adopted universally enough for everybody in science to agree not to differ.

Fifty or so years later thermometers were to make a bit of a splash in oceanography. When Benjamin Franklin was in England, he heard about the curious matter of Atlantic sailing times. Ships from London to Rhode Island, whose captains had to follow the entire southern coastline of England before striking out across the ocean, were taking two weeks less to get to America than ships taking the much shorter route from Falmouth (in the far west of England) to New York. Franklin's seafaring cousin, Timothy Folger, told him why.

The Rhode Island packet crews were acquainted with whalers who knew about the three-mile-per-hour eastbound Gulf Stream, which would sometimes drive a westbound ship backward faster than her sails carried her forward. So, knowing this and avoiding it, the Rhode Island boats got across the ocean at a faster lick. In 1775, on his way home, Franklin lowered his thermometer into the water, found the Gulf Stream to be six degrees warmer than the surrounding sea and produced the first chart of the current.

It was during his London stay that Franklin formed a lifelong friendship with a young woman called Mary Stevenson, when he and his son, William, lodged in her widowed mother's house. It's thought likely that he had wedding bells in mind for Mary and William. Well, it never worked out, as Mary ended up marrying a guy called Hewson. But she and Franklin corresponded regularly after he had returned to the U.S., and in 1786 Mary moved to Pennsylvania to be near him and to nurse him through the last days of his life.

This was nearly 20 years after her husband's own death, from an infection caught during a dissection. William Hewson had been a successful surgeon-anatomist and spent over two years assisting one of the great surgeons of the day, John Hunter, who had a school of anatomy in London with his older brother, William, the other great surgeon of the day. John Hunter was a self-educated man who, among other things, wrote a natural history of teeth, discovered hearing organs in fish and the lymphatic vessels in birds, founded surgical pathology, was obsessed with hedgehogs, studied Portuguese geology and married a woman who wrote librettos for Franz Joseph Haydn.

So let's hear it for frogs.

John Hunter taught everybody who was anybody, including a young country surgeon named Edward Jenner, who lived an extraordinarily dull life except for the moment in 1798 when he used liquid from cowpox pustules to vaccinate people against smallpox and became humongously rich as a result (one of those "grateful nation" deals). Smallpox had been a killer for decades, and, before Jenner, entire hospitals were dedicated to not curing sufferers. Back in 1747 one of these, Middlesex Smallpox Hospital, had a new high-tech ventilating system installed. Based on the design of an organ bellows, it had been invented by one of the hospital's governors, a public-health-conscious London vicar called Stephen Hales, whose other claim to fame was that he spent a lifetime studying why sap rises.

His electrifyingly titled work, *Vegetable Staticks*, shocked an Italian experimenter, Bologna University professor of obstetrics Luigi Galvani, into searching for the motive power that drove the human equivalent of sap around the body. He (and many others) thought that some kind of mysterious electrical fluid running from the brain to the muscles made them work.

At one point in 1786 Galvani (what follows is not for the squeamish) hung a prepared dead frog, by a brass hook embedded in its spinal cord, onto an iron railing in his garden to see if "electrical" things would happen to the muscles during a thunderstorm. They didn't. At one point, however, in clear weather, when he pressed the hook against the railing, the frog's legs twitched! The twitch also happened, to a greater or lesser extent, when he used hooks of different metals. Galvani immediately dashed off a terminally boring Latin tome announcing the discovery of galvanism, a.k.a. "animal electricity."

Ten years later, in Padua, Alessandro Volta stacked alternate disks of silver and zinc (to reproduce the differing metals of Galvani's hook-and-railing arrangement), sandwiched the disks between disks of wet paper (to reproduce the moist frog tissue), attached wires to each end and produced a spark. This proved that Galvani's current had been made not by the frog but by metal-frog-metal juxtaposition. Volta's pile of disks

Continued on page 104

D. GWYNNE

COURTESY OF EPRI

Wonders, *continued from page 102*

nant wavelength impinges on it. Thus, one incoming photon becomes two, and the first two start a photon chain reaction within the pumped section of fiber. The pumping energy cascades into a narrow coherent wave that faithfully amplifies the weaker incoming pulse.

Every 50 or 100 kilometers one such erbium-doped laser length with its pumping system is spliced into the long oceanic cable. The amplifier is very energy efficient. The few kilowatts of DC power required to run the pumping lasers travels down a heavy copper sheathing, to feed the entire string of amplifiers in series. The return circuit is through the ocean waters.

The infrared offers more than ample bandwidth. Recall that an AM radio carrier signal at around one megahertz brings abundant speech and music. Independent audio channels can be assigned every 10 kilohertz on the dial. But for acceptable moving color images, the myriad of fast-changing pixels demands bandwidth of around four megahertz per channel. The entire width of the AM radio band can hardly provide one worthy television channel.

A practical carrier frequency is usually at least an order of magnitude higher than any program bandwidth it can support, so American TV is sent via VHF radio, the carriers around 200 megahertz. Infrared light around one micron wavelength is higher in frequency by three orders of magnitude than the millimeter downlinks of the latest television satellites. Bandwidth greatly favors the eternally "blue skies" held in clear fiber.

FLAG's bandwidth still falls 10,000-fold short of the 200-terabit-per-second potential of optical fiber. Two paths seem open to full use of an infrared carrier. One scheme is to multiply many similar channels at micron wavelengths, each a distinct color of infrared. In laboratory tests last year that straightforward design realized a bandwidth of a terabit per second—a quarter million TV channels in one all-optical fiber. Going beyond that may require mastery of nonlinearity. One bold proposal is to use ultrashort pulses, called solitons, to form a pulse whose shape remains almost magically constant as it travels. Maybe someday a single worldwide fiber of opulent bandwidth can call at everyone's door? SA

Connections, *continued from page 103*

(he called it a "pile") was the world's first battery. So let's hear it for frogs.

Curiously, Volta's other great passion, besides frogs, was fogs. Well, miasmas. Well, bad smells of any kind. Most of which Volta found in marshland and which turned out to be a mix of hydrogen sulfide and methane. If you know cows, you'll know what I mean. Anyway, at one point in his smelly miasmic investigations Volta invented a kind of electric glass bomb: a corked vessel inside which two wires almost touched. The other ends of the wires were attached to a turpentine and beeswax cake that, when rubbed with a cat skin, would generate static electricity. Volta would fill the glass bomb with a suspect gas (like methane). Electrifying the wires would cause a spark, and the effect would show if the particular gas were explosive (big deal). It would also one day inspire the invention of the spark plug (really big deal). But why would a genius like Volta do a daft thing like that? Because everybody thought this kind of work would change the world of medicine. Miasmas (bad smells, dank mists) were reckoned to be the source of such diseases as malaria—which got its name from *mal aria,* the contemporary Italian for "bad air."

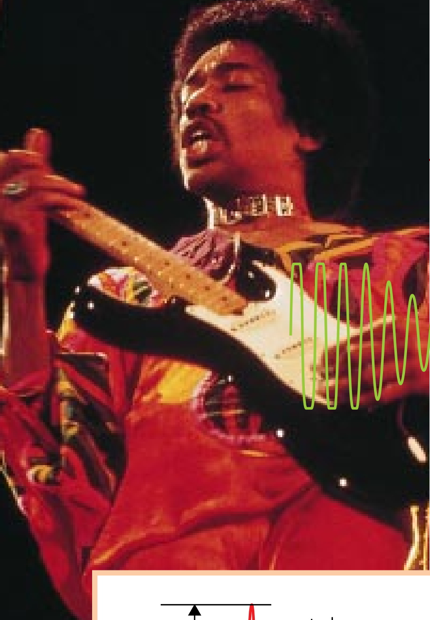
The other thing besides miasma that most likely caused malaria was heat. This was the view of one John Gorrie, a doctor living in Apalachicola, Fla., in 1850. He'd noticed perspicaciously that people living in cold climates never got malaria, whereas in the steamy swamps where he practiced, they frequently did. Because it was to be another 30 years before the word "mosquito" entered the discussion, Gorrie, like Volta, went off in the wrong direction. He built a small steam engine to drive a piston in a cylinder immersed in brine. The piston first compressed the air, and then on the second stroke, when the air expanded, it drew heat from the brine. At a certain point the brine became so cold it began to cool down the air, which was then released into Gorrie's hospital ward to cool and cure his malaria patients.

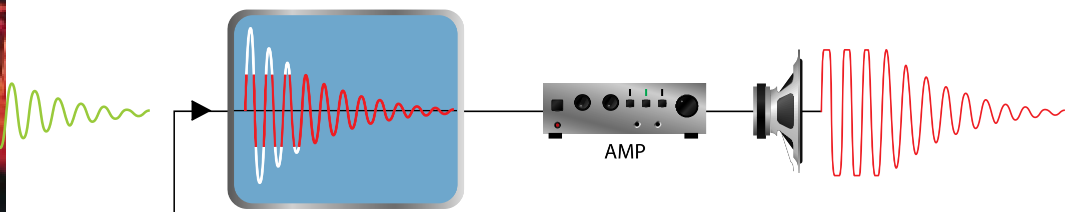
Of course, it didn't cure them. But as the grandfather of all air conditioners, the antimalaria machine ended up making my life bearable in that hot American hotel room.

OK, that's it. Off to chill out. SA

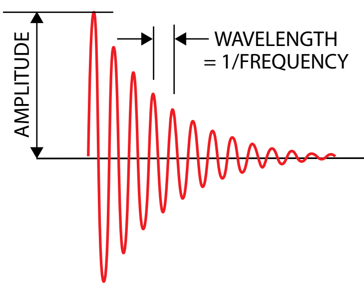
WORKING KNOWLEDGE

GUITAR-EFFECTS PEDALS

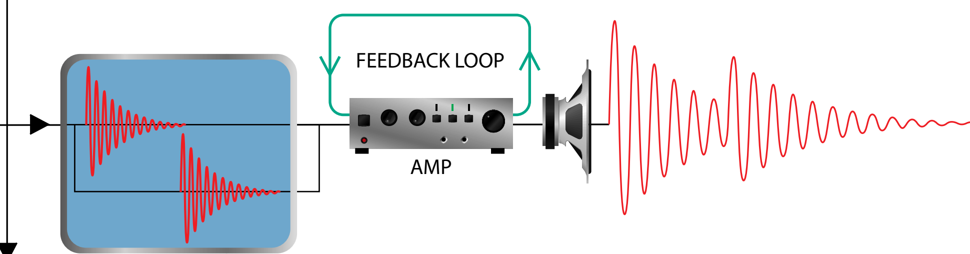




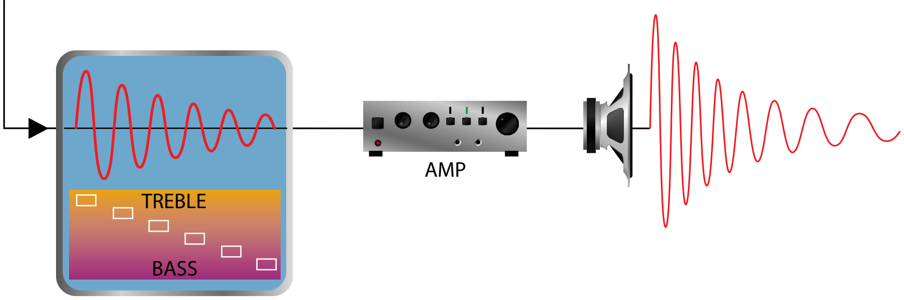
BIG MUFF produces a guitar note of relatively constant amplitude, drawing out the sound until it eventually decays. It does so by clipping off the high and low peaks. The effect resembles one that the musician Jimi Hendrix (*left*) produced by vibrating his finger on the guitar fret to delay the note from dying out.



WAVEFORM of a guitar note is characterized by its volume, or amplitude, represented by the height of the sine wave, and its frequency, the number of oscillations for a given interval of time. The guitar's characteristic waveform can be represented by an initial sharp peak that falls off rapidly.



DELAY EFFECTS store information about the frequency and amplitude of a plucked guitar note. The device then resends the same note to an amplifier a few milliseconds after the string is first plucked, producing a reverberation similar to that heard in a large concert hall. The delay can also be cycled back to the amplifier through a feedback loop to create an even more distinct echo effect. The delay sound is often used in rockabilly music.



"WAH-WAH" sound is produced electronically with a filtering device that selects a series of tones, which are the frequencies that make up a note. The blue box representing the filter shows that at a given amplitude (*sine waves on top*), the device excludes all but a few tones (*descending boxes at bottom*). Consequently, the output note shifts from high- to low-frequency tones as the amplitude diminishes: clear, bright treble sounds gradually become muffled bass tones, evoking the familiar "wah" sound. The effect is similar to one produced by mechanically pumping a "wah-wah" pedal with the foot. It has been used by funk rock groups such as Parliament-Funkadelic.

MICHAEL GOODMAN (*illustrations*); JOEL AXELRAD *Michael Ochs Archives (photograph)*

by Mike Matthews
and Robert Myer

The history of rock and roll is one of contorting the resonant note of a plucked guitar string—a tradition that began with the echo and delay sounds that characterized the recordings of Elvis Presley, Gene Vincent, Jerry Lee Lewis and others in the 1950s.

Tape recorders produced the earliest guitar effects. But new ways to alter the sound emerged during the 1960s as circuitry that varied volume (tremolo) or introduced signal delay (reverberation) was built into amplifiers. Perhaps the most dramatic advance came with the advent of the guitar-effects pedal, which is plugged into an amplifier and activated by the tap of a foot.

Effects pedals, marketed with names such as the Big Muff, alter the amplitude, frequency or phase of a signal to produce sounds ranging from a tinny buzz to a throbbing "wah-wah." Hundreds of effects devices have been invented during the past 35 years. And hundreds more may be forthcoming, because there are virtually an infinite number of ways a note or chord can be modified.

MIKE MATTHEWS and ROBERT MYER worked on the design of many early guitar-effects devices. Matthews is president of Electro Harmonix, a New York City manufacturer of pedals. Myer retired in 1989 as a Distinguished Member of the technical staff at AT&T Bell Laboratories.