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DEPARTMENTS

THE COVER painting of a late-model automobile emphasizes the importance of smooth fit and finish to enhancing the efficiency of cars. New painting and laser-welding techniques, as well as gently rounded corners and a low front end, help to decrease aerodynamic drag. Minimizing other energy losses, including those from braking, tire friction and accessories, provides a valuable and often overlooked approach to raising fuel economy (see "Improving Automotive Efficiency," by John DeCicco and Marc Ross, page 52).

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LETTERS TO THE EDITORS

A Misbegotten Moon

I read "The Scientific Legacy of Apollo," by G. Jeffrey Taylor [SCIENTIFIC AMERICAN, July], with increasing disbelief. To consider the moon as the result of an interplanetary liaison in the formative phase of the earth would only seem valid if we ignore the satellites in the remainder of the solar system. Are we to believe that 16 interplanetary collisions resulted in the moons of Jupiter and that 21 caused the formation of the satellites of Saturn? Neptune and Uranus also have a large number of moons; Mercury and Venus are the only planets not to have at least one. The odds of this number of moons developing after random hits are minute.

If God doesn't play dice with the universe, then it's unlikely he would tolerate billiards.

DIGBY QUESTED
Epsom, England

Taylor's excellent article raised as many questions as it answered. He cites the slow rotation of Venus as evidence of the low spin acquired by accretion but conveniently leaves out that of Mars, with its 24.6-hour period. Neither Mars nor Venus has a sizable moon. Unless convincing evidence is produced as to how Mars acquired its high rate of rotation, the theory that the moon is an outcome of a collision between the earth and a Mars-size body remains very much a conjecture.

M. H. KUBBA
Steinhausen, Switzerland

Taylor replies:

No one really claims that all solar-system satellites formed in the same manner. The moons that make up miniature solar systems around the giant outer planets almost certainly formed in fundamentally different ways than the earth's moon did. The gas-giant planets and their major satellites probably formed in ways somewhat analogous to that of the solar system as a whole. Furthermore, the huge gravitational pull of the gas giants most likely captured any debris that would have been lifted by impacts.

The most intriguing problem is why Mars rotates as fast as it does (almost a 24-hour day) yet has only two tiny moons. The giant-impact hypothesis argues that the earth's rotation is mostly attributable to the giant impact that made the moon. Perhaps giant impacts on smaller bodies (Mars has only 10 percent of the earth's mass) completely disrupted them, leading to the re-accretion of a single larger body rather than to a shaken but intact target body surrounded by orbiting raw materials from which its satellite formed. Alternatively, the total energy of collision with the proto-Mars body may not have been sufficient to cause large amounts of material to reach orbit. Perhaps only scraps made it into orbit and are represented by Phobos and Deimos, the two little satellites orbiting Mars. Then, too, perhaps we do not fully understand how planets accrete or how moons form.

Raising Consciousness

I enjoyed reading "Can Science Explain Consciousness?" by John Horgan [SCIENTIFIC AMERICAN, July], but you went overboard in your enthusiasm for "firsts" in the field. The exhortations by Francis Crick and Christof Koch toward a scientific assault on awareness have certainly been beneficial to advancing the field. In my less prominent position, I in fact initiated such scientific experimentation in the late 1950s, with the first major papers out in 1964 (*Journal of Neurophysiology*) and 1965 (*Perspectives in Biology and Medicine*).

The statement that the Society for Neuroscience would host its first symposium on consciousness in November 1994 is incorrect. I organized and chaired a symposium on "Cerebral Processes and Conscious Functions" held at the 1985 annual meeting of the society. Also, when Robert W. Doty of the University of Rochester was the president of the society, he held a symposium on "Consciousness from Neurons" at the annual meeting in 1976.

BENJAMIN LIBET
Department of Physiology
University of California, San Francisco

When Koch cautions mysterians by quoting Wittgenstein about things "whereof one cannot speak," he is on the right track. Another great philosopher, Mark Twain, spoke of the same category of endeavor as that of Colin McGinn and David J. Chalmers in his speech "The Science of Onanism": "As an amusement it is too fleeting. As an occupation it is too wearing. As a public exhibition, there is no money in it."

BOB FOSTER
Tucson, Ariz.

Horgan characterized my *New Yorker* article as raising the possibility that Gerald M. Edelman would win a second Nobel Prize for his work on consciousness. Actually, the speculation concerning a return trip to Sweden centers on Edelman's role in the discovery of cellular adhesion molecules.

STEVEN LEVY
Otis, Mass.

Further Fabre

As one of the scientists inspired at an early age by Fabre's writings, I was delighted to read "Jean Henri Fabre," by Georges Pasteur [SCIENTIFIC AMERICAN, July]. I was disappointed, however, that the "Further Reading" did not list any of Fabre's work that has been translated into English—it would be nice if those of us who teach young people could leave a copy lying where someone might pick it up! Fortunately, there is a nice edition, *The Insect World of J. Henri Fabre,* edited by Edwin Way Teale, available in paperback from Beacon Press in Boston.

J. E. HOLMES
Portland, Ore.

Letters selected for publication may be edited for length and clarity. Unsolicited manuscripts and correspondence will not be returned or acknowledged unless accompanied by a stamped, self-addressed envelope.

ERRATA

In the timeline illustration on page 48 of "Life in the Universe" [October], the date for Robert Hooke's microscope should be 1665. Also, the vertical scales on the second and third charts on page 88 of "Software's Chronic Crisis" [September] should begin at five, not at zero.

50 AND 100 YEARS AGO

DECEMBER 1944

"Approximately $25,000,000 has been invested in television research and development by the radio industry to get television ready for the public, according to James H. Carmine, of Philco Corporation. 'As soon as television receivers can be made and sold, the public will eagerly buy them in tremendous quantities,' Mr. Carmine says."

"A new synthetic foam rubber, as soft and fluffy as an angel food cake, has been announced by The Firestone Tire and Rubber Company. Whipped into a creamy froth, much as a housewife beats egg whites for her cake, the synthetic latex traps innumerable interconnected tiny air bubbles, which give the foam rubber its softness and permit free circulation of cooling air."

"Standard textile machinery adapted to handling glass textiles is now allowing continuous glass filament and staple fibers to be twisted, plied, and woven. The fineness and strength of the latest glass fibers are almost incredible. Fibers with a diameter of 23/100,000 of an inch have a tensile strength of more than 250,000 pounds per square inch. Experimental fibers have been produced with a diameter of 2/100,000 of an inch and with a tensile strength exceeding 2,000,000 pounds per square inch."

"Development of a precision x-ray tube that operates at two million volts makes it practical for the first time to inspect by x-rays exceedingly thick sections of metal. Physicians will likewise welcome the new tube as a more effective tool for research in cancer therapy."

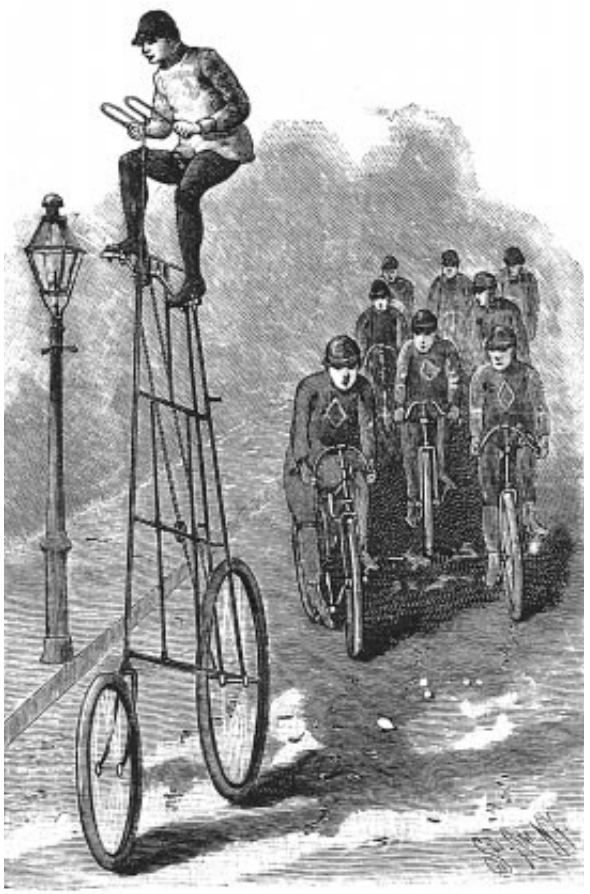
"In heavy industry, the main objection to female labor was the lack of physical strength for lifting heavy parts into and out of machines. This was overcome through the installation of mechanical lifting devices such as hand or electric hoists, or by overhead traveling cranes. It was shown that once women were relieved of the physical exertion, they actually liked machine-tool operations better than did the men."

"More than 16 types of wood go into the building of the giant Douglas C-54. The woods range from featherweight rattan to heavy mahogany. About 30 percent more wood is used today in aircraft than just a year ago, largely because of the metal shortage."

SCIENTIFIC AMERICAN

DECEMBER 1894

"One lady, of whom we read not long ago as having reached the age 120 or thereabout, maintained that single blessedness is the real elixir vitae. She ascribed the death of a brother at the tender age of ninety to the fact that he had committed matrimony in early life."



The Eiffel Tower Bicycle

"Investigations have been undertaken to determine the specific action of a considerable lowering of temperature upon the brilliancy of bodies which shine in the dark after having been exposed to sunlight. Apparently, the production of phosphorescent light requires a certain movement of the constituent molecules of bodies. When these are frozen, the luminous waves are not produced and the phosphorescence disappears accordingly."

"Donations to the Society of the New York Hospital amount to a minor fraction of its total income, so that the refreshing spectacle of a great charity run on strictly business principles is presented in perfection by the society's administration."

"Before the Society of Amateur Photographers a few days ago Mr. Frederick E. Ives, of Philadelphia, exhibited his new triple-colored lantern slide on the screen. Specimen slides shown of landscapes had the sky too blue. But several flower and fruit pictures appeared so accurately that one could imagine they were solid enough to be picked up or plucked."

"Many persons weigh themselves frequently and imagine that they know their weight. Sweet illusion! Nothing is more difficult than to know one's weight exactly, even with access to first class scales. For adults, though, it is good to consult the scales, for they are the barometer of health. Any sudden increase of weight, amounting to a pound or so in a day, indicates a tendency to disease."

"One of the most curious sights recently seen is called the Eiffel Tower Bicycle. This machine is constructed on the same principle as an ordinary one, but has a frame which carries the rider at a distance of some ten feet from terra firma. The adventurous spirit who rides this remarkable wheel is usually accompanied by a number of companions who prevent vehicles and pedestrians from obstructing the way."

No-Polluting Zone

Russia follows Adirondack approach to environmental protection

For decades, Lake Baikal has symbolized the threat of economic development to Russia's wilderness. The largest, oldest, deepest container of freshwater on the planet, Baikal has engaged the passions of Siberia's poets and the intellect of its scientists, who have charted its increasing burden of pollution. Now there is reason to hope that Baikal will come to symbolize something else: rational compromise between the economic needs of a people and the ecological needs of their land.

BOYD NORTON

LAKE BAIKAL, with one fifth of the planet's freshwater, may be saved by zoning.

With only a modicum of support from the U.S. and the United Nations, a team of American scientists and environmental advocates has persuaded Russia and Mongolia to develop sustainable land-use programs for the Baikal watershed. The ambitious plans aim to save the lake and to propel the region toward a free-market economy.

Although their success is not assured, the Baikal agreements are already serving as a model elsewhere. In November, China and Russia began drafting a similar plan for the Ussuri River basin. The Altai Republic in Siberia has also agreed to work on an "ecological-economic zone." If adopted and enforced, these programs will protect a combined area more than twice the size of California.

The projects share a common approach and leader, George D. Davis, president of Ecologically Sustainable Development. Davis has adapted a strategy he used successfully two decades ago to protect the six-million-acre New York State Adirondack Park, for which he was chief planner. Inspired by zoning laws that cities use to segregate industrial from residential areas, Davis ordered a scientific survey to determine the carrying capacities of the park's resources. He then drew up a zoning map and rules restricting where and how forestry, farming and construction are allowed—even in the 58 percent of the reserve that is privately owned. The result was the first U.S. regional land-use plan.

After winning a MacArthur Foundation grant in 1989, Davis was invited to apply his method to the Baikal watershed, a 150-million-acre region encompassing parts of Mongolia and three provinces of Russia. With foundation funding, Davis joined forces with 30 American and Russian scientists.

Through sometimes heated debate and many public hearings—among the first ever held in Siberia, Davis notes—the team forged a consensus. It gerrymandered the watershed into 25 different kinds of zones, ranging from farmland to industrial parks. Each zone has been assigned "preferred" and "conditional" uses; the latter require permits. Anything unspecified is forbidden. More than 52 million acres, including the lake itself, have been set aside as national parks, scientific reserves, landscapes, scenic rivers, greenbelts and landmarks.

For Baikal, protection arrives none too soon. More than a mile deep and flush with oxygen, the lake is home to some 1,800 species found nowhere else. Its 5,330 cubic miles of drinkable water are as pure as rain—which is unfortunate, because the rain over Baikal has turned acidic, contaminated by the smokestacks of Irkutsk to the west. Many more pollutants pour in from the Selenga River. "Boat captains will not go within a mile of the Selenga delta, because the pollution is so thick," reports Gary A. Cook, director of Baikal Watch at the Earth Island Institute in San Francisco.

The threats to Baikal have diminished noticeably as Russian industry has ground to a halt, Cook reports. And at least two provincial governments are beginning to act on the plan. But as ministers sell off defunct state-owned factories and farms, and new owners convert them, it is unclear whether the Baikal plans will be enforced. Last year, after the Buryat Republic and Chita Oblast adopted the zoning strategy as policy, Russian president Boris Yeltsin signed a decree creating—but not funding—a commission to carry it out.

So far, says Sergei G. Shapkhaev, director of the 15-person commission, "we have encountered no organized opposition. The most serious problem seems to be that the actual mechanisms of enforcing the laws in court are not in place." A special court that allows citizens to sue polluters is now operating, Shapkhaev reports, but the republic has not found money to provide any legal assistance to the public.

Davis confidently predicts that since

Siberians only recently gained the right to own land, "they won't feel the sting of restrictions on what they can do with it." Businesses may be harder to placate. The U.S. Agency for International Development has promised $3.4 million for 12 projects in areas such as ecotourism and forest management. Davis's firm is identifying American companies willing to abide by the new rule that all foreign-owned facilities must meet the environmental regulations of the owner's country as well as local standards.

The two provinces that have adopted the land-use program cover 95 percent of the Russian watershed. But Irkutsk, which has balked at the Baikal plan and recently accepted German funding for its own survey, accounts for 40 percent of the lake's shoreline and much of the waste that is dumped from it. Another 70 million acres of Baikal's watershed lies in Mongolia, which has just begun reviewing its own, very similar plan.

Perhaps more important than the Baikal project itself is the speed with which it is being copied. Davis is now working with the Khabarovsk and Primorsky territories—1,500 miles to the east of Baikal. Nestled against the Heilongjiang Province of China, with which they share the Ussuri River, these Far Eastern Russians worry less about the threat of pollution than the temptation to sell off rights to their lush woodlands. The forest supports the richest diversity of plant species in the former Soviet Union.

"On the Chinese side, the Ussuri basin contains the most wetlands remaining anywhere in the country," says Jim Harris, deputy director of the International Crane Foundation, which has been monitoring wetland destruction in China. "Hundreds of thousands of acres have already been drained and converted to farms," he explains. What little is left is worth preserving. "In this basin live the last 250 Siberian tigers, last 30 Amur leopards and two endangered species of cranes," Davis reports.

The Russian, American and Chinese scientific teams will soon present their recommendations to ensure that development in the 60-million-acre area does not overburden the ecosystems. At that point, says Elizabeth D. Knup, program director of the National Committee on U.S.-China Relations, the real fireworks may begin. "To have the two sides now talking about how to jointly manage the watershed is pretty extraordinary," Knup says. "It's a very sensitive border—they were shooting over it until the 1960s."

Davis notes that the plans have raised relatively little opposition because of the area's remoteness and the slow growth of these economies. "We're fortunate in all of these areas that we aren't dealing with an overpopulation situation," he concedes. "But if we can prove that it can work in these regions, then we can consider other, more challenging areas." It appears as though Davis may get that chance: he has been approached by the Haisla Indian Nation of British Columbia, by the Miskito Indians of Nicaragua and by officials in Bolivia and in Chile.

In time, the ultimate symbolism of Lake Baikal will emerge, and it may well be the failure of good intentions. On the other hand, practice could well make sustainable development, if not perfect, at least more practical. —*W. Wayt Gibbs*

The Astronomical Naming Game

A quick flip through the baby book for heavenly bodies

This past March a team of scientists poring over images from the *Galileo* spacecraft made a remarkable discovery. The asteroid Ida—a chunk of rock just 50 kilometers across, orbiting between Mars and Jupiter—has a tiny moon. For the astronomical community, the finding raised big questions about the origin of Ida and its satellite. For the *Galileo* researchers, it posed a more pressing problem: What should the moon be called?

The task is more difficult than one might suppose. Naming planets in the solar system has proved easy because only three have been discovered in modern times. Comets turn up more frequently but benefit from a well-established convention: each bears the name or names of the astronomers who spotted it. For asteroids, however, the process is rather chaotic. Hundreds are found annually, and the discoverer has fairly free rein in picking the name. In addition, robotic spacecraft have sent back images of most of the major bodies in the solar system, unleashing a flood of unnamed surface features.

JET PROPULSION LABORATORY/NASA

ASTEROID IDA is accompanied by the first known asteroid moon, Dactyl* (far right). *Such discoveries test the system for coming up with distinctive but consistent names.

To keep a little order in the Wild West of celestial nomenclature, scientists founded the International Astronomical Union (IAU), which lays down the law. Features on planets cannot bear the name of a living person—a restriction that does not apply to asteroids. Names of political and religious figures of the past 200 years are a no-no: too controversial. And planetary satellites and asteroids cannot share names. "Oh, yes, names get rejected," says Brian G. Marsden of the Smithsonian Astrophysical Observatory, who oversees much of the naming of the solar system's minor players. Sometimes the names are too silly; sometimes they just run contrary to his sensibility. "I objected to calling a feature on Venus Elizabeth Tudor. Nobody calls her Elizabeth Tudor; she's Queen Elizabeth I."

"Ida" comes from the traditional end of the naming spectrum. Found in 1884 by Austrian astronomer Johann Palisa, the asteroid was named after the mythic mountain where the infant Zeus hid from his father. Honoring Palisa's spirit, the *Galileo* team proposed call-

ing Ida's moon Dactyl, after the Dactyli, a group of magicians who inhabited Mount Ida.

At first, the IAU was not sure whether the moon even merited a moniker of its own. Because asteroids are so numerous, the union approves a name only after the orbit has been determined; *Galileo* did not observe the moon long enough to describe its motions. Marsden finally decided the discovery of the first asteroid satellite was important enough to modify the requirements.

At the more free-form end of solar-system nomenclature is the asteroid Zappafrank. After the death of musician Frank Zappa, Arizonan John Sciatti led a campaign to have a celestial body named after the late guitarist. Marsden rapidly found himself inundated with E-mail. Because of Zappa's close relationship with Václav Havel, president of the Czech Republic, Marsden prevailed on Czech astronomers to "produce" an unnamed asteroid to bear Zappa's name. An asteroid named Zappala already existed, as did several whose names began with Frank, so the IAU settled on Zappafrank.

Although the IAU can stomach a certain amount of whimsy, it does draw the line. News that three planets had been discovered around a pulsar prompted National Public Radio to solicit suggestions for what to call them. The winners: Curly, Moe and Larry. "I don't think the IAU would go for that," Marsden chuckles. In addition, he notes, "the IAU does not name stars." Marsden is particularly disdainful of the International Star Registry, an unofficial and utterly unrelated organization that names stars for a fee. "It's a total racket," he hisses.

From Marsden's point of view, the whole naming game is just a pleasant distraction from the real business of astronomy. "I don't care about the names—I study the orbits," he crustily jokes. But he concedes that the impulse to name is tough to fight; the best the IAU can do is try to bring some order to the process. "If the IAU declares 'no more names,' " he sighs, "somebody else will just do it." —*Corey S. Powell*

Trapped in the Light

Laser beams levitate droplets of superfluid helium

Rise and shine has taken on new meaning in the physicist's vocabulary. Investigators at Brown University have managed to trap floating droplets of liquid helium in midair by shining laser light on them. The feat should allow researchers to probe for the first time how the fluid behaves in free space.

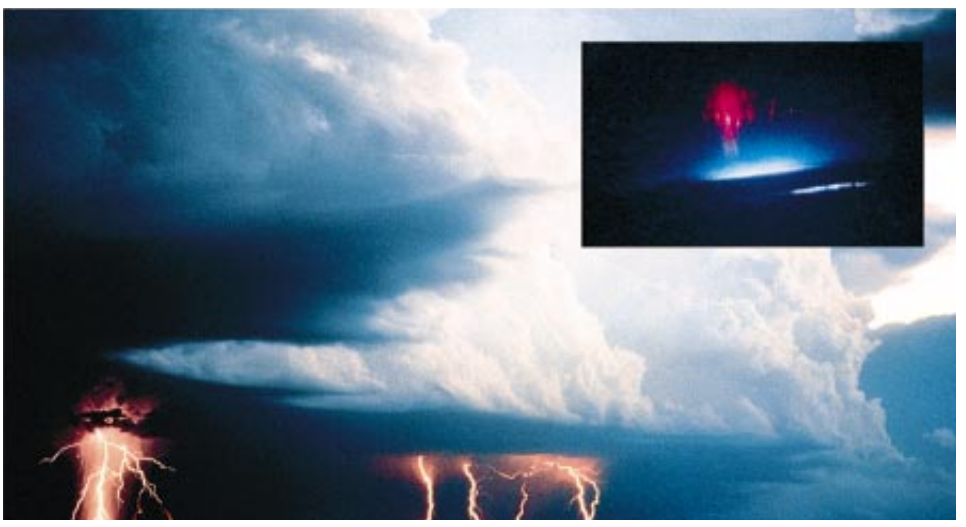
Although helium is most familiar as a gas that fills up balloons and changes the pitch of the human voice at parties, it serves in its liquid form as a major tool in condensed-matter physics. That is because it behaves unlike anything else when cooled to near absolute zero. Specifically, below 2.172 kelvins helium becomes a quantum liquid known as a superfluid. It loses all resistance to flow and viscosity, enabling it to seep through cracks even a gas could not penetrate. Sloshing a bucketful of it around in circles produces even stranger phenomena. The rotation creates nanometer-size whirlpools—called quantized vortices—throughout the liquid. Researchers have been exploiting the properties of superfluid helium to study condensation, turbulence, fluid flow and new forms of matter.

But physicists had never looked at isolated drops of superfluid helium—in fact, nobody is quite sure how the drops behave. To help answer that question, Mark A. Weilert, Dwight L. Whitaker, Humphrey J. Maris and George M. Seidel of Brown applied a technique that has been refined to an art during the past several years: the trapping of particles by laser beams. They submerged a small piezoelectric speaker in a superfluid helium bath kept in a cryostat. Turning on the speaker produced a fine mist of superfluid helium droplets above the surface of the liquid. Two laser beams shot through windows in the cryostat were aimed in opposite directions at the droplets.

"Most of the droplets simply fall down," Maris explains, "but we are able to trap one or even a few at a time." The investigators could tell they had succeeded by looking at the laser light reflected off the surface of the drops. They deduced that they had suspended drops 10 to 20 microns in size for up to three minutes, during which time the droplets slowly shrank through evaporation. Larger drops could not be held, because they would require lasers stronger than those that could be provided.

The work, to be published in the January issue of the *Journal of Low Temperature Physics,* represents the first step in exploring a novel realm

Electrical Activity above Thunderstorms



Red sprites and blue flashes were recently found to live above some thunderstorms—although pilots have been reporting the luminous phenomena for many years. The red flashes appear for only a few thousandths of a second and can extend upward for 60 miles; the blue jets also appear atop the storms and can rise for about 20 miles. These first color images of the activity, shown here inside a photograph of a storm, were taken by researchers at the Geophysical Institute at the University of Alaska at Fairbanks.

for superfluid helium. "There are a lot of things to do with superfluid drops," says Russell J. Donnelly, a physicist at the University of Oregon who has been attempting to levitate superfluid drops with electric and magnetic fields. One could, he remarks, observe how drops collide or move about. Indeed, Maris's group is primarily interested in seeing how a superfluid drop rotates—"a surprising thought a couple of years ago," Maris says. An ordinary drop of liquid may rotate in a complicated fashion for a while, but it eventually settles into a motion like that of a rigid body, where each part has the same angular velocity.

A superfluid droplet, however, would not behave that way. The liquid has no viscosity and must obey certain quantum-mechanical conditions that prevent it from rotating as a rigid body. Instead theorists suggest that the droplet might become peppered with quantized vortices or produce a bulge that circles the droplet.

To see such dynamics, workers will probably need to suspend larger drops, perhaps several centimeters in size. For that job, Maris and his colleagues have already begun redesigning their apparatus, using superconducting magnets rather than lasers. Helium is slightly repelled by magnetic fields, so drops should be able to float on a magnetic cushion, sidestepping the practical energy limitations of lasers.

In fact, the new magnet should enable the physicists to go beyond exotic drops of fluid. "We're thinking about levitating frogs," Maris says, because the ability to float amphibians offers an alternative to seeing how they develop in the absence of gravity. Besides, it would make a great party trick. *—Philip Yam*

The Annual Ig Nobel Prizes

This year's winners are, well, just as pathetic as last year's

If a little knowledge is a dangerous thing, it might follow that vast amounts of knowledge concentrated in one place are downright hazardous. Evidence for such a conclusion could be found at the Massachusetts Institute of Technology this past October, when a good portion of America's scientific elite, including three bona fide Nobel laureates, cringed through an evening of ear mites, constipation and threats of eternal damnation. Yes, it was time once again for the awarding of the Ig Nobel Prizes.

Some 1,200 spectators jammed M.I.T.'s Kresge Auditorium to witness the "Fourth First Annual Ig Nobel Prize Ceremony." They also ogled real Nobelists William Lipscomb (Chemistry, 1976), Dudley Herschbach (Chemistry, 1986) and Richard Roberts (Medicine or Physiology, 1993), who were somehow persuaded to take part in the proceedings.

Unlike the awards won by these exemplary scientists, the Ig Nobel Prizes go to individuals "whose achievements cannot or should not be reproduced," according to the official program. A joint production of the *Annals of Improbable Research* (described by some as the *Mad* magazine of science) and the M.I.T. Museum, the Igs take their name from the "legendary Ignatius (Ig) Nobel, co-inventor of soda pop," allegedly a distant relative of TNT inventor Alfred, who founded those other prizes. Whereas proof of Ig's existence might be hard to document, the Igs are awarded to real people, embarrassed though they may feel, for real work, embarrassing though it may be.

The evening got off to a rocky start with the first Ig, for Biology, awarded to the authors of "The Constipated Serviceman: Prevalence among Deployed U.S. Troops," which appeared in *Military Medicine* in 1993. W. Brian Sweeney, one of the writers, showed up to receive the Ig, a gold-painted, wax brain hemisphere. "I'd like to acknowledge all of our wonderful U.S. servicemen," he said, "who were willing to become constipated for the country. There were various theories as to why constipation occurs, until it was pointed out to me by one of the marines in the field. He said, 'Doc, let me tell you. When we're out in the field, we're scared s—less.' "

Patient X, who refused to be named, won the Medicine Ig for his attempt to use electroshock to neutralize venom after he had been bitten by his pet rattlesnake. The juice came from a car engine revved to 3,000 rpm for five minutes. It was applied through sparkplug wires attached to Patient X's lip. X shared the award with the authors of a medical report of the incident, "Failure of Electric Shock Treatment for Rattlesnake Envenomation," published in the *Annals of Emergency Medicine.* In a taped message, co-author Richard C. Dart of the Rocky Mountain Poison Center said, "I was stunned to receive the 1994 Ig Nobel Prize in Medicine, although not as shocked as our patient."

Veterinarian Robert A. Lopez took the Entomology Ig for his brave and successful attempts to find out whether ear mites from cats can inflict damage on humans. He did this by inserting mites into his own ears, not once, not twice but three times. Lopez's chilling report was published in the *Journal of the American Veterinary Society.* At a post-Ig gathering, Lopez elaborated on his actions: "Somebody's got to be crazy enough to do it. Hey."

Former Texas state senator Bob Glasgow copped the Ig in Chemistry for his sponsorship of a 1989 drug-control law that would make it illegal to purchase laboratory glassware without a permit. Accepting for him was one Tim Mitchell, a representative of Corning. Rather than a total ban on glassware, Mitchell suggested a "five-day cooling-off period." He admitted, however, that beakers and

JESSICA BOYATT

***INTERPRETIVE DANCE** of the electrons cast authentic Nobel laureates as atomic nuclei. William Lipscomb* **(left),** *winner of the 1976 Prize in Chemistry, notes that his rhythm is good, "but I'm a lousy dancer."*

test tubes can start a habit that might leave one "strung out, begging for grant money."

The awards were interrupted periodically for Heisenberg Certainty Lectures (named for that pillar of modern physics, the Heisenberg uncertainty principle), delivered by the real Nobel laureates and other honored guests. The certainty: no lecture lasts more than 30 seconds, or a black-clad referee whistles the speaker off the stage. Artificial-intelligence maven Marvin Minsky barely finished his comments, but Lipscomb wrapped up his address with plenty of time to spare. "The following statement of the Heisenberg Certainty Principle is dedicated to the U.S. Congress," Lipscomb began. "If your position is everywhere, your momentum is zero," he concluded.

One of last year's winners, Harvard University's John Mack, had been asked to deliver the keynote address, but he backed out. Mack won the 1993 Psychology Ig for his theory that people who believe they were abducted by aliens probably were. "We're disappointed and hurt" over Mack's absence, said Ig master of ceremonies Marc Abrahams, "but above all, we're concerned."

The evening's final Ig, for Mathematics, went to the Southern Baptist Church of Alabama, for "their county-by-county estimate of how many Alabama citizens will go to hell if they don't repent." The Honorable Terje Korsnes, consul of Norway, accepted the Ig on behalf of the people of Hell, a little town in Norway. "We have a special place in Hell for all of you," Korsnes said.

During the après-Ig celebration, Minsky summed up his impressions of the ceremony. "It's one of my principles that if I have a complex experience that lasts a couple of hours, I can never think of any few silly words to describe it," he stated. "So I think it's bad to summarize." —*Steve Mirsky*

And the other 1994 Ig Nobel Prize winners are:

Lee Kuan Yew, former prime minister of Singapore. Winner of the Ig in Psychology for his 30-year study of the effects of negative reinforcement, namely, the punishing of the citizens of Singapore "whenever they spat, chewed gum, or fed pigeons."

The Japanese Meteorological Agency. Awarded the Physics Ig Nobel "for its seven-year study of whether earthquakes are caused by catfish wiggling their tails."

L. Ron Hubbard. Recipient of the Ig in Literature "for his crackling Good Book, *Dianetics,* which is highly profitable to mankind or to a portion thereof."

Chile's **Juan Pablo Davila,** former employee of the state-owned company Codelco. Davila's Ig in Economics was awarded for instructing his computer to "buy" when he meant "sell." The ultimate consequence was the loss of 0.5 percent of the gross national product. In Chile "davilar" is now a verb meaning "to botch things up royally."

John Hagelin of Maharishi International University and the Institute of Science, Technology and Public Policy. Winner of the Ig Nobel Peace Prize "for his experimental conclusion that 4,000 trained meditators caused an 18 percent decrease in violent crime in Washington, D.C." —*Mervin Stykes*

Deciphering the Breast Cancer Gene

Experts grapple with the implications of the finding

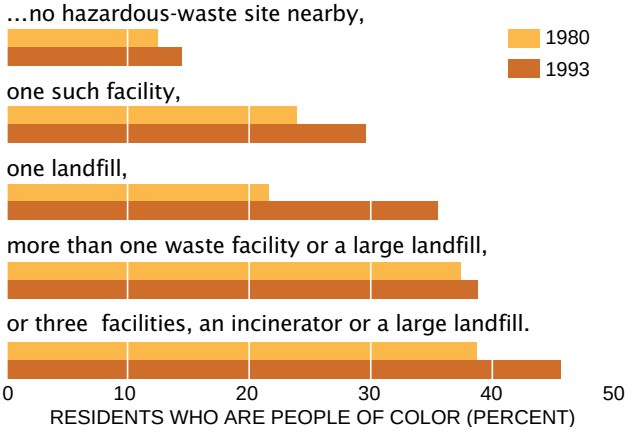
Mark H. Skolnick of the University of Utah and his 44 collaborators at five research facilities had good reason to celebrate when they found *BRCA1,* a gene whose malfunction accounts for nearly half of all inherited breast cancers, or some 5 percent of the total. The discovery ended one of the most widely publicized and potentially profitable gene hunts to date. Once revealed, *BRCA1*'s secrets may eventually lead to better treatments for familial breast and ovarian cancers.

But despite such promise, some advocacy groups and scientists alike are questioning how knowledge of the elusive gene will be applied in the interim—and who stands to gain, by how much. These ethical and legal issues are complicated by the fact that *BRCA1*—a stretch of chromosome 17 that is some 10 times longer than the average human gene—seems far from ordinary. Unlike most other known cancer genes, which play a role in both familial and nonfamilial cancers, *BRCA1* apparently plays no role in nonfamilial breast and

Toxic Waste and Race: An Unnatural Association

Hazardous-waste sites are too close for comfort in many minority communities, concludes a report by the Center for Policy Alternatives in Washington, D.C. The recent update of the well-publicized 1987 study by the United Church of Christ Commission for Racial Justice, *Toxic Wastes and Race in the United States,* found that the situation has worsened during the past six years. People of color—defined by the report as the total population less non-Hispanic whites—are currently 47 percent more likely than are whites to live near a commercial toxic-waste facility.

The population of neighborhoods changes according to whether there is . . .



ovarian cancer. And so far the discoverers have identified five mutations that occur in different regions of the gene, all of which prevent it from producing whatever protein it normally should, presumably a tumor suppressor.

Because *BRCA1* is so complex, it will be difficult to invent a simple test that accurately predicts a woman's risk for breast cancer, says David E. Goldgar, a member of the team at Utah. "Certain mutations seem to confer a higher risk of ovarian cancer, and some seem to trigger an earlier onset of the disease," he explains. "It could be random chance that one woman never develops breast cancer and that another with the same mutation does before age 30."

Current estimates suggest that a woman who has inherited a *BRCA1* mutation faces an 85 percent lifetime risk of battling the disease—but that figure is based on studies done before the debut of *BRCA1*'s location. In fact, a woman's risk might vary considerably depending both on which hallmark mutation her family passes along and on environmental factors, notes Donna Shattuck-Eidens, a co-discoverer and project leader at Myriad Genetics, a company based in Salt Lake City founded three years ago by Skolnick and Nobel laureate Walter Gilbert of Harvard University. The firm is currently seeking patent protection for *BRCA1*.

By January 1996 Myriad hopes to offer a blood test (costing about $1,000) that detects deleterious copies of *BRCA1,* Shattuck-Eidens says. Hybritech, a subsidiary of Eli Lilly that contributed $1.8 million to the *BRCA1* quest, has licensed the right to market this test. Because the test screens for one specific mutation at a time, Myriad will need to know which one a woman might carry—probably from having tested a relative with breast or ovarian cancer. "The results will take some expert interpretation to assess what risks a woman really faces," Shattuck-Eidens admits.

Because women who learn their risks can, for the moment, do little to change them—short of having their breasts surgically removed before a tumor appears—some people question the merit of Myriad's planned service. Fran Visco, president of the National Breast Cancer Coalition, an advocacy group, points out that women who show positive results might forfeit their health and life insurance. A 1993 survey of health insurance commissioners in 32 states found that 44 percent believed a family history of breast cancer was sufficient reason to deny coverage.

"When it comes to health issues, the more information you have, the better off you are," Shattuck-Eidens counters.

Certainly, detecting breast cancer at an early stage is crucial. If it is treated before cancerous cells metastasize to other sites in the body, the five-year survival rate is 95 percent. Once it has invaded other systems, that window narrows to 17 percent. Moreover, cancers that emerge at a young age—a quarter of which are genetic in origin—can spread more quickly.

An estimated 600,000 U.S. women harbor bad copies of *BRCA1,* and experts all agree that translating the gene's code into treatments for them, if possible, will require great effort. Some worry that Myriad's pending patent will impede such progress by discouraging cooperative research. A group at the Institute of Cancer Research in England decided not to participate in the Utah search for another likely breast cancer gene, *BRCA2,* citing disagreements over the ethics of patenting human genes.

"You can agree to disagree, but it certainly doesn't mean you can't work together," Goldgar says, observing that reports of the split between American and British teams are overblown. (*BRCA2* may cause as many cases of inherited breast cancer as does *BRCA1,* and its identity could soon be uncovered—workers now know that it resides somewhere along chromosome 13. Evidence suggests that other such similar genes—including *BRCA3* and *4* and perhaps even *5* and *6*—may exist as well, although taken together, they would account for far fewer cases of cancer than does *BRCA1* or *2* alone.)

In the past, gene hunters have shared vast amounts of data so that they might rapidly ferret out the cause of a disease. Patents and the call of profits, however, might make some researchers more secretive. At present, the U.S. Patent Office requires that any discovery or invention be novel (or unpublished) and nonobvious—standards that, if misread, could limit free exchange. Moreover, the find must be useful and neither an idea nor a product of nature. Many researchers maintain that human genes—particularly partial DNA fragments or sequences of unknown function—do not fully meet these final criteria.

Reid G. Adler, a patent attorney at Morrison & Foerster in Washington, D.C., and former director of the Office of Technology Transfer at the National Institutes of Health, concedes that a special system may be needed to protect some gene-related discoveries. Nevertheless, *BRCA1*'s case seems clear-cut, he says. The gene's malformation gives prediagnostic indication of a disease, and although the gene itself is nature's handiwork, a diagnostic kit based on the characterization of its role in certain cancers is not. "No one develops commercial products that are risky and require vast sums of money when anyone else could then profit from them," Adler says. "The main purpose of the patent system is to encourage people to invest in research by giving them some economic advantage."

Without the promise of patent protection, Goldgar guesses that *BRCA1* would not have been located so expeditiously. Rival researchers began chasing down this gene four years ago, when Mary-Claire King of the University of California at Berkeley traced *BRCA1* to the long arm of chromosome 17. "Part of the reason it was found when it was is because there was a company involved with adequate resources to get a lot of people working on it," Goldgar says. Shattuck-Eidens concurs: "This undertaking was a cooperative effort between research, university and industrial partners—and of course they all have different weights and measures—but I'm of the opinion that it works to everyone's advantage in the end."

Adler dismisses any fears that *BRCA1*'s medical potential might be compromised by its commercialization. "Myriad and Eli Lilly can't monopolize the entire universe of breast-cancer test kits," he notes. Because the NIH helped to fund the project, the government could establish sublicensing arrangements if knowledge about *BRCA1* were not being used in the public's best interest. The NIH has never sought these so-called margin rights, though, and it seems in this case the agency hopes to assume an active role in licensing technology based on *BRCA1.* On October 6, the NIH filed a counterapplication to add its scientists' names to Myriad's patent as coinventors. "Patents don't interfere with academic science," Adler states, "and they are essential in the commercial realm."

The Office of Technology Assessment will produce an investigative report early next year. But *BRCA1* is by no means the first human gene that scientists have sought to patent. Human Genome Sciences and SmithKline Beecham hold a patent on *APC,* which causes colon cancer, and Sequana Therapeutics likewise has rights to the so-called obesity gene.

Still, *BRCA1* has stirred up far more controversy. "Breast cancer is a much more emotional issue for many people," Goldgar says, "and incredibly common." One in eight American women will acquire breast cancer during their lives, and the disease claims some 46,000 mothers, sisters, wives and daughters every year. In that light, *BRCA1* deserves all the scientific, legal and public attention it can get. —*Kristin Leutwyler*

Global Politics

Mathematicians collide over a claim about packing spheres

Mathematicians like to think their truths are as objective as any we humans are permitted to know. That may be so, yet an unusually persistent and rancorous dispute over a famous problem called Kepler's conjecture has revealed just how subjective the process of judging those truths can be.

The controversy began innocently enough four years ago, when Wu-Yi Hsiang of the University of California at Berkeley decided to teach a course in classical geometry. To sharpen his skills in this old-fashioned field, he took on a conjecture posed in 1611 by Johannes Kepler, the same German polymath who discovered that planets travel in elliptical rather than circular orbits.

Kepler contended that the most compact method of packing spheres is the one exploited by nature to arrange atoms into crystals and by grocers to stack oranges into four-sided pyramids. The easiest way to create this pattern is to form a layer of spheres consisting of even vertical and horizontal rows; spheres in the next layer up nestle in the niches between each foursome of spheres in the layer below.

Few mathematicians doubt Kepler's conjecture—which is related to problems in solid-state physics, information processing and other fields—but they have had a devilishly difficult time proving it. After all, there are infinite ways to arrange spheres in a given volume. Douglas J. Muder, until recently of Mitre Corporation, has established that spheres can fill no more than 77.3 percent of a volume, but Kepler's conjecture states that the upper bound is approximately 74 percent (that is, π divided by the square root of 18).

After six months of pondering the problem, Hsiang became convinced he had a proof. Although his argument drew on relatively standard techniques from geometry and calculus, it was long—more than 100 pages in an early draft—and intricate. Hsiang's basic approach was to calculate the "local" density achieved by various finite configurations of spheres and then to extrapolate these results to infinitely large volumes.

Hsiang began circulating a draft of his proof and lecturing on it in 1990, and his work was soon hailed in *Science, New Scientist* and this magazine. Meanwhile a group of four experts on sphere packing—Muder, John H. Conway of Princeton University, Neil J. A. Sloane of Bell Laboratories and Thomas C. Hales of the University of Michigan—started questioning the proof. The group complained that Hsiang's paper, as long as it was, was short on details: its jumps from particular cases to generalities were insufficiently justified.

The critics wrote several letters to Hsiang challenging his proof. Far from retracting his claim, Hsiang submitted his paper to the *International Journal of Mathematics,* which is edited by another Berkeley mathematician, Shoshichi Kobayashi. After Hsiang had made some revisions, the journal published Hsiang's 92-page paper in October 1993.

This past spring Conway, Hales, Muder and Sloane announced in *The Mathematical Intelligencer* that they "do not consider that Hsiang's work constitutes a proof of Kepler's conjecture, or can be completed to one in a reasonable time." In the summer issue of the *Intelligencer,* Hales presented a tart, 12-page summary of the group's main objections to Hsiang's work. He suggested that Hsiang's paper was at best a series of conjectures that, if demonstrated, might constitute a proof. "Mathematicians can easily spot the difference between handwaving and proof," Hales concluded.

Conway predicts that Hsiang will sacrifice his "distinguished" reputation if he persists in claiming to have a proof. "I think he'd be better advised to drop it," he remarks. According to Muder, the controversy has already discouraged other mathematicians from working on Kepler's conjecture, since no one wants to pursue a problem that may be solved. "It slowed things down a lot," he says.

Sloane contrasts Hsiang's behavior with that of Andrew J. Wiles of Princeton University. In 1993 Wiles announced he had proved Fermat's Last Theorem—perhaps the most celebrated conundrum in mathematics—but he promptly withdrew his claim after colleagues pointed out shortcomings. Sloane calls Hsiang's decision to publish his paper in spite of the objections "extraordinary." "You can't regard [Hsiang] as a serious mathematician," Sloane sniffs.

Hsiang, whose rebuttal to his critics will be published in the winter 1995 *Intelligencer,* retorts that their complaints consist of "misunderstandings, misinterpretations, misaccusations." His proof "gives all the crucial understanding" and omits only "boring computation," he declares. Hsiang admits only that he may have a "communication problem." In collaboration with Karoly Bezdek, a Hungarian mathematician now at Cornell University, Hsiang plans to construct a more detailed version of his proof.

Bezdek agrees with Hsiang that Hales and his colleagues "have either misunderstood or by purpose did not want to follow" his ideas. Yet he also thinks Hsiang's proof is not complete. "I'm optimistic" that at least one crucial component of the proof can be completed,

GEOFFREY WHEELER *Black Star*

***PYRAMIDS OF FRUIT** display what Johannes Kepler conjectured in 1611 to be the most compact arrangement of spheres, the so-called face-centered cubic lattice.*

Bezdek notes, "but there are gaps." Moreover, Bezdek acknowledges that he may be inclined to favor Hsiang's work in part because it extends an approach first developed in Hungary. Struggling to sum up his view of the situation, Bezdek says, "The picture is at the moment not so objective."

For now, public opinion seems to have turned against Hsiang. In 1992 Ian Stewart of Warwick University still thought Hsiang might have achieved "one of the most astonishing successes in the entire history of mathematics." Stewart cheerfully admits that he is not an expert on sphere packing; his assessment was based on secondhand reports about Hsiang's reputation and argument rather than on a rigorous analysis of the proof. Now Stewart is inclined to believe Hsiang's critics, who are equally eminent.

Indeed, some observers fear that the spat over Kepler's conjecture points to a deeper, more pervasive quandary facing mathematics: as the field grows increasingly complex and specialized, the evaluation of proofs is becoming more difficult. "It is harder to check proofs than it used to be," confirms Chandler Davis of the University of Toronto, editor of the *Intelligencer*. "The process has become unmanageable."—*John Horgan*

The No-Name Virus

Questions linger after the Four Corners outbreak

The power of modern medicine has rarely been demonstrated so well as it was in the spring of 1993, after physicians near the junction of New Mexico, Arizona, Utah and Colorado reported a spate of severe respiratory illness resulting in more than a dozen deaths, primarily among Navajo Indians. Within months, researchers from the Centers for Disease Control and Prevention and elsewhere had identified a viral culprit in the so-called Four Corners outbreak.

Yet medical mysteries rarely succumb to science without a struggle, and investigators of the incident are still trying to tie up some significant loose ends: Why do some people become infected while others seemingly exposed to the same risk factors do not? Why do some people who show all the signs of the respiratory illness not test positive for the virus? "I still think lots of questions need to be answered," remarks Shyh-Ching Lo, a researcher at the Armed Forces Institute of Pathology.

The CDC has tentatively named the new pathogen the Sin Nombre, or no-name, virus. It is genetically similar to a family of viruses, called hantaviruses, known to cause acute kidney-related illness in Asia and Europe. Hantaviruses take their name from the Hantaan River, which runs through an area in Korea where the disease is endemic. Hantaviruses were first detected in the U.S. more than a decade ago but only in a nonvirulent form.

By October of this year the CDC had reported 94 cases of the hantavirus pulmonary syndrome—more than half of them fatal—in 20 states. Investigators believe victims become ill by inhaling dried urine or feces of infected deer mice, which are the primary vectors of the virus. About 30 percent of the deer mice in the Four Corners region carry the Sin Nombre agent; infected rodents have been found in other parts of the country as well.

Yet some victims seem to have contracted the illness after little or no contact with rodent carriers. One Rhode Island man who died this past January of hantavirus pulmonary syndrome was initially thought to have contracted the virus a month earlier while sweeping out a warehouse in Queens, N.Y. Yet a recent report in the *Journal of the American Medical Association* noted that none of the rodents trapped in that location—or any others where the victim had been during the two months before his death—had positive results for hantaviruses.

Studies have also shown that even people seemingly most at risk rarely become infected and that the virus does not trigger illness in all those it infects. Laurie R. Armstrong of the CDC recently tested more than 900 pest-control workers and others who frequently handle deer mice and other rodents known to carry hantaviruses. Only eight—less than 1 percent—were positive for Sin Nombre. Of these, only one recalled having an illness resembling hantavirus pulmonary syndrome.

The CDC has analyzed blood samples taken from some 500 Navajos in the Four Corners area before the outbreak. One percent of that group had antibodies to the Sin Nombre virus, but none reported having an illness resembling the pulmonary syndrome. A study of southern California's Channel Islands has turned up similar results. The islands are so infested with deer mice that the animals commonly run over the feet of hikers; a significant percentage carry hantaviruses. Yet Michael S. Ascher, an investigator for California's Department of Health Services, says a survey of residents of the islands has turned up no apparent cases.

James E. Childs of the CDC acknowledges that the link between rodents and victims remains unclear. "We do not know why some people become infected and others don't," Childs says. Peter B. Jahrling of the U.S. Army Medical Research Institute of Infectious Diseases suggests that the Sin Nombre virus might act in concert with a cofactor to cause the pulmonary syndrome. Workers at the CDC and elsewhere say they have considered such cofactors as *Chlamydia, Mycoplasma* and various environmental toxins but have found no supporting evidence.

Perhaps the most disturbing question raised by the outbreak concerns people who exhibited symptoms of hantavirus pulmonary syndrome but showed negative results for the virus. This issue was highlighted in a recent letter to the *New England Journal of Medicine* by two workers at the University of California at San Francisco, Tina Harrach Denetclaw, a pharmacologist, and her husband, Wilfred F. Denetclaw, a cell biologist who grew up in a Navajo family in the Four Corners region.

The Denetclaws pointed out that a minority of the cases investigated by the CDC had shown signs of infection by the Sin Nombre virus. "Regardless of whether hantavirus is the etiologic agent of the hantavirus pulmonary syndrome, a large number of cases in the outbreak were not associated with hantavirus and remain unexplained," the Denetclaws stated.

Indeed, Bruce Tempest of the Indian Health Service notes that at least one such case has occurred recently in New Mexico. In California, Ascher has uncovered half a dozen incidents in which relatively young and healthy people died suddenly of acute respiratory failure yet did not test positive for hantavirus or any other pathogen. The victims had all the classic symptoms of hantavirus syndrome, including exposure to rodents, Ascher says. Similar cases have turned up in Nevada, according to Arthur F. DiSalvo, director of the state's public health laboratory.

Clarence J. Peters, chief of the CDC's hantavirus task force, confirms that only 25 percent of the cases of suspected hantavirus pulmonary syndrome reported in the Four Corners area by this past January had been linked to the Sin Nombre virus. The percentage may be much smaller when cases from other parts of the country are taken into ac-

count. Peters says the tests cannot be blamed: they are highly sensitive. Instead he argues that most of the negative cases, if investigated, would be found to stem from bacterial pneumonia and other known causes of respiratory distress—after all, officials have estimated that some 50,000 cases of respiratory failure occur in the U.S. every year, and many of these cases are never adequately explained.

But the undiagnosed cases of apparent pulmonary syndrome from the Four Corners region and elsewhere intrigue Peters's co-worker Sherif R. Zaki. "After I get out from under [the Sin Nombre investigation]," he says, "my first plan is to go back and see what caused the deaths of these other patients." After all, it is always possible that yet another unknown—and deadly—virus is on the loose. *—John Horgan*

THE ANALYTICAL ECONOMIST

The Wages of Haiti's Dictatorship

A thin layer of soot falls continuously on Port-au-Prince, a visitor reports. This black dust is not so much the fallout of two years of international oil embargo as of two centuries of economic myopia. Made indiscriminately from any wood, charcoal powers dry-cleaning plants, bakeries and the cookstoves of the rich—the poor burn their wood only once. More than 90 percent of Haiti has reportedly been denuded, leaving the country bereft of natural resources crucial to its economic survival.

Wallace Turnbull, a missionary who has spent most of his life in Haiti, once asked officials why they did not import cheap kerosene to reduce deforestation. They replied, he says, that such largesse would endanger the profitable tax on diesel fuel because people might adulterate the kerosene to run trucks. Other officials, meanwhile, were exporting charcoal to the neighboring Dominican Republic, where environmental regulations forbid its production.

This kind of bizarre subtext seems typical of the Haitian landscape. Barbara Lynch of the Ford Foundation recounts how the Haitian army destroyed tree seedlings that were part of a reforestation project. Although the trees might have been good for the environment and hence the country as a whole, she explains, the rural development program that planted them brought peasants together. The resulting coalition diminished the army and the Tonton Macoutes' control over the countryside, threatening the long-standing arrangements by which they "extracted resources upward."

Political and economic power are often closely linked, but in Haiti the two became almost indistinguishable. The government, according to Michel-Rolph Trouillot of Johns Hopkins University, had "no role other than as a predatory mechanism for the elite." Viewed in this light, many counterproductive aspects of the Haitian economy can be understood not simply as shortsighted individualism run amok but rather as trade-offs between the perceived utility of higher profits for the island's owners and the risk that any money trickling down might upset the established imbalance. Lynch notes the lack of investment in the simplest of infrastructure: roads, schools and public utilities, even in rich neighborhoods.

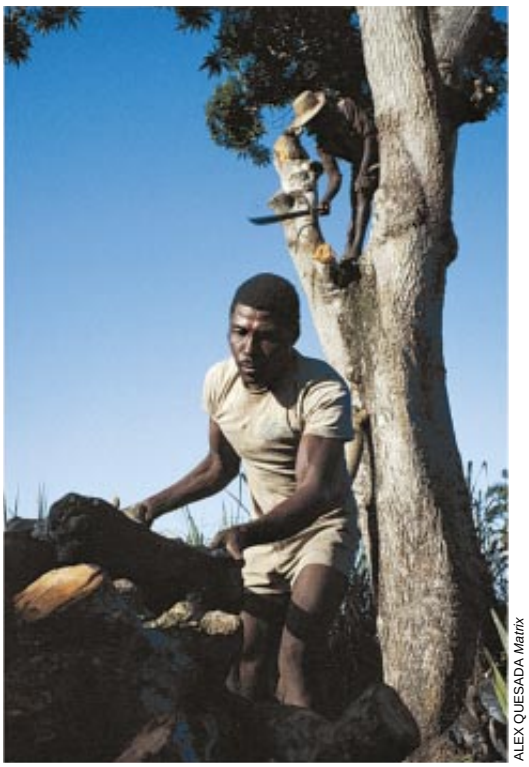
Some of the elite have made a profit from both the instigation and the aftermath of environmental destruction. Government lands near Port-au-Prince served as free quarries for concrete to build mansions, Trouillot says, but the resulting erosion loaded nearby rivers with sediment. The delvers then trucked in potable water from more distant rivers and sold it to those whose supply they had rendered undrinkable.

Yves Renard, director of the Caribbean Natural Resources Institute, reports malign neglect throughout the countryside, where hoe-based farming methods have not changed substantially since the early 19th century. Wealthy landowners had little incentive to raise their opponents' standard of living, and peasants saw no reason to improve their husbandry as long as those above them stood ready to extract whatever surplus they might produce. Turnbull recalls how the annual harvest of mangoes from the village of Marmont, near St. Michel in central Haiti, dwindled from $60,000 to nothing in two years during the late 1980s, as farmers cut the trees to make perhaps $15,000 worth of charcoal.

The current challenge for Haiti is to set such a self-destructive system on a sustainable path. The U.S. occupation has mitigated the traditional means of enforcing distinctions of wealth and power, but most of the perverse incentives are still in place. Initial U.S. plans for funneling half a billion dollars of aid to the island have called for the standard measures that the International Monetary Fund and the World Bank impose on supplicants: cutbacks in government spending (a near oxymoron here) and removal of tariffs on imported goods.

This "urban" plan, drafted without input from the incoming Ministry of Agriculture, could be disastrous, Trouillot warns. If imported foodstuffs undercut local production, the poor will become even poorer, and the last non–firewood use of the land will disappear.

As Renard points out, however, simply injecting capital into the rural economy could easily do more harm than good—either reinforcing existing inequalities or creating new ones. Wise investments may depend on getting people forcibly silenced for nearly 200 years to speak up and on having a government—currently as bereft of independent power as any of its predecessors ever were—in a position to listen to them. *—Paul Wallich*



ALEX QUESADA *Matrix*

DEFORESTATION, carried out by manual laborers, reflects the elite's economic shortsightedness.

Virtual Reality Check

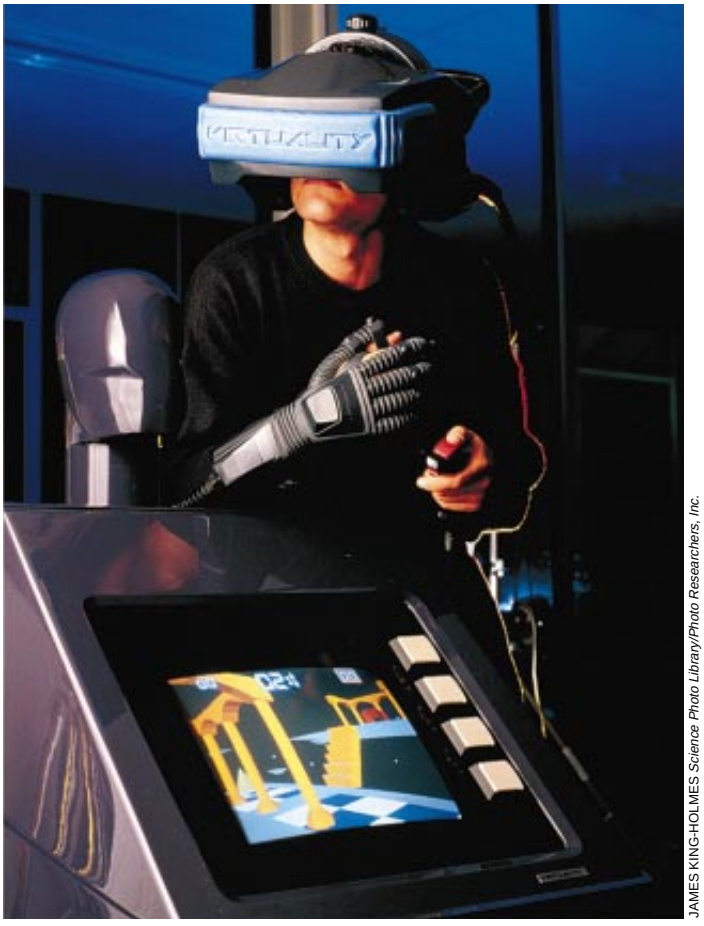
Imaginary environments are still far from real

Proselytes of virtual reality have promised a technology that can immerse participants in synthetic worlds of compelling illusion. It would seem from recent headlines—witness "VR Revolution Looms Larger Each Day" (*Business Times*), "Virtual Reality Finally Getting Real" (*Orlando Sentinel*) and "VR Arrives Home" (*Financial Times*)—that these boosters have persuaded an initially skeptical public that virtual reality has cleared its major technical hurdles and will soon hit the mass market.

Yet in a report released this autumn by the National Research Council (NRC) a panel of computer scientists, engineers and psychologists reached quite a different conclusion. Despite the hype surrounding the field, the experts wrote, "there is a substantial gap between the technology that is available and the technology that is needed to realize the potential of [VR] systems." Henry A. Sowizral, who leads a VR research project at Boeing Computer Services in Bellevue, Wash., agrees. "The three biggest problems in VR are performance, performance and performance," he quips, referring to persistent inadequacies in the state of the art for virtual-reality displays, computers and software.

Fooling a human brain into believing it is somewhere it's not is a tricky task. So far most research has focused on deceiving the eyes. High-resolution, wide-angle, three-dimensional displays are one obvious prerequisite; devices that track the direction of your gaze are another. Yet current VR helmets that place a miniature liquid-crystal screen in front of each eye are grainy and expensive. The military spends up to $1 million each for the best, which offer the resolution of a typical desktop computer monitor—viewed at a distance of about four inches. "Most affordable headsets render you legally blind," Sowizral says. "You can't make out the big E on an eye chart at a virtual 20 feet."

Although screens will quickly get sharper, it will not be so easy to make lighter helmets, and that bodes ill for VR explorers. At several pounds, head-mounted displays make it hard to turn your head. Combined with a strictly visual illusion of movement, the weight induces motion sickness in many wearers. Nausea and headaches are just the beginning, the NRC report notes. "A more severe problem…is the sopite syndrome. This refers to the chronic fatigue, lack of initiative, drowsiness, lethargy, apathy and irritability that can persist for prolonged periods" even after short gambols through virtual worlds.



JAMES KINGHOLMES *Science Photo Library/Photo Researchers, Inc.*

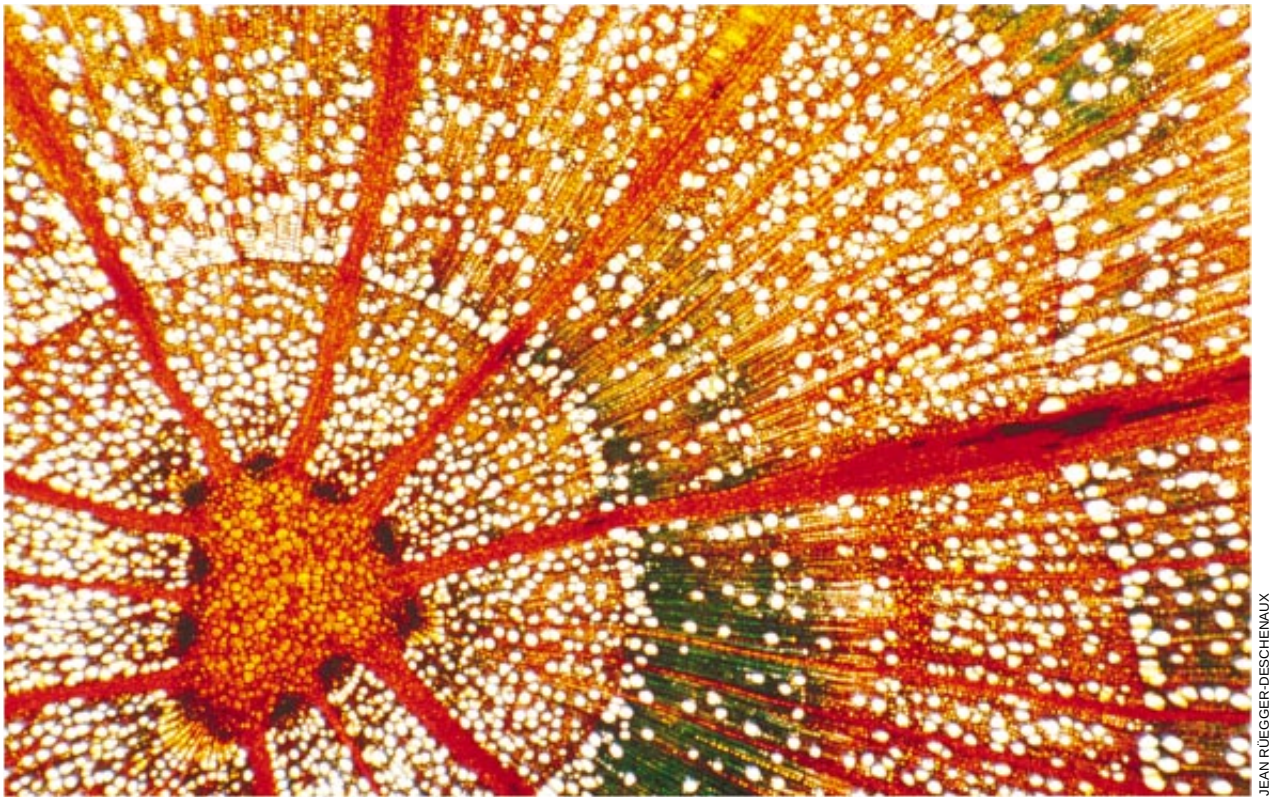
***IMAGINARY WORLDS** may be the province of virtual reality travelers. But a National Research Council report concludes that the technology cannot yet meet public expectations.*

Current VR tracking systems are even clumsier than are helmets. "Tracking is the stepchild that nobody talks about," Sowizral says. Mechanical booms attached to the face and hands are fast and accurate but tend to get in the way—especially when the eyes are covered. Magnetic systems that use compasslike sensors are also popular, Sowizral reports. "But they are susceptible to interference from anything metal—like computers, for example. I once put a Coke can down next to the field source, and I must have jumped 50 feet in the virtual environment," he chuckles.

Vision aside, virtual environments won't feel real until you can reach out and touch them. Various computer-controlled devices for simulating force and texture have been tried, but, Sowizral warns, "unless a few problems are solved, they may be very dangerous." To create the illusion of a solid where there is none requires brawny robotic arms that follow your hand and resist where appropriate. "But if you slam your hand down on a virtual table, the device needs multiple horsepower motors to make it feel like you've hit a tabletop," Sowizral observes. "Well, multiple horsepower is enough to break your arm if someone has written the program wrong. So people are wimping out and using much smaller forces," making apparently solid objects actually feel soft and squishy.

While they may feel spongy, these virtual objects will look unrealistically angular and will react strangely to touch until computers become more powerful. To the computers that draw virtual worlds, three-dimensional objects are composed of many two-dimensional polygons. Experts estimate that each frame of a VR animation must contain about 80 million polygons to appear photorealistic. At least 10 frames per second are needed to sustain the illusion of continuous motion. (Cinematic films run at 24 frames per second; television uses 30.) So any VR system that aspires to visual realism must be able to compute and draw at least 800 million polygons per second.

1994 Nikon International Small World Competition



JEAN RÜEGGER-DESCHENAUX

A cross section of a young beech tree won the 1994 Nikon International Small World Competition. The photomicrographer, Jean Rüegger-Deschenaux of Zurich, colored the specimen with chrysoldine and astral blue before shooting it at a magnification of 40-fold. The competition was established 20 years ago.

For about $200,000, Silicon Graphics in Mountain View, Calif., offers a graphics supercomputer, called the RealityEngine^2, that can render two million polygons per second under ideal conditions—0.4 percent of the speed needed for verisimilitude. The PixelFlow, a more costly experimental system under construction at the University of North Carolina at Chapel Hill, is expected to reach about 30 million polygons per second. Virtuality, a video arcade game billed as virtual reality by W Industries in Leicester, England, renders scenes of just a few hundred polygons with all the complexity of LegoLand.

"If you want photorealism, then for many environments, a RealityEngine^2 is woefully inadequate," states Joshua Larson-Mogal of the Advanced Graphics Division at Silicon Graphics. "But while realism may have something to do with VR, it is not a necessary condition by any means." The NRC committee agreed but added in its report that drawing is just one part of the work required of a VR computer.

Useful VR applications need more than just pretty moving pictures. Virtual objects must also mimic the behavior of their real counterparts, which means making millions of additional calculations each second to ensure that they act like massive solids rather than massless surfaces. Add a sense of touch, as many programs strive to, and the workload again increases dramatically, since textures must be updated hundreds of times a second to feel lifelike.

The NRC report warns that while research proceeds apace on VR display hardware, equally important efforts on software lag behind. Cognitive studies have shown that separating the sight, sound and touch of an event by a few tens of milliseconds can cause confusion. VR researchers have yet to write operating software that can guarantee simultaneous responses from visual, auditory and tactile displays. And the job of Creator is a tough one: "It takes months or years" to create these environments, Sowizral says. The committee recommended that the federal government fund "a major unified research program" to develop VR software.

So why all the hype that VR has arrived, when even Larson-Mogal estimates that it will be eight to 10 years before the marginal VR capabilities of a RealityEngine^2 reach the consumer market? Perhaps because researchers tend to focus on future improvements rather than current limitations and seem to thrive on publicity. "Virtual reality currently has an extremely high talk-to-work ratio," the NRC report admonishes. The study also suggests that most VR researchers are interested primarily in the graphics software. "Thus, the importance of adequate hardware, without which the VR field will never come close to realizing its potential, tends to be underplayed by the VR community."

More disturbing, the study notes that scientists in the field seem to have abandoned their scientific objectivity. "The extent to which the usefulness of virtual reality has actually been seriously evaluated is vanishingly small," the committee concluded. Rather than comparing the cost-effectiveness of a virtual-reality system with a more traditional approach, the higher-tech solution is too often simply pronounced better. Letting students swim with virtual dolphins sounds cool, but taking them to a real aquarium may be both cheaper and more valuable. Sometimes reality doesn't bite. —*W. Wayt Gibbs*

Watch Your Electronic Mouth

Cyberspatial speech runs into legal quagmires

Law and order is coming to the electronic frontier, by fits and starts. But hardly anyone, even lawyers, seems pleased by the prospect. One deeply unsettled, and unsettling, question is "which law?" Cyberspace permeates nearly every corner of the physical world, so people who enter it at one keyboard and monitor may find themselves dragged out through another terminal halfway around the country or the globe to face charges for crimes they have no idea they've committed. Statutes differ from country to country or even city to city, so cybernauts may be considered wrongdoers even if their acts are perfectly legal in their home jurisdiction.

Last year, for instance, a Canadian sued several American universities for libel because their computers transmitted derogatory messages about him that had been broadcast by a British graduate student. The universities—which owned property in England, where libel laws are stricter—reportedly settled instead of fighting.

And in July a San Jose couple who ran an adult bulletin-board system called Amateur Action found themselves convicted for obscenity according to the straitlaced standards of Memphis, Tenn. Law-enforcement officials there dialed up the system in California, downloaded pornographic images and had the pair extradited to stand trial. The two face additional charges in Utah.

The Amateur Action case will be appealed, but in the meantime bulletin-board operators have already begun purging their files. Some Internet access systems have dropped discussion groups that might get them in trouble. Karl Denninger of MCS in Chicago says he has probably lost customers since he stopped carrying "alt.binaries.pictures.tasteless" and "alt.binaries.pictures.erotica," but he does not consider the legal risk to be one worth taking.

Denninger and others are more concerned by proposals to regulate text as well as pictures. Senator J. James Exon of Nebraska introduced a measure this past summer that would have given the Federal Communications Commission authority to regulate "indecency" on the net, just as it now does for radio, television and telephone-sex lines. The legislation to which it was attached died in the Senate in October, but observers expect it to return. "Nobody wants to pass the Exon Amendment" because it is unworkable and probably unconstitutional, says Michael Godwin of the Electronic Frontier Foundation. "But if it goes to a vote, they'll pass it" to avoid appearing in favor of pornography.

Mikki Barry, an attorney at InterCon Systems Corporation and one of the founders of the Internet Business Association, asserts that network access providers should not be responsible for policing every file that passes through their computers. She notes that courts have long held that booksellers cannot generally be prosecuted for libelous or obscene material on their shelves and advocates similar protection for electronic purveyors.

There are, however, some kinds of free speech that net users are fighting to eliminate. An entire Usenet discussion group ("alt.current-events.net-abuse") is now devoted to complaints about "spams," material posted to dozens or hundreds of unrelated news groups or mailing lists. Advertisements for anything from software tools to herbal weight loss regularly clutter mailboxes.

Often, spammers have paid for access to the Internet and so cannot easi-

ly be squelched. In mid-September, for instance, a southern California company carpet-bombed all Internet mailing lists beginning with the letters A and B with a missive that opened, "Dear Friend, Since you are someone who reads E-Mail…" Complaints to Delphi, the large on-line service where the spam originated, went unanswered.

More devious approaches to on-line marketing have met with negative public responses as well. In the jazz discussion group "rec.music.bluenote," a consultant for Atlantic Records used several different names to write a series of glowing reviews of new releases by the company's artists. The scheme backfired when another net denizen exposed the connection, but the vigilante briefly lost access to the net because of his "harassment."

Rather than broadcasting their advertisements at others' expense, some companies have begun taking advantage of the World Wide Web, a distributed hypertext system, to let potential customers come to them. With programs such as Mosaic, users can browse through information from all over the world; Mosaic Communications Corporation has announced a version that can encrypt commercial information such as a credit-card number so it can safely traverse the Internet. Net surfers may then be able to buy products as well as just scan on-line catalogues.

When that day comes, however, Barry foresees more legal headaches. No one knows what jurisdiction these transactions will take place in: that of the buyer, the seller or the Internet site where the product's "page" is located. Although sellers may attempt to attach contract terms to network sales (similar to the "shrink-wrap licenses" included in most commercial software packages), there is no guarantee that courts will enforce them. Says Barry: "Judges and juries have no clue what's going on—they still think the information superhighway is about 500-channel cable TV systems." —*Paul Wallich*

Bad Apple Picker

Can a neural network help find problem cops?

If reputation is everything, Chicago and its police department may never completely live down the summer of 1968, when violent clashes erupted between officers and demonstrators. Chicago Mayor Richard M. Daley, a son of the Richard J. Daley who was mayor 26 years ago, knows that. When the Democrats announced this past summer that the convention would return to Chicago in 1996, the younger Daley had to rush to the defense of the city that had been the site of what a presidential commission termed a "police riot."

A few weeks before Daley's remarks, the Internal Affairs Division of the Chicago police had made public an attempt at preserving its officers' reputations. The division, which looks into allegations of wrongdoing by its own officers, enlisted the help of a software package that purports to emulate the way brain cells operate. Every 90 days the division intends to come up with a list of officers that the software suggests may be headed for trouble.

To produce these names, the software uses a predictive model called a neural network. The program forecasts whether each of the 12,500 officers on the force is likely to behave in a manner similar to their nearly 200 colleagues who were dismissed or resigned under investigation during the past five years for actions ranging from insubordination to criminal misconduct. The first list, with 91 names, was to have been delivered to the personnel office in late October. Those officers were to have enrolled in a counseling program.

The seeming ability of neural-network software to extract meaningful conclusions from disparate data has resulted in its use for everything from predicting recidivism by criminals on probation to recognizing mosquitoes from the sound of their beating wings. The Chicago police may be the first to employ the technology to anticipate misconduct by law-enforcement officers.

The network consists of a software simulation of a grid of interconnected processors. The processing elements and the connections among them correspond roughly to neurons and synapses in the brain. Like the brain, the network must undergo a "training" process. In the police network, input processors accept personnel information about an individual officer—such as citizen complaints and traffic accidents—that have been translated into a series of numeric values. These variables alter the strength of signals, or synaptic weights, that move from one processor to another. The change in weights sets up a chain of events—for example, the signal strengths are multiplied with and added to other values at each processor. The process continues until the network yields values that estimate the likelihood or not of dismissal. The values are then compared with another number, a zero or a one, that signifies whether the officer being considered has, in fact, been fired or is in good standing.

If the network has guessed incorrectly, and it usually does initially, a mathematical formula makes a correction to the weights. By exposing the network to hundreds of examples of dismissed officers and those with a clean record, the network continuously adjusts the weights for about half an hour. Hence, it "learns" to make accurate predictions consistently.

At least that is how things are supposed to work. Neural networks have true disbelievers. The police union, for one. Relations between internal investigators and the union are uneasy even at the best of times. When the union heard about a computerized brain quietly mulling through personnel files to find problem cops, it experienced the institutional equivalent of an aneurysm. "It's absolutely ludicrous—it stinks," fumes Bill Nolan, president of the Fraternal Order of Police in Chicago. Nolan says the neural network, which he has called a "crystal-ball thing," is merely a tactic by the department to avoid managing their officers. "You got a guy slacking off? Supervise him, correct him," Nolan demands. And he adds: "I told them if this thing is so good, we should give it to all the detectives so they can solve all the murders and robberies."

Nolan's impressions do not differ markedly from those of some cognitive psychologists and computer scientists. "Voodoo," remarks Zenon Pylyshyn, a professor of cognitive science at Rutgers University. "People are fascinated by the prospect of getting intelligence by mysterious Frankenstein-like means—by voodoo! And there have been few attempts to do this as successful as neural nets."

The critics' main objection is that neural networks are a form of black box: they do not indicate how they arrive at a conclusion. Unlike expert systems—another kind of artificial-intelligence technique that makes recommendations based on an explicit set of rules—neural networks operate by complex nonlinear processes. "A neural network's abilities, as such, reside in connection weights, a vast numerical table that defies effective analysis," write Charles X. Ling and A. K. Dewdney of the University of Western Ontario. "It is next to impossible to interpret and understand what neural networks of a moderately large size have learned. As technology, the art may have promise, but as science, it fails on this count alone."

Ling and Dewdney represent one po-

sition in a debate that has continued for decades. Leaving aside hyperbole about similarities with the human brain, proponents of neural networks maintain that the technology is nothing more than a complicated twist on the standard statistical method of deducing a pattern from numeric values by drawing a curve over a set of data points. Moreover, the underlying methodologies are open to analysis. "Most of the time, users don't need to know what the software is doing—they only need to know whether it works," says Michael Mittmann of California Scientific Software, which sold the Chicago Police Department its $795 BrainMaker Professional software package.

The Chicago police, in fact, found that about half of the 91 individuals identified by the software had already been placed in a program set up by the personnel department to counsel officers who had experienced misconduct problems. The software is now intended to complement that program, letting the Internal Affairs Division find officers who may run into difficulties before a supervisor does. "In departments of 150 people or less this software wouldn't be necessary," says Raymond Risley, the assistant deputy superintendent in charge of the Internal Affairs Division. "But for the Chicago police, it is pretty much impossible for all at-risk individuals to be identified."

Companies that sell neural-network software may inadvertently add fuel to skeptics' arguments. California Scientific Software cites a number of highly speculative uses for the product. Customers claim to have achieved better than average results in forecasting winners of horse and dog races.

The dog track is one thing. But whether BrainMaker or any other neural network can outpoint a grizzled line sergeant remains to be seen. —*Gary Stix*

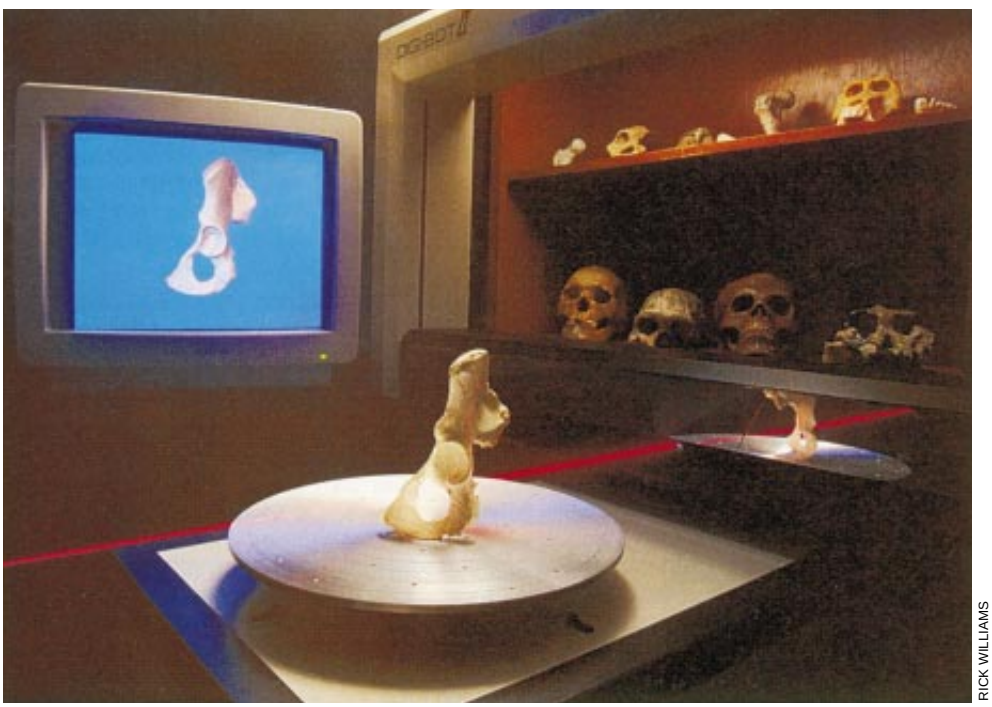
Relinquishing Relics

3-D copies of artifacts could stand in for the real thing

The Stone Age literally meets the space age in John Kappelman's laboratory at the University of Texas at Austin, where laser beams bounce off skulls and blasts of x-rays penetrate ancient bones. A computer monitors the results and compiles information on the exact, three-dimensional shape of specimens such as the skeletal remains of long-dead Native Americans or fossils of even longer-dead hominid ancestors. In a matter of hours these ancient objects are transformed into data files that can be stored on a CD-ROM or restored into precise replicas of the original. "It's a very new and very untried technology," Kappelman explains eagerly. The anthropologist is convinced that the process will transform his field and resolve some of the bitter conflicts that have arisen over issues of ownership and access to relics.

Such an embrace of high technology is unusual in a discipline more closely associated with notebooks and calipers. "Archaeologists and anthropologists always get to the technology about 20 years after everyone else," sighs Thomas R. Hester, director of the Texas Archeological Research Laboratory. A few years ago, however, Kappelman latched on to the idea that electronics might offer an easier and more thorough way to analyze fossils. He did not have to look far to follow up on the notion. "We're right in the middle of 'Silicon Hills,'" he says, referring to the gathering of high-technology companies around Austin.

Sensing an opportunity to showcase their products and explore new markets, three companies—Digibotics, Scientific Measurement Systems and DTM Corporation—are working with Kappelman's group. Each firm provides a complementary piece of equipment. Digibotics manufactures 3-D laser scanners, which record the contours of a specimen by running a laser beam across its surface. The scanners can capture details smaller than a millimeter across.



RICK WILLIAMS

***LASER SCANNER** captures a 3-D image of a pelvic bone from "Lucy," an early hominid. The scanned bone can then be analyzed, animated or replicated by computer.*

The second company, Scientific Measurement Systems, builds computed tomography machines. Computed tomography is a 3-D x-ray imaging technique widely used in medicine. The newest tomography devices provide enough resolution to measure such diverse details as the worn enamel on a hominid tooth, healed injuries in an ancient bone or subtle aspects of the methods used to make a shard of pottery.

Laser scanning and computed tomography both produce digital data files that describe the form of an object. "But we're still tactile animals," Kappelman reflects. "Millions of years of evolution have taught us to learn by touching." To satisfy that need, he turned to DTM Corporation and a new process known as laser sintering—a way to do 3-D photocopying. Sintering essentially reverses the result of scanning: a computer-guided laser

marks out the shape of the sample and etches it into nylon or polycarbonate powder. The laser then fuses the powder and builds up a replica.

Computer scanning and replication technologies are still costly and unfamiliar to most anthropologists. Stephen Koch, president of Digibotics, says that even given a discount for universities, a laser scanner would cost about $30,000. A complete scanning, tomography and sintering setup might run close to $1 million.

So far the university has purchased only the laser scanner. Learning how to apply engineering analysis techniques to anthropological research may take some time. In "the next six months we'll start to see where we can go with this technology," says Samuel Wilson, who collaborates with Kappelman. Or, in the more skeptical words of anthropologist Ralph L. Holloway of Columbia University, "It's not something that makes you think, 'Oh, God, I've got to do this right away.' You don't want to end up with a system that forces you to fritter your time away."

If the new technologies do realize their promise, they could assist museums and universities wrestling with the need to repatriate Native American relics. With the passage in 1990 of the Native American Graves Protection and Repatriation Act, all institutions that accept federal funds are required to honor requests for the return and reburial of bones and artifacts. The law has led to a massive project to catalogue such relics by the November 1995 deadline; it has also engendered concern among anthropologists about the tremendous amount of knowledge that will disappear into the ground. "Once it's buried, it's gone forever," as Kappelman puts it.

Laser scanning could offer a way to return artifacts to their rightful owners while maintaining an electronic simulacrum (or an actual model) for future study. "In no way is the process destructive," Kappelman insists. "It just involves shining light on the specimen." At least one tribe, which has requested anonymity, agrees: they consented to let Kappelman's group scan bones before reburial. The Smithsonian Institution is also experimenting with laser scanning. But again the issue of cost arises, as many museums express dismay that the repatriation act is already straining their finances. Martha Graham of the American Museum of Natural History reports that the museum "doesn't have the resources to do anything beyond compliance with the law."

Repatriation is only one potential application. The techniques could revolutionize education and research by changing the rules of who gains access to primary materials. A CD-ROM database now being compiled at the University of Texas, with the aid of a grant from the National Science Foundation, will make images of rare artifacts, fragile fossils and extinct primates available throughout the university. Students will help with the time-consuming laser scanning. "We've got lots of graduate and undergraduate labor here; we'll be scanning nearly 24 hours a day," Kappelman says.

And after the CD-ROM project? "Eventually there will be an Internet archive. That's a few years down the road, but it's inevitable." If the price of sintering devices falls, even relatively poor institutions could afford to buy the devices and hook them up with a computer tied to the Internet. An anthropologist could then call up a file over the modem, download it and then print out a perfect replica of a rare fossil.

Such is the irony of the forward march of computer technology. Even as it pushes humans steadily into a world our ancestors would hardly recognize, it provides a new way—literally—to get a feel for the past. —*Corey S. Powell*

PROFILE: CYNTHIA MOSS

On the Trail of Wild Elephants

Like grounded albatrosses, the great bleached jawbones of elephants past encircle one of Cynthia Moss's tents. While the veteran researcher sits in a chair in the shade, two students examine the shape of each heavy relic and count its massive molars, looking for dental confluence, a sign of age. Moss checks her records, using the wealth of information about each bone to describe why one could not but be that of a 30-year-old female and why another is clearly from a 15-year-old male.

Sexing and aging such ghostly jaws can be tricky, but making such determinations about free-roving elephants is even harder. Which is why the two young members of Ethiopia's wildlife service have traveled to Kenya to visit Moss's camp in Amboseli National Park. For more than 20 years, Moss has studied some 1,300 elephants, identifying every individual and family. Her findings about the social structure of the community as well as about communication and behavior have changed how many people perceive the creatures. These insights have, in turn, posed questions about how elephants should be protected in a world that increasingly has less room for them. "Elephants have a really complex problem-solving intelligence, like a primate might have," Moss explains in her characteristic even tones, as the students poke around and the wind picks up, cooling the marshy campsite.

Moss herself could be compared to any one of the "trimates"—researchers Jane Goodall, Dian Fossey and Biruté Galdikas, who lived in the rough African and Asian field for decades observing chimpanzees, gorillas and orangutans, respectively. Moss's up-close behavioral observations are part of the same tradition, as is her familiarity with the elephants and, perhaps more important, theirs with her. This intimacy has made possible some surprising insights.

Moss hastens to point out that her powers of perception do not come from a classical scientific education. Instead they come from training at Smith College in philosophy and experience in a world that science sometimes shuns: journalism. Moss, who grew up near the Hudson River just north of New York City, was a researcher at *Newsweek* when she decided in 1967 to take a leave to travel in Africa. "I was always interested in animals, but I was not a wildlife person. I was a wilderness person," she recalls. "And I wanted to go to one of the last wilderness areas."

BOYD NORTON

ELEPHANT MAVEN Cynthia Moss has lived in the field for more than 20 years.

During her trip, Moss visited the camp of Iain Douglas-Hamilton, a renowned elephant researcher who had pioneered a means of using photographs to recognize individual elephants. The story has it that Douglas-Hamilton was struck by Moss's remarks about the elephants' behavior and her attention to detail; she agreed to work as his assistant for about a year in Tanzania and, in the end, moved to Kenya. Moss continued to write as she raised money for her own elephant project in Amboseli—for 14 years, in fact, she edited the magazine of the African Wildlife Foundation, the organization for which she now works. In 1972 she started her study.

Amboseli proved to be an ideal site. Just across the border from Tanzania and in full view of Mount Kilimanjaro, the 390-square-kilometer (150-square-mile) park has been relatively untouched by the poachers who have more than halved Africa's elephant population in the past two decades. Between 1973 and 1988 the number of elephants in Kenya fell from 135,000 to 22,000; in Africa at large, the population fell from 1.3 million to 600,000 between 1979 and 1989. Amboseli, which now has a population of 830 elephants in 50 families, may have been secure because of the Maasai. The tribe herds cattle on the surrounding land and has no patience with hunters.

The continuity of elephant families has permitted Moss to collect extensive demographic data. "The information on age at sexual maturity and inter-calf intervals and other reproductive parameters is just so valuable for people working on other studies—just to give them an idea of what is more or less a baseline," Moss notes. In the case of the jawbones, the most complete description has been a 1966 paper based on a few elephants, some of unknown age. Moss is gradually building up a collection of jaws of elephants whose births and histories have been recorded. Every elephant has six sets of four teeth that grow forward as the previous assemblage is worn down; when the series runs out, often after more than 50 years of grazing, the animal can no longer forage and dies.

The droughts that have occurred over the past two decades—particularly a severe one in 1976—led Moss to another discovery: elephants can cease breeding in response to changing environmental conditions. This finding could have implications for wildlife managers seeking to anticipate the population dynamics of their herds. According to Moss, most previous reports about fertility had come from culled animals—that is, elephants that are killed, often by the hundreds, in order to stabilize populations, a common practice in some protected areas in southern Africa. Information from culled creatures, however, "is only from one point in time," Moss says, so it is not helpful for recognizing patterns of fertility and correlating them to external shifts.

Working with other researchers—including Joyce Poole, formerly of the Kenya Wildlife Service, and, currently,

Karen McComb of the University of Sussex—Moss has also begun to investigate the apparently complex repertoire of elephant vocalizations. So far they have identified 25 different calls, some of which contain low-frequency infrasonic components that are out of the range of human ears. One day, for instance, Moss watched a family crossing a channel. A week-old calf became stuck and emitted a low-frequency distress call. "Suddenly, all the adults turned around—the mother was already in the water with it—and ran back to the channel. Two of them started digging the bank out" and rescued the calf, she describes.

MARGUERITE HOLLOWAY

***FAMILY OF THREE** feeds in a lush marsh near Moss's campsite. The mother, Esmeralda, has two calves: Eartha and one not yet named.*

Some of Moss's records cannot be quantified in the way that sounds, teeth and fertility patterns can be. Moss cannot explain why the animals sometimes recognize, touch and carry the desiccated bones of their relatives. Or how precisely older females, such as Echo, whom Moss recently followed closely for a film, direct their families. "It is a very difficult concept to be able to describe scientifically: leadership," Moss says. Elephant families are led by females and tend, in Amboseli, to have about 11 members; bulls usually remain loners. The families have very different characters, which reflect the personality of the matriarch. In the case of Echo, the family is low-key and nonaggressive.

How the 50-year-long relationships between elephants in a family or between elephant families are established and maintained remains a mystery—a long-standing one. In *West with the Night,* pilot Beryl Markham describes flying over herds trying to find a suitable male for hunters to track. She sees one huge elephant with its head immersed in foliage and circles it until the others have dispersed. Finally, the elephant moves away from the tree, only to reveal itself as a small-tusked female. And Markham wonders if the matriarch deceived her expressly.

"These animals are different," Moss concurs. "They are incredibly intelligent and long-lived, and they have complex social lives." They are incredibly threatened as well. In 1988, when it became apparent that the African population was plummeting because of ivory hunters, Moss turned to conservation work. The efforts of researchers such as Moss and of Richard Leakey, then head of the Kenya Wildlife Service, resulted in a ban in ivory trade that has dramatically reduced poaching and hunting.

MARGUERITE HOLLOWAY

***JAWBONES** of elephants collected in Amboseli National Park form an unprecedented database.*

Today, although several countries are seeking to overturn the ban, Moss says the most pressing threats to the animals are different. Elephants are increasingly invading agricultural land that is right up against the borders of many of the national parks. "There are more people being killed by elephants now than before," Moss points out. "It seems virtually every week you hear of someone being killed, and it is not because of reporting, but because people are right up against the elephants' ranges."

In Moss's opinion, the choices are limited: "Those areas obviously cannot have elephants. It is not a question of choosing elephants over people; you have to choose people over elephants. So you just have to confine elephants to places where there is going to be no conflict." Such sites would include remote areas of the bush, places where people cannot easily thrive because of, say, tsetse-fly infestation. "And maybe we should just work on having elephants in some of the parks where the population can be self-regulating and we do not have to interfere so much," she adds.

For now, Amboseli is tucked away from encroaching populations of people, and Moss continues to follow the families, noting their patterns of movement, their mating and birthing cycles. Driving out one morning, she spots a family of nine making its way back into the park after a night of foraging closer to Kilimanjaro. The elephants seem less overwhelming up close than they do on the horizon, where they assume majestic proportions. Like the great birds of the sea that Charles Baudelaire described in his poem *L'Albatros,* elephants need that very distance from humans to survive: "Exiled on earth amid the shouting crowds/ He cannot walk, for he has giant's wings." —*Marguerite Holloway*

SCIENTIFIC AMERICAN

Improving Automotive Efficiency

Batteries and fuel cells? Cleaner air and reduced oil imports can be won by redesigning conventional internal-combustion-powered vehicles

by John DeCicco and Marc Ross

Public concerns about health and safety, the environment and petroleum dependence create pressure to build a better car. Although congestion and accidents result from driving itself rather than from fuel use, much of urban air pollution, greenhouse gas emissions and the economic burden of oil imports can all be tied directly to fuel consumption. Automobile use continues to grow in the U.S. and worldwide. Fuel efficiency must increase at least as fast just to prevent fuel-related problems from worsening. Efficiency must improve even more rapidly to begin to solve these problems.

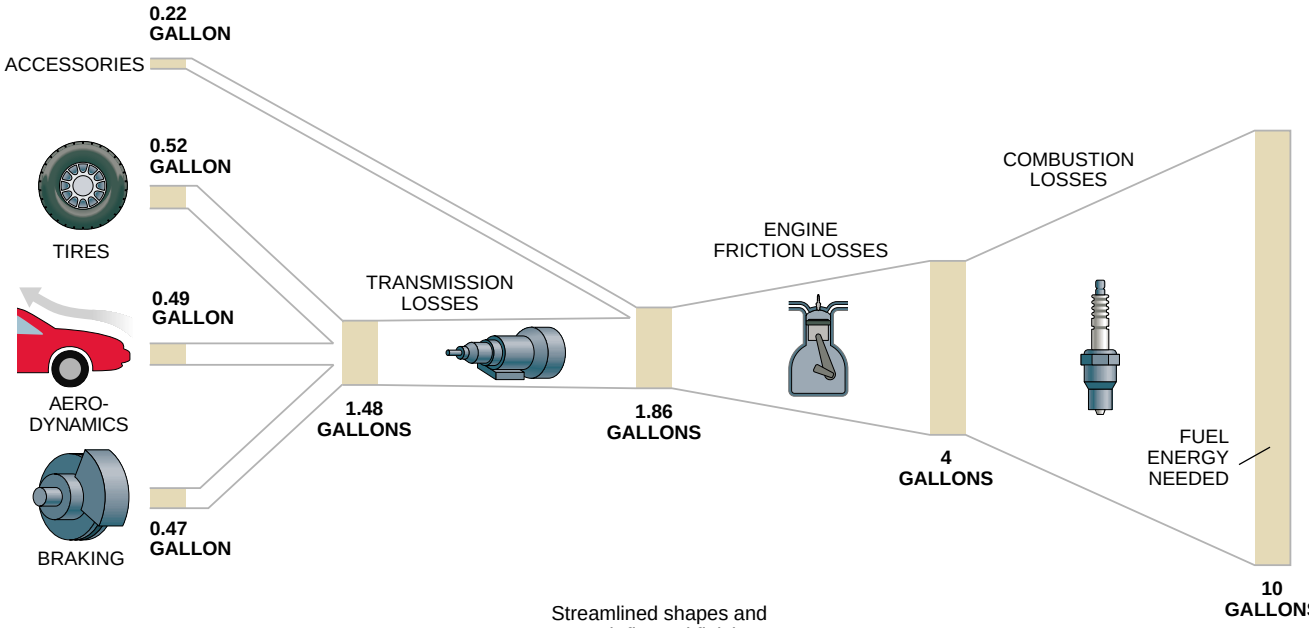
In September 1993 the U.S. auto industry and the Clinton administration announced a historic partnership to develop vehicles having three times the fuel economy of today's fleet while providing the same comfort, safety and performance. Prominent options include electric vehicles powered by batteries or fuel cells and hybrid vehicles combining an electric drivetrain with a combustion engine that might use a variety of fuels. While such alternatives are being studied and tested, however, gasoline and diesel cars and trucks will most likely dominate the roads for decades to come. They offer remarkable reliability, comfort and utility at an affordable cost. Moreover, they are sustained by an enormous economic infrastructure: factories, petroleum refineries, service stations and all the people, from auto workers to garage mechanics, trained to make the system work.

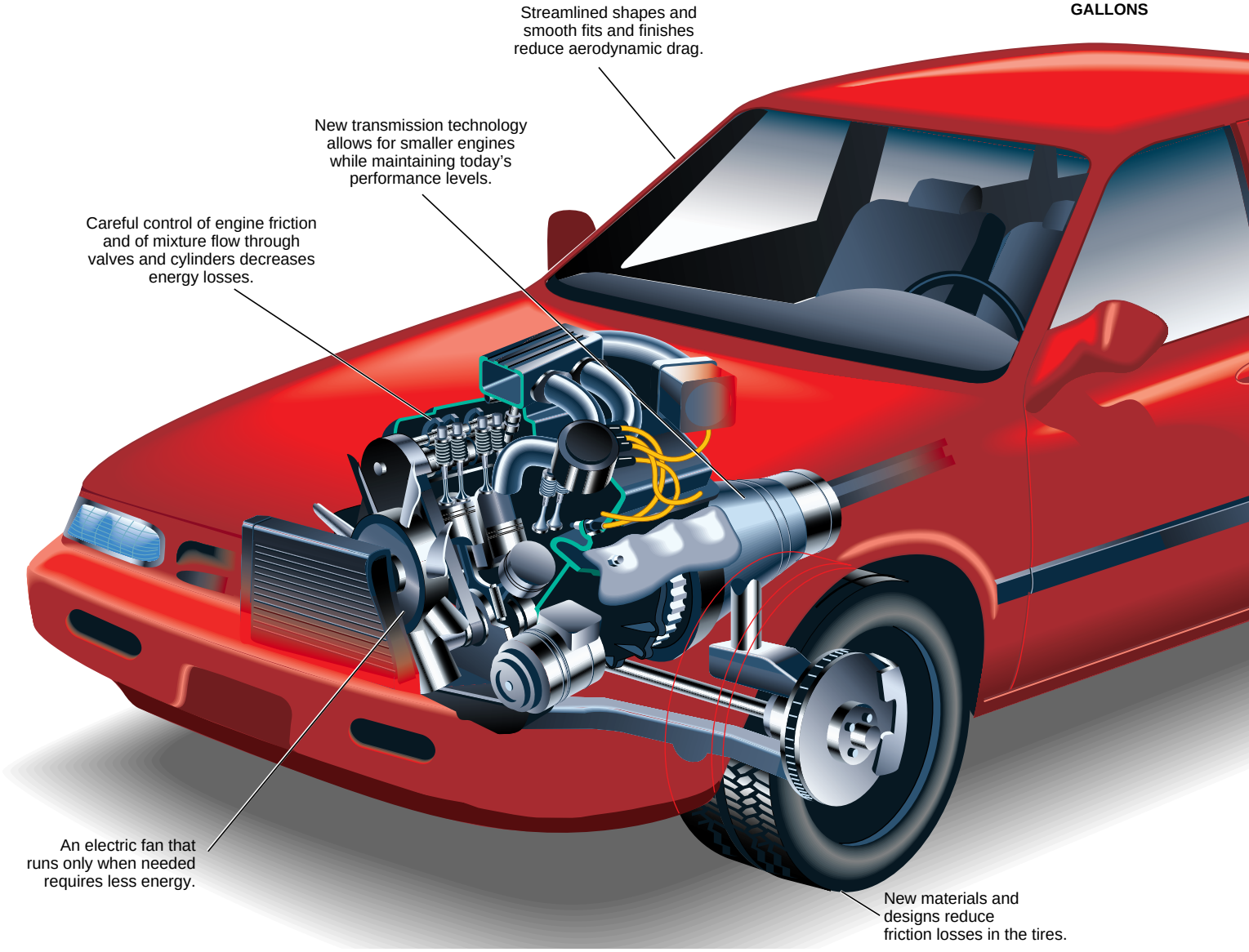
The vibrant state of automotive engineering also contributes to the longevity of cars powered by the internal-combustion engine. Although pioneers like Carl F. Benz and Rudolph C. K. Diesel envisioned almost all its potential refinements a century ago, only recently have many of them become practical, as new techniques liberate design and production engineers. Microprocessors, sensors and electronic controls now permit optimization of many operations; materials have become stronger, lighter and more adaptable. Computers enable designers to create and improve vehicle models rapidly. Many advances useful for refining conventional cars and light trucks are, in fact, essential for alternative vehicles. Radically different approaches may be needed in the long run, but breakthroughs are not necessary, because late 20th-century engineering capabilities can deliver substantial environmental and economic benefits over the next decade.

The effort to improve fuel efficiency begins by examining how and where a car uses energy [see "The Amateur Scientist," page 112]. Fuel use depends on the type of driving as well as on vehicle characteristics. For example, fuel economy is worse in congested streets because of more frequent starting and stopping. Engineers use the term "end-use load" to refer to any aspect of vehicle operation that consumes power provided by the engine. Loads include braking loss, tire resistance, aerodynamic drag and accessories, such as air conditioning and power steering. The energy needed to meet these loads is greatly multiplied by the need to overcome losses throughout the drivetrain. Consisting of the engine, transmission and associated components, the drivetrain converts fuel energy into useful mechanical energy that propels the car and runs its accessories. After the thermodynamics of combustion and the friction have been accounted for, only about one sixth of the energy available in gasoline remains for the end-use loads. Put another way, today's drivetrains are only 17 percent efficient in average driving.

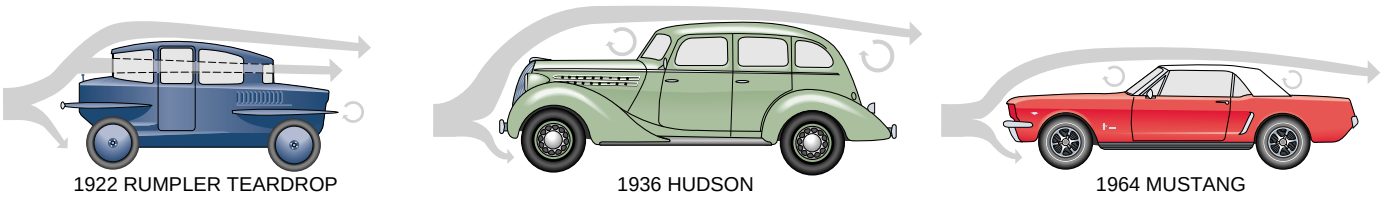
To estimate the potential for raising fuel economy, we analyzed a set of low-

JOHN DECICCO and MARC ROSS have collaborated for several years on analyzing ways to improve motor vehicle fuel economy. DeCicco is a senior associate with the American Council for an Energy-Efficient Economy, where his research has focused on the technical opportunities for reducing energy use and emissions in the U.S. transportation system. He received his Ph.D. in mechanical engineering at Princeton University's Center for Energy and Environmental Studies in 1988. Ross is professor of physics at the University of Michigan. His current research includes investigating energy use and emissions of conventional and alternative vehicle systems. Ross received his Ph.D. in physics from the University of Wisconsin in 1952.





FUEL NEEDS arise in stages (***top illustration***), starting with the energy lost by tires, air drag, braking and accessories. Energy requirements are multiplied by 1.11 to overcome transmission friction and again by a factor of 2.2 to offset engine friction. Finally, combustion losses increase the energy demand by another 2.5. New materials, designs and technologies (***bottom illustration***) that minimize losses in the early stages of the multiplication process will raise fuel efficiency.



STYLING IMPROVEMENTS have lowered aerodynamic drag. The Rumpler Teardrop was an early attempt at streamlining. Future designs, most likely based on ones similar to the Opel Calibra or the Impact, can lower drag by 25 percent or more.

cost design changes, most of which are found in some models already on the road. Improving the drivetrain by reducing friction offers one clear path to greater efficiency. Reducing end-use loads presents another. Even without any tinkering with the drivetrain, modifications to tires, aerodynamics and vehicle mass will trim a car's energy requirements. Each unit of energy savings achieved by lower loads yields six units of energy savings overall. Thus, load reduction is fundamental.

Cutting vehicle mass provides important leverage on efficiency because it exerts a ripple effect. A lighter vehicle requires less power, and so it can be equipped with smaller drivetrain components. Consequently, mass drops even further. The current weight of a new car with the gas tank and radiator filled but without passengers averages just under 3,000 pounds. Although downsizing is an obvious way to reduce mass, we excluded this option from our analysis. Instead we considered the use of lighter, stronger materials combined with refined design and manufacturing techniques. New materials and better use of space can reduce mass without sacrificing vehicle size and carrying capacity. We estimated the degree to which cars could be made lighter based on these approaches, adjusting for the weight added by airbags and strengthened door panels needed for safety. On balance, applying the best designs available and adopting new materials can cut as much as 25 percent from a car's weight.

Some opponents of fuel economy regulation assert that decreasing mass decreases safety. But the protective benefit of heavier automobiles comes at the expense of greater damage to people. Cars built with lightweight but strong materials can shield passengers more effectively than can many heavier vehicles of today yet pose less risk to the occupants of other cars during collision. Safety is assured largely through better restraint systems and improvements to vehicle structure and interior surfaces that minimize the crash energy transferred to people in the car. Better crashworthiness comes not from vehicle size or mass itself but from features that safeguard passengers, regardless of vehicle size.

Whether a vehicle is massive or light, drivetrain inefficiencies hurt fuel economy. The best opportunities for improving the drivetrain lie in reducing engine friction, which accounts for about one half of fuel use. In a car's motor, pistons move through the cylinders, each displacing a certain volume. Expanding gases pushing on the piston produce power. The combined volume for all the cylinders is termed engine displacement. A larger engine can deliver more power but entails greater friction.

Rubbing friction occurs among moving parts such as valves, pistons, connecting rods and the crankshaft. There are losses in ancillary parts such as the radiator fan and water pump. Pumping friction occurs when the air and fuel mixture is drawn into the cylinders and the exhaust is expelled. A particular site of pumping friction is the throttle valve that controls air intake.

Refinements in design, manufacturing technique, materials and lubrication minimize rubbing friction. Ancillary losses can be reduced through modifications such as replacing a belt-driven fan with an electric fan that runs only when needed. Pumping friction can be cut by intelligent control of intake and exhaust processes. And all these frictional losses can be lessened with a smaller engine.

Studying how frictional work relates to engine power reveals important ways to enhance drivetrain efficiency. Power output is reduced by internal friction; it must meet the needs of the end-use loads plus the transmission. Engine friction is proportional to engine speed and displacement. Output, however, does not necessarily depend on these factors. Technologies that provide needed power while reducing average engine speed or displacement—or that even turn the engine off when power is not required—offer opportunities to cut engine friction while meeting output requirements.

The value of many efficiency enhancements lies in their effect on specific power: the ratio of maximum power output to engine displacement. Technologies that enhance specific power permit reduced displacement while satisfying vehicle loads. Increasing the number of valves improves flow through the cylinders. For example, the specific power of four-valve engines averages 40 percent higher than that of two-valve engines. Similarly, overhead camshaft designs boost average specific power by at least 20 percent. There are trade-offs, such as increased rubbing friction with added valves. Motors with four valves per cylinder and overhead camshafts achieve peak power at high engine speeds, so that compensating changes in gearing are needed for good driveability. Successful designs take into account such considerations to yield more miles per gallon at acceptable cost.

Perhaps the most profound engine refinement now being commercialized affects the control of intake and exhaust processes. Fuel ignition takes place within a motor's cylinders. Carefully manipulating the flow of the fuel mixture and exhaust products through the cylinders can boost mechanical efficiency. In conventional engines, when and how far a valve opens depends on the position of the piston, not on engine speed or load. Electronic sensing and control capabilities, together with precision manufacturing methods, have made it possible to use variable valve control. This technique optimizes cylinder flows over a broad range of conditions. Greater valve opening increases maximum power, allowing engine displacement reduction. Under low loads, reduced valve opening time can largely replace throttle operation, thereby decreasing pumping friction.

In the past, high cost limited installation of variable valve control mechanisms. Advanced design and assembly techniques now permit widespread application. Since the late 1980s Japanese automakers have increased their use of variable valve control in both Japan and the U.S. In 1992 Honda introduced a notable improvement in valve control that brought a lean-burn engine to the U.S. market.

Most contemporary gasoline motors

1992 TALON

FUTURE MODEL BASED ON 1990 OPEL CALIBRA

FUTURE MODEL BASED ON 1994 IMPACT

normally operate with precisely the amount of oxygen needed for complete combustion. Lean-burn engines run on mixtures containing excess air. Advantages include reduced pumping losses and better thermal efficiency. But the emission of nitrogen oxides (NO_x) from such engines creates a problem: catalytic reduction of NO_x compounds is difficult under lean conditions. Development of an appropriate catalyst is an active area of research, because success would lead to more general use of lean-burn technology.

Another possible refinement, the advanced two-stroke engine, is also capturing industry attention. Two-strokes accomplish compression and ignition of the fuel and air mixture in fewer strokes than do the more conventional four-stroke engines. Fewer piston strokes lead to less frictional loss. Lighter and potentially less expensive than four-strokes, two-strokes also burn lean air-fuel mixtures.

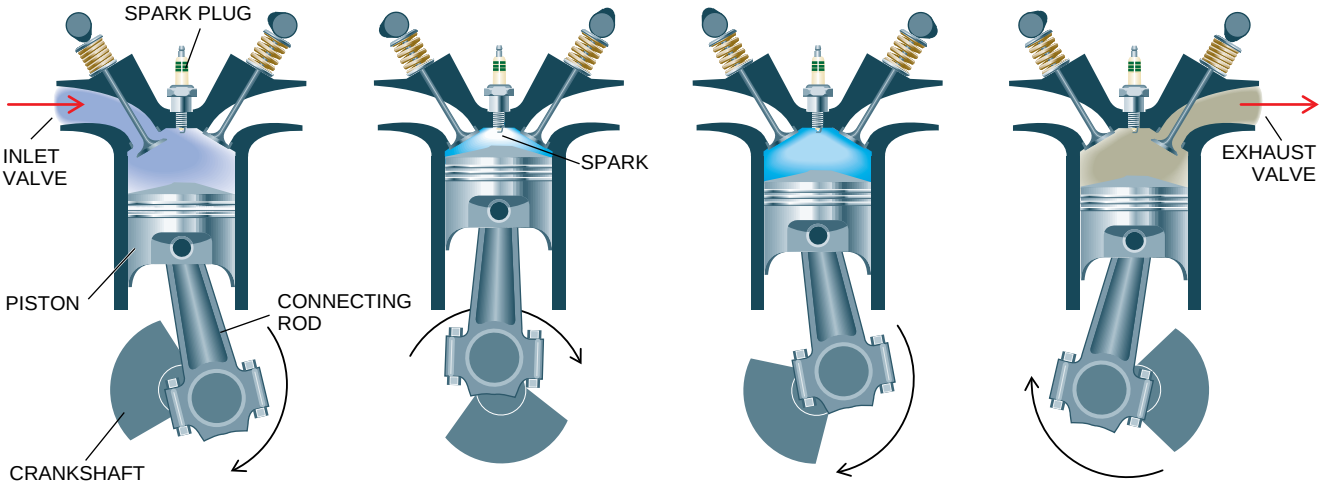
Modifications to the transmission along with the engine can bring impressive energy savings. Although a car's wheels must cover a wide range of road speeds, the engine operates most quietly and efficiently in a relatively narrow range of revolutions per minute. The transmission has a range of gear ratios to couple the motor to the wheels so that the motor can run effectively at all road speeds. To take full advantage of the benefits of engine downsizing, one must design the transmission to maximize the amount of time the motor operates at high efficiency.

Microprocessors permit engineers to program a transmission to optimally match engine speed to power requirements. Adding gears to the transmission accommodates more gear ratios, so that a narrow band of engine speeds can better cover the driving range. With a smaller engine, more frequent gear shifting will be required, and driving in traffic might feel different. Alternatively, a continuously variable transmission can replace discrete gears with a device for smoothly varying the gear ratio. In either case, careful attention to design and electronic control will help smooth shift transitions and avoid compromising driveability.

Using the 1990 new-car fleet as a base, we developed a range of estimates for the feasibility of increasing miles per gallon. The analysis examined the extent to which available technology can be applied to reach this goal. Our mid-range projections do not include lean-burn or two-stroke engines, as common use of them is less certain because of emissions constraints. After screening technologies for their cost-effectiveness, we estimate that by 2005 average new-car fuel economy can be raised by 65 percent, from 28 to 46 miles per gallon. A comparable increase can be made for light trucks, because their energy losses are similar to those of cars.

Raising gas mileage to 46 miles per gallon would add about $800 to the retail price of a car. Compared with today's new-car average of 28 miles per gallon, the higher fuel economy would save 2,100 gallons of fuel over a typical 12-year vehicle lifetime, worth $2,500 even if fuel prices do not go up. Phasing these improvements into U.S. cars and light trucks over the next 10 years would save 2.8 million barrels a day of gasoline by 2010. The yearly fuel cost savings to all consumers would be $71 billion, far exceeding the estimated $12 billion added annually for the technology refinements.

Because we import a growing fraction of our oil, the 2.8 million barrels a day of gasoline conserved imply that U.S. oil imports could be cut by at least



FOUR-STROKE CYCLE powers most of today's cars. Advanced designs enable control of air and fuel that flow into the cylinder. Decreasing the work to pump gases in and out of the cylinder provides further opportunity to conserve energy.

two million barrels a day in 2010. These savings are much larger than the supplies that might be obtained by exploiting reserves offshore or in the Arctic National Wildlife Refuge. Moreover, such oil savings would be achieved with reduced rather than increased environmental damage.

Reduced fuel consumption brings additional environmental benefits. Carbon dioxide emissions are proportional to fuel consumption, so higher fuel economy means lower greenhouse gas emissions. The amount of hydrocarbon vapors released into the air is also tied to gasoline use, so increased efficiency reduces their impact as well. Hydrocarbons react with nitrogen oxides to form ground-level ozone, a major air pollutant that aggravates asthma and causes other respiratory problems. Because higher efficiency pays for itself through fuel savings, there is no added cost for the associated reductions in carbon dioxide and hydrocarbon releases.

Better emissions-control technology, apart from advances in fuel economy, can lead to further large reductions in air pollution. Extensive industry and regulatory efforts are under way in this area. Unfortunately, progress has been much slower than expected because of a lack of real-world data analysis. We would be more optimistic if pollution-control efforts were more solidly based on fundamental science and well-designed observations.

Higher fuel economy for cars and trucks yields broad economic benefits as well. Money spent on oil imports is mostly lost to the U.S. economy, and gasoline purchases provide relatively few jobs per dollar spent. Because enhanced fuel economy produces savings for consumers, they have more money to spend on goods and services other than gasoline. That stimulates domestic industries, including auto production, resulting in employment gains. During congressional deliberations, U.S. auto manufacturers claimed that raising mileage standards would lead to employment loss. Although that might be conceivable if higher fuel economy were obtained by rapidly mandating smaller vehicles, it is not true for a phased-in, technology-based approach. For a scenario similar to that described here, our economic modeling shows a net increase of 100,000 to 250,000 U.S. jobs by 2010.

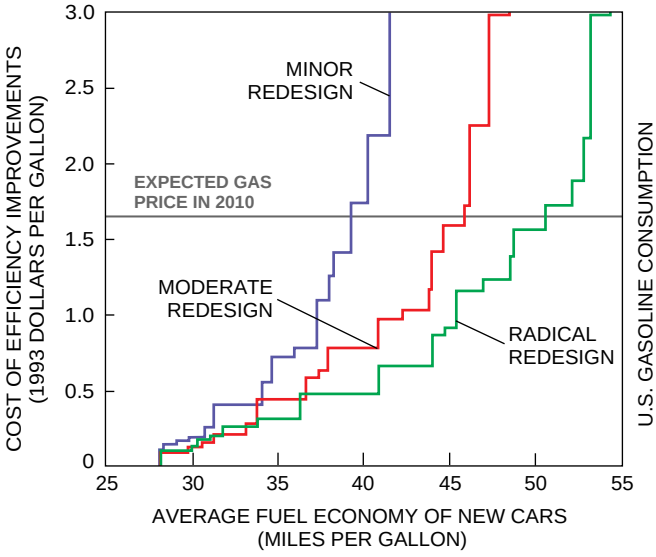
Most of the technologies we have considered appear in cars already on the road. Although higher fuel economy is clearly cost-effective in the long run, there is little market interest in applying better technologies for cutting energy consumption. Gasoline prices are at an all-time low. So manufacturers instead concentrate on applying engineering advances to enhance vehicle performance or luxury, through increased size and weight, rather than to provide better mileage. High-performance and luxury models dominate the more profitable segments of the market. Among the models offered for sale in a given year, the more fuel-efficient ones tend to be the smaller, slower, bottom-of-the-line vehicles.

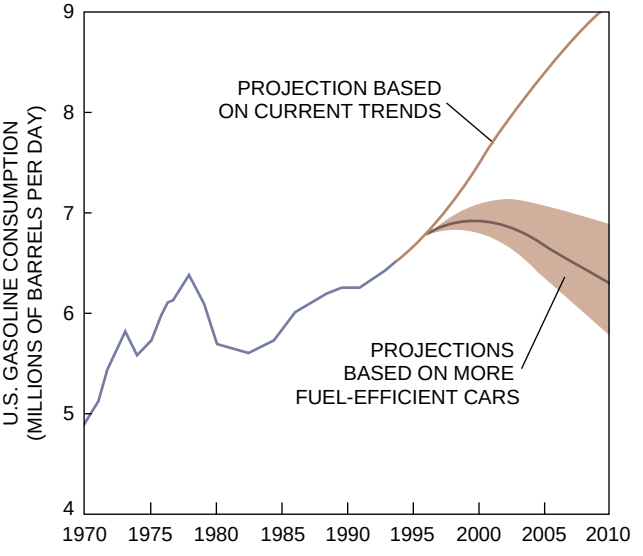
More fuel-efficient cars and trucks would sell well under different conditions, which could be brought about by such factors as national policies (fuel economy regulation, vehicle-pricing incentives or dramatically higher fuel taxes) or international events (wars or cartel decisions to limit the oil supply). The widespread benefits of reducing gasoline consumption justify public policies designed to put more efficient vehicles on the road.

The Cost of Improving Fuel Economy

Estimating the cost of higher fuel economy is difficult because information on manufacturing is not generally made public. The authors developed an economic model using published reports that examined prices of available and useful technology. Assessing how extensively each potential refinement could be used in new cars and light trucks, the researchers ranked the technologies according to their costs as amortized over the average vehicle lifetime of 12 years. Although this treatment does not apply to any particular car, it provides a reasonable idea of the average expense of improving cars in general. The mid-range, or moderate, cost-effective level of 46 miles per gallon (*left*) was estimated by determining the curve's intersection with expected gas prices in 2010.

Without a change in U.S. policy, auto fuel use is forecasted to rise along the projection shown in the graph at the right (*light brown*). The shaded band predicts gas use if the technologies for increased fuel economy are phased in over the next 10 years. The moderate estimate (*dark brown*) corresponds to 46 miles per gallon.





Consumers and automakers both face a dilemma when it comes to increasing mileage. In today's market, individual customers have little interest in forgoing better performance or luxury for higher fuel economy because their direct fuel savings are not compelling. As concerned citizens, however, many want to see energy and environmental problems solved. Approaches in which everyone participates, rather than those that rely only on the choices of individual new-car buyers, can effectively respond to public concerns despite market disinterest.

Similarly, a manufacturer that applies engineering advances to increase mileage might risk losing customers, whereas another that uses the same refinements to boost performance would probably fare better in today's market. Regulations that give all automakers an incentive to raise fuel economy can overcome the risk faced by an individual manufacturer acting alone. Strengthening the fleet-average fuel economy standards would give such an incentive while also offering design flexibility. The industry can use different approaches for each vehicle line and ensure that the overall goal of reducing fuel consumption is met.

To enhance market interest, standards can be usefully complemented by special incentives, such as an expanded gas-guzzler tax and rebates on vehicles that are more efficient than average. Standards and incentives must apply equitably to manufacturers, so that all face similar pressures to increase fuel economy. The risk to any one firm would then be minimized.

Some economists point out adverse side effects of fuel economy regulation. Higher efficiency lowers the cost of driving, so people drive more and partly offset the savings. Some therefore conclude that raising gasoline taxes is a preferred approach for reducing gasoline consumption. Empirical evidence indicates, however, that such effects only fractionally offset the benefits of regulation. The price of gasoline affects the amount of driving far less than might be expected. Parking prices—or lack thereof—and road building have much more influence. Thus, a higher gasoline tax can be helpful and may be justified for a number of reasons (current taxes do not even fully cover highway costs), but taxation alone is a weak lever for controlling fuel consumption.

The time may come when conventional gasoline cars and light trucks will have to be replaced by fundamentally new designs. This eventuality justifies research and development efforts today. But more efficient conventional vehicles offer—sooner rather than later—large, tangible benefits. Many of these advancements, especially load-reduction measures, are essential steps on the way to the next generation of vehicles that will use electric drivetrains and fuel cells.

AUTOMATED WELDING SYSTEMS are crucial to the assembly of vehicle bodies. Innovations in the manufacturing process, such as use of laser welding that leaves joints smooth, will help raise energy efficiency of new models.

The average mileage of new light vehicles has been stagnant for a dozen years. Lack of market interest, not lack of technology, is the most serious obstacle to tackling automotive fuel use. Enacting stronger standards and other incentives for higher fuel economy calls for public policy leadership. Compared with today's new cars, refined autos would be the same size, with the same carrying capacity and acceleration ability; they would be lighter, more aerodynamic and have greater crashworthiness. They would also have lower emissions and better mileage. The benefits—direct consumer savings, lower oil imports, reduced hydrocarbon and greenhouse gas emissions and higher employment—indicate that increasing fuel economy is one of the best investments the country can make.

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Fossils of the Flaming Cliffs

Mongolia's Gobi Desert contains one of the richest assemblages of dinosaur remains ever found. Paleontologists are uncovering much of the region's history

by Michael J. Novacek, Mark Norell, Malcolm C. McKenna and James Clark

The Gobi Desert of Central Asia is one of the earth's desolate places. Its million square miles of sand dunes, sculpted badlands and saw-toothed mountains are alternately scorched by summer's high-latitude sun and frozen by winter's Siberian winds. It is not a place to explore unprepared: crossing vast, uninhabited areas between a sprinkling of oases requires careful planning akin to the siege tactics for scaling a Himalayan peak or traversing the Antarctic continent. There are few maps, and modern satellite navigation is of limited help to a traveler trying to choose among deeply rutted, wildly crisscrossing roads that wander as unpredictably as the nomadic settlements they connect. Even a modern expedition runs the risk of water, fuel and food shortages. Getting lost is not merely frustrating but a matter of serious danger.

MICHAEL J. NOVACEK, MARK NORELL, MALCOLM C. McKENNA and JAMES CLARK have together explored fossil sites in the Gobi Desert under the auspices of the American Museum of Natural History and the Mongolian Academy of Sciences. Novacek, Norell and McKenna are curators in the department of vertebrate paleontology at the museum; Novacek is also vice president and dean of science there, and McKenna holds a professorship in geology at Columbia University. Clark, who worked at the museum for three years, is now an assistant professor of biology at George Washington University.

Yet the Gobi is a paradise for paleontologists. Its eroding terrain exposes nearly complete skeletons of creatures hitherto known only through painstaking reconstructions from a few scattered bones. Our expeditions, jointly sponsored by the Mongolian Academy of Sciences and the American Museum of Natural History, have excavated dinosaurs, lizards and small mammals in an unprecedented state of preservation. Freshly exposed skeletons sometimes look more like the recent remains of a carcass than like an 80-million-year-old fossil. The skeletons and skulls we have found are often complete or nearly complete, in sharp contrast to the "spare parts"—fragmentary jaws, teeth and isolated bones—that paleontologists typically recover elsewhere.

No one knows why fossils in the Gobi are so well preserved. In other specimen-rich areas, such as the one that became the Rocky Mountains, streams or rivers carried animal remains to fossil sites, disarranging them along the way. The late Cretaceous environment in the Gobi, however, may have been much as it is today: open valleys of sand dunes and cliffs, sparsely watered by small, seasonal lakes or streams. Indeed, indications of ancient sand dunes can be observed in rock sections there.

It is also apparent that the animals were buried very soon after their death, before scavengers or weather had much time to get at them. Poorly sorted layers of sandstone in the Cretaceous rock formations suggest deposits of the kind one would expect in violent sandstorms; Tomasz Jerzykiewicz of the Geological Survey of Canada in Calgary and his colleagues have studied fossil beds in Chinese Inner Mongolia and found that vertebrate fossils are often embedded in these layers. Such storms might not merely have buried carcasses but killed animals as well. Entombed in a matter of minutes or hours, their remains emerge some 80 million years later, almost undisturbed.

Mongolia was not always recognized for its bounty of prehistoric material. During the late 19th and early 20th centuries, the Rocky Mountain region of western North America was the mecca for vertebrate paleontologists. Then, in 1922, Roy Chapman Andrews, a scientist from the American Museum of Natural History,

SANDSTONE ESCARPMENT in southern Mongolia made headlines in the early 1920s, when paleontologists found dinosaur eggs there. Seventy years later the Flaming Cliffs continue to yield a rich lode of well-preserved fossils.

led an expedition into the heart of the Gobi and changed the geography of the fossil world. He never attained his primary objective—a search for the fossil origins of humans in Central Asia—but a series of spectacular, more ancient discoveries soon diverted the interests of the scientific team. The Gobi held an extraordinary treasure of dinosaurs, mammals and other vertebrates whose richness is undiminished even today.

Andrews chronicled his five expeditions in a remarkable narrative entitled *The New Conquest of Central Asia*. The romance and excitement of the enterprise foreshadowed the exploits of the movie character Indiana Jones. En route, the explorers were challenged by trackless dune fields, raging sandstorms and marauding bandits. Andrews's caravan of camels and spindly-wheeled Dodge motorcars was a logistic nightmare, extending like the *Algoy horkhi horkhi,* the legendary (and probably mythical) Mongolian sandworm, across the moonscape of the Gobi.

One of the most important discoveries in the history of scientific exploration came in the midst of such difficulties. Late in the first field season of 1922, the expedition got off track on a vast plain just north of the Gurvan Saichan Mountains. Hopelessly lost, Andrews ordered the party to stop near a *ger* (the domed-shaped tent of Central Asian nomads, also known as a yurt). While Andrews sought directions from the frontier soldiers occupying the *ger,* team photographer J. B. Shackleford wandered toward an unassuming rock rim at the edge of a field. There he was startled to find a fantasy of red cliffs and spires—and fossils.

Within 10 minutes he had uncovered the first known skull of the *Protoceratops,* a parrot-beaked, shield-headed dinosaur that has since become a reference fossil of the late Cretaceous of Central Asia. Lingering for the rest of a warm afternoon, the crew recovered more bones and even a small egg, which they mistook for that of a bird. They returned the next summer to find an extravagance of dinosaurs, ancient mammals and other vertebrates, as well as the first known cluster of dinosaur eggs. Their findings, particularly the eggs, became front-page news from New York to New Caledonia. Andrews named the place the Flaming Cliffs, inspired by the magnificent red-orange glow as the sand cliffs blazed in the late afternoon sun.

By the beginning of the 1930s Andrews, frustrated by a volatile, less sympathetic political scene in Mongolia, gave up his exploration. The Gobi was inaccessible to Western interests for more than 60 years, leaving Soviet-bloc scientists to extend the work Andrews had begun. Between 1946 and 1949, joint Russian-Mongolian expeditions penetrated the Nemegt basin, a region of awesome desert beauty whose remoteness had defied Andrews's attempts to explore it. They uncovered rich badlands of Cretaceous and Cenozoic fossils there.

Zofia Kielan-Jaworowska, a world-renowned fossil mammal specialist, now at the Paleontological Museum of the University of Oslo, led a highly skilled and energetic Polish-Mongolian team to the Nemegt and other areas between 1963 and 1971. She and her colleagues produced a series of classic scientific monographs and a magnificent display of dinosaurs and other fossil vertebrates at the Natural History Museum in the Mongolian capital of Ulan Bator. Since the 1960s Mongolian paleontologists have conducted extensive fieldwork both independently and in collaboration with Soviet (now Russian) scientists.

Westerners first returned to the country after the development of Mongolian democracy in 1990. That summer our colleagues at the Mongolian Academy of Sciences invited us for a reconnaissance that paved the way for four more ambitious expeditions during succeeding years. Japanese, German and other American parties have also begun field projects. Soon Mongolia may be trampled by a stampede of bone hunters, but meanwhile we feel fortunate to be the first Westerners to resume the adventure that Andrews inaugurated.

If anything, the contrast between the Gobi and other, more accessible fossil areas has increased since Andrews's time. A century ago, in the glory days of dinosaur hunting in the American West, prospectors encountered valleys and canyons where skeletons were exposed like corpses on a deserted battlefield, but today many prime dinosaur hunting grounds appear nearly exhausted. Modern paleontologists look back with envy at predecessors who roamed that virgin territory.

The cumulative activities in Mongolia over the past 70 years, in comparison, do not approach those in the Americas. Erosion is still exposing a wealth of fossils even at sites well mined by Andrews and others. Moreover, the very difficulty and unexplored nature of the Gobi increases the chance that paleontologists may yet stumble onto wholly unexplored pockets of badlands.

Early in the 1993 season, with our Mongolian colleague, Demberelyin Dashzeveg of the Mongolian Academy of Sciences, our field party struck out for an undistinguished set of red-brown sandstones on the north side of the Nemegt Valley, near the base of a jagged mountain range called Gilbent Uul. Previous expeditions, Dashzeveg said, had ignored this region in their rush to reach the more dramatic badlands of

OVIRAPTORID, a large predatory dinosaur, stands near its nest by the bodies of two young velociraptors (another fleet-footed predator). The authors found an oviraptorid nest that contained two skulls of infant dinosaurs of the same family as

the western Nemegt Valley. We arrived at the area, struggled for a few miles along a wash and established a bivouac where our heavy gasoline tanker and trailer buried itself in the sand.

The next morning we started prospecting the hills and gullies nearest camp. Within hours it was clear that we had come across one of the richest concentrations of fossils ever recovered from the age of the dinosaurs. In a basin less than two kilometers across, we found scores of dinosaur skeletons and egg nest sites weathering on gentle slopes. Intermixed with the dinosaur fossils were abundant smaller vertebrates—lizards and mammals—that were also key members of the ancient Cretaceous ecosystem.

The local name for the site of this bonanza is Ukhaa Tolgod ("Brown Hills"). Its natural amphitheater contained roughly 100 readily visible dinosaur skeletons, many of them in nearly pristine condition. During the past two field seasons, we have selected the most desirable specimens. Among them are 25 skeletons of theropod dinosaurs. This group of agile carnivores runs the gamut from the enormous *Tyrannosaurus* and *Allosaurus* through fast-running dromaeosaurs such as *Velociraptor* (the villainous predator of *Jurassic Park,* a title some 60 million years out-of-date) to smaller birdlike creatures such as the oviraptorids. We also gathered an unprecedentedly rich collection of small vertebrates: more than 200 skulls of mammals—many with their associated skeletons—and an even greater number of lizard skulls and skeletons.

ADULT OVIRAPTORID SKULL was found at Ukhaa Tolgod in the western Gobi. This birdlike family of dinosaurs bore a resemblance to modern ostriches. Some oviraptorids (perhaps only of one sex) grew a large bony crest after they matured.

As the variety of our specimens makes clear, the flowering of terrestrial life during the Cretaceous of Central Asia was not limited to dinosaurs. The Gobi of 80 million years ago supported a wide variety of lizards, crocodilians and mammals. We have found specimens representing more than 30 species of lizards; some are extremely well preserved and display anatomical features that offer clues to the relations among major lizard families.

Probably the most spectacular of these is *Estesia.* Early one morning during our reconnaissance in 1990, we came on an exquisite, eight-inch-long skull with knife-edged teeth half embedded, like a bas-relief, in a vertical slab of sandstone. At the time we thought it belonged to a small carnivorous dinosaur, but later examination determined that the skull was that of a wholly new kind of large predatory lizard, closely resembling the Komodo dragon alive today. We named the species after the

Velociraptor; **the interlopers might have been raiding the nest, they might have been brought by a parent oviraptorid to feed its young, or they might even have been laid in the nest surreptitiously (as the cuckoo does today) and incubated there.**

late Richard Estes of San Diego State University, the world's foremost authority on fossil lizards.

Estesia is a very primitive animal and as such is significant for understanding the family tree of the varanoid lizards (the group that includes the Komodo). The skull has an unusual series of canals at the base of the teeth that suggests *Estesia* injected poison into its prey. This lethal weapon is not common to living varanoids but is found in the Gila monster of the southwestern U.S. and northern Mexico.

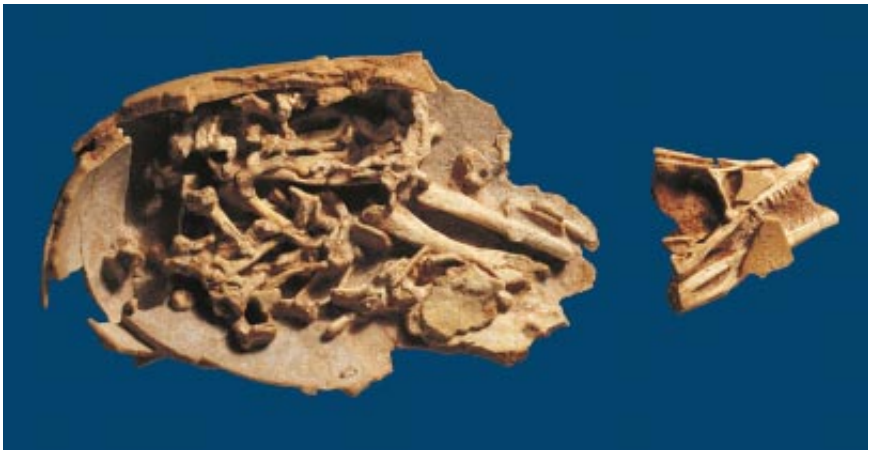
We have since found fragments of *Estesia* in other sites where smaller lizards, tiny mammals and dinosaur eggshells are common. Modern varanoids are noted for their voracious and wide-ranging appetites. It is likely that *Estesia* ate smaller vertebrates, small dinosaurs and possibly dinosaur eggs.

Although much of the Cretaceous Gobi was dry, water must have been abundant in at least a few places and times. We found occasional fossils of turtles, usually associated with aquatic habitats. (Turtle shells, skeletons and bone fragments are abundant in rock formations from the North American Cretaceous, where most evidence suggests an ancient environment of ponds, streams, mudflats and deltas.) At one site, in a chromatic badlands west of the Nemegt Valley, a small depression roughly the size of a wading pool held shells and skeletal parts of more than 50 individuals representing two turtle genera.

Some of the greatest treasures of the Gobi Cretaceous are easy to miss when scanning the slopes and gullies: the tiny skulls and skeletons of mammals. These fossils represent important precursors of the great mammalian radiation that followed the extinction of the dinosaurs at the end of the Mesozoic.

The bulk of scientific information on these earlier mammals comes from North American fossils, which are mostly fragmentary jaws and teeth. In fact, there are virtually no complete skulls of these Cretaceous mammals from North America. As a result, the Gobi assemblage, including our finds and those of earlier expeditions, surely represents the world's reference collection for late Cretaceous mammals.

A small block recovered from Ukhaa Tolgod in 1994 revealed six shrewlike placental mammals, each only a few inches long. Amazingly, the fossils consist of complete skulls attached to skeletons; such tiny bones are usually highly vulnerable to disarticulation and



OVIRAPTORID EGG (*left*) contains an almost perfectly preserved embryo. The skull (*right*) of a young dromaeosaur (the family of predators that includes *Velociraptor*) was unearthed in the same nest; it is not clear how the interloper arrived.

ROY CHAPMAN ANDREWS (*left*) led the first fossil-hunting expedition to the Gobi Desert in 1922. His group, which included both camels and primitive cars, became lost on several occasions; one such episode sparked the discovery of the Flaming

breakage. These small creatures were probably buried and preserved rapidly after they had died.

We have found two basic groups of mammals. The first is the multituberculates, or "multis," as paleontologists call them. They are a curious array of animals with long front incisors and molars with a complex of bumps (tubercles) on the tooth crowns. The Mongolian Cretaceous multis offer by far the best accumulation of skeletal material for examining the relations of these creatures with other mammal lineages.

Multis can be thought of as the rodents of their times, even though they are in fact only distantly related to modern groups of mammals. Their rodentlike adaptations are a sign of convergent evolution with the rats, mice and squirrels familiar today. The multis thrived through the first several million years of the Tertiary period, after the dinosaurs had died out. They then dwindled in number and disappeared, replaced by more recent groups of similar habits.

The second group is the therians, ancestors of both marsupials and modern placental mammals (a category ranging from whales to bats, aardvarks and humans). These early therians consist of half a dozen shrewlike forms whose traits offer clues to the origins of later members of the group. Fossils from the genus *Deltatheridium,* for example, seem to straddle the line between marsupials and placentals.

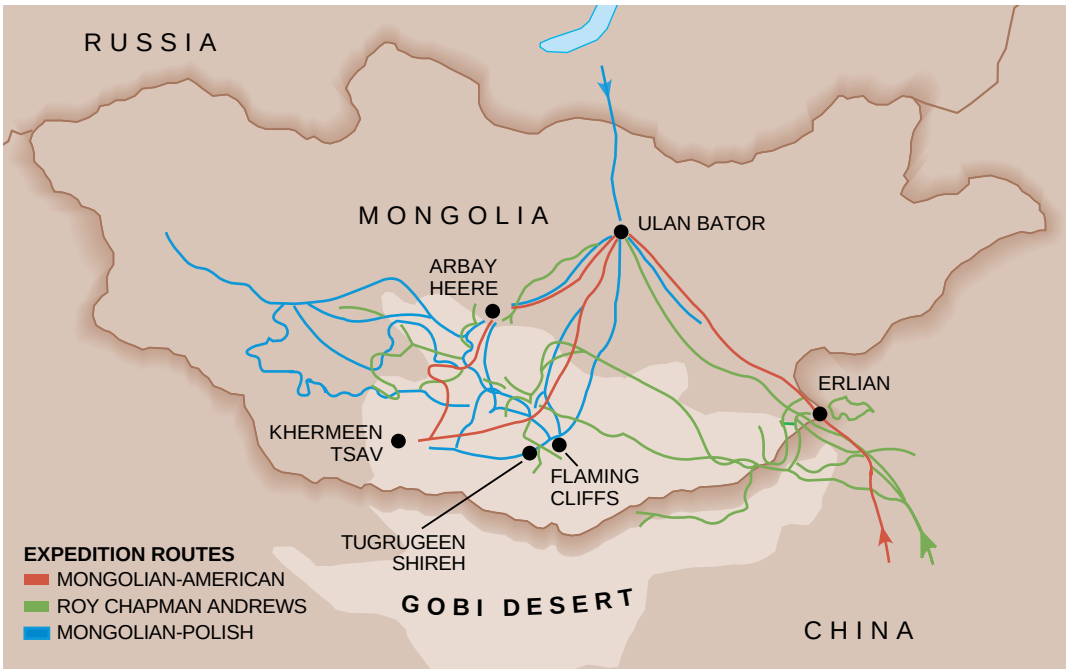
Other species point to a more primitive age of placental mammals. Modern species have at most four premolar teeth on each side of the jaw, but certain Mongolian specimens of placental mammals, such as juvenile individuals of the genus *Kennalestes,* have at least five. Another group, *Zalambdalestes,* is interesting because it has rabbitlike or rodentlike incisors and a skeleton adapted for running and hopping, also like that of living rabbits. Paleontologists are divided on whether *Zalambdalestes* might be an early rabbit ancestor or simply an example of convergent evolution.

One of the most spectacular prizes of our expeditions is the best-preserved skull of *Zalambdalestes* yet recovered. In collaboration with Timothy Rowe of the University of Texas, we examined it using a very high resolution computed tomography scanner. The three-dimensional x-ray images allowed us to reconstruct the paths of arteries, veins and even nerves. The CT images confirm an earlier hypotheses by Kielan-Jaworowska: the carotid arteries, the main channels supplying blood to the brain and the eye, enter the skull along the midline rather than at the sides, as they do in most living mammals.

Mammals, lizards and other vertebrates are crucial to reconstructing the past environment of the Gobi and to tracing the main lines of evolution. But dinosaurs still occupy center stage in the public eye. The Cretaceous Gobi is unquestionably one of the world's great dinosaur hunting grounds. The fossils range from complete skeletons of *Tarbosaurus,* a fierce carnivore closely related to the North American *Tyrannosaurus,* to giant sauropods, duck-billed dinosaurs, armored ankylosaurs, frilled ceratopsian dinosaurs such as *Protoceratops* and a magnificent assemblage of smaller carnivores. Birdlike oviraptorids and dromaeosaurs such as *Velociraptor* are better represented in the stratified rocks of the Gobi than anywhere else in the world.

These remains have given rise to controversies but also to some definitive conclusions. Artists often depict *Velociraptor* hunting in packs like African wild dogs, for example, but there is no definitive proof that it was capable of such cooperative behavior. The predator's taste for *Protoceratops,* however, is more than a matter of speculation. In the late 1960s a group of Polish and Mongolian scientists at Tugrugeen, a white sandstone escarpment about 50 miles west of the Flaming Cliffs, excavated one of the most remarkable pair of specimens in the history of paleontology. Two nearly complete skeletons—a *Protoceratops* and a *Velociraptor*—are preserved locked in mortal combat. *Velociraptor* desperately clutches the lowered head of *Protoceratops* with its forelimbs and raises the killing hooks of its hind claws high against its prey's flanks. The "fighting dinosaurs," which may have met their end in one of the Gobi's sandstorms, are one of the great exhibits of the Natural History Museum in Ulan Bator.

Velociraptor skeletons are not only



Cliffs. Current expeditions (*center*) can rely on satellite navigation aids, but they face no less arduous conditions. Although paleontologists have mapped many rich fossil territories, much of the Gobi remains unexplored (*map at right*).

fascinating for the image they convey of intelligent, swift and lethal terrors. They offer clues to the evolutionary connection between birds and dinosaurs. *Velociraptor* and its relatives have many very birdlike features, including the construction of the bony case of the brain and the design of the elongated limbs and digits. A nearly complete skeleton of *Velociraptor* unearthed at Tugrugeen in 1991 has a more complete braincase than any other specimen; in its details the architecture of the braincase is surprisingly similar to that of modern birds.

An unexpected discovery at Tugrugeen in 1992 further amplified the proposed connection between dinosaurs and birds. We found a delicate skeleton that was identical, except for its smaller size, to one discovered by Mongolian scientists some years earlier. The animal, roughly the size of a turkey, has a remarkably gracile frame with long legs. In addition, the keel of the breastbone is very well developed. In modern birds, strong pectoral muscles that power the downstroke of the beating wing attach to this keel. Instead of long wing bones, however, this creature has stubby, massive forelimbs somewhat like those of a digging mole. The end of the arm and hand is appointed with a single very large claw; hence, the scientific name bestowed on the animal is *Mononykus*—literally, "single claw." (The original spelling was the more etymologically correct *Mononychus,* but it turned out that a beetle had first claim.)

Mononykus is a bizarre creature. Although it has no wings, it has several features that suggest a closer relation to modern birds than the famous primitive bird *Archaeopteryx*. In addition to the enlarged sternum, these features include an antitrochanter, a small protrusion on the pelvis at the hip joint that serves as a muscle attachment point, a continuous crest on the femur for the attachment of the limb muscles, and a greatly shortened fibula, the thinner of the lower limb bones. A detailed analysis of *Mononykus* favors the view that this creature was a flightless relative of modern birds.

That argument has drawn some criticism. Certain specialists claim *Mononykus* is simply a small dinosaur whose birdlike features are a product of convergent evolution. The weight of the evidence, however, does not favor convergence. The history of birds is marked by species (such as the ostriches, emus and kiwis) that have lost flight. Our *Mononykus* fossils do not show evidence of feathers, but it is only by some miracle of preservation that the fine Jurassic limestone entombing *Archaeopteryx* leaves impressions of tiny feathers. *Mononykus,* like most fossils, is not preserved in such unusual rock.

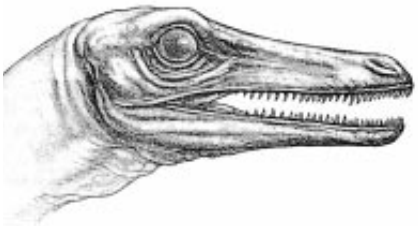
We have detected remains of this animal at many localities. Among the several skeletons most recently recovered from Ukhaa Tolgod is a nearly complete specimen that includes for the first time a well-preserved skull. This fossil, though not yet fully exposed and prepared in the laboratory, shows evidence of an elongated head. What we can see is much different from previous reconstructions, which were extrapolated from partial fragments of the braincase. New information from this skull should have critical bearing on the current debate over *Mononykus* and the dinosaur-bird connection.

Eggs of both dinosaurs and birds, found in many parts of the Gobi, add another dimension to the fossil record. Some of the eggs contain small embryonic skeletons of the bird *Gobipteryx,* and others preserve the skeletal remains of a small embryonic dinosaur. In some places, several nests may be clustered on a hillside, and we infer that these nests mark a congregation of dinosaurs, much like a colony of seabirds today.

At Tugrugeen Shireh, we found 12 jumbled skeletons of *Protoceratops* on a flat not much larger than a putting green. The Sino-Canadian team has also reported such accumulations of *Protoceratops* in Cretaceous rocks of northern China.

The *Protoceratops* sample also includes several growth stages, providing a glimpse of this largely unknown aspect of dinosaur biology. Adults typically measure two meters long; in 1994 our team recovered some *Protoceratops* less than nine centimeters long. These skeletons are obviously those of very young individuals, possibly newborns.

As we make such new discoveries,



DINOSAUR AND MAMMAL FOSSILS from the Gobi are remarkably well preserved. The newly discovered troodontid (*life-size photograph of skull and sketch at left*) was a small carnivore closely related to birds. It has yet to be given an official name. The multituberculate skeleton (*at center and rotated at right*) is almost com-

however, the picture of dinosaur life that emerges becomes more complex. Because *Protoceratops* is the most common dinosaur fossil in the region, paleontologists have long assumed that the many shells and egg aggregates found at the Flaming Cliffs and elsewhere belong to it. Yet evidence for this supposition has been unsatisfactory. None of the hundreds of dinosaur eggs collected have clearly identifiable *Protoceratops* embryos within them. Even the tiny skulls of *Protoceratops* we recently discovered cannot be positively linked with an egg of a particular type.

A new find from Ukhaa Tolgod suggests that this assumption may have been wrong. The examination of a clutch of eggs containing dinosaur embryos found on our first day there revealed that an oblong, somewhat wrinkly egg usually attributed to *Protoceratops* held a nearly perfect oviraptorid skeleton. It appears likely that many of the eggs found at Ukhaa Tolgod (and possibly elsewhere) belong to these small carnivores rather than to the parrot-beaked, herbivorous Protos.

The Ukhaa Tolgod "nest" contains other fossils of great intrigue. Two tiny skulls of a dromaeosaur (possibly *Velociraptor*) were found in the clump of eggs; bits of oviraptorid eggshell were associated with their bones. This curious coincidence of eggs, an oviraptorid embryo and two very young or newborn dromaeosaurs has several plausible explanations.

Perhaps the young dromaeosaurs were honing their skills at a very early age by raiding dinosaur nests. Alternatively, the parent oviraptorid may have been feeding the dromaeosaurs to her offspring. The dromaeosaurs might also have been interlopers, their eggs placed in the oviraptorid nest in much the same way that cuckoo birds place their eggs in the nests of other bird species. Although the mystery cannot be resolved, these fossils suggest ways of life and nesting behaviors for theropod dinosaurs that had thus far not been tied to hard paleontological data.

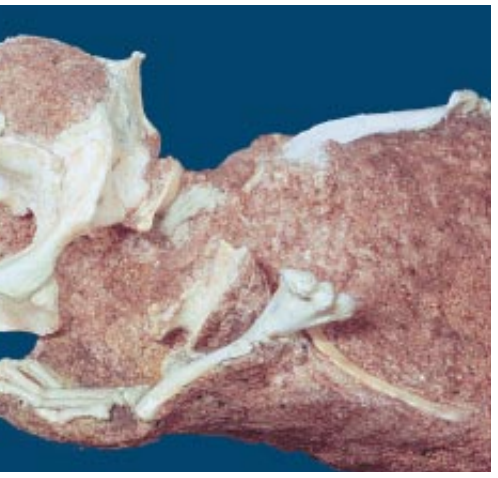
This discovery also puts an ironic twist on nomenclatural history. The Andrews expeditions applied the name *Oviraptor* to a skeleton at the Flaming Cliffs because it was found atop a clutch of eggs. They assumed that the eggs belonged to the common *Protoceratops* and that *Oviraptor* (literally, "egg hunter") was raiding a nest. Our find demonstrates that *Oviraptor* may not have been devouring eggs but rather incubating them. The name will stick because of nomenclatural rules, but it hardly befits the true circumstances behind the discovery of the first known skeleton.

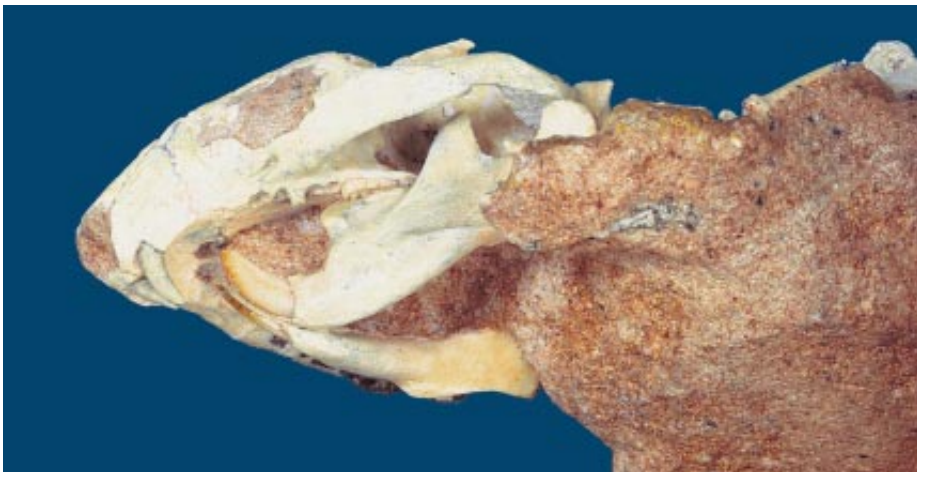
Nesting sites and skeletons of birds, dinosaurs, mammals and other vertebrates all make up a fairly detailed picture of life in the Gobi during the late Cretaceous. The new evidence contributed by the Mongolian Academy–American Museum expeditions has been gathered by logging thousands of kilometers over a wide stretch of the Gobi rather than concentrating for a prolonged period on a single or a few sites. This method not only increases the chance of finding new fossil sites, it conveys a better sense of the rock sequence through comparison of fossil-bearing strata over a broad area. Thus, we can try to determine whether assemblages of animals and sediments representing a particular environment and time interval are widespread or confined to isolated outcrops.

For example, paleontologists have generally believed that the community of fossils in the Djadokhta Formation (a Central Gobi bed of brilliant red sandstones named for the Flaming Cliffs) is slightly older that of the Barun Goyot Formation (which gets its name from an ancient settlement in the Nemegt Valley) in the western Nemegt. Both our new findings at Ukhaa Tolgod and our broad survey, however, suggest that the two formations preserve contemporary, virtually identical fauna. We found an extension of this community in the magnificent red and vermilion beds of Khermeen Tsav, an isolated set of badlands in the arid desert west of the Nemegt region that strongly resembles the canyon lands of southern Utah.

We have also found fossils from the Djadokhta community, including the familiar *Protoceratops,* in an area called Khugene Tsavkhlant, near the eastern railway. These discoveries are particularly significant because the sandstones there appear to be the result of stream or river action, a situation more typical of North American sites than of the Gobi. It is slowly becoming clear that the animal community once thought to be localized at the Flaming Cliffs may have occupied a range of habitats.

The wide geographic separation of many sites, however, impedes these comparisons of fossil localities. In addition, Gobi rock sequences are entirely sedimentary, without even traces of volcanic rocks. Thus, geologists cannot determine the age of these strata by ana-





pletely intact even though some of its bones are barely half a millimeter thick; the skull is about 2.5 centimeters long. Multis (*sketch at right*), recognizable by the many bumps (tubercles) on the crowns of their teeth, were small mammals whose habits presaged those of rodents such as squirrels and mice.

lyzing their proportions of radioactive isotopes. Estimates of the age of various formations must rely on the similarity of the vertebrates to those of reference faunas on other continents and on correlations with invertebrate fossils from Cretaceous marine rocks in Central and East Asia.

We have sampled representative rock sequences in the hope of obtaining paleomagnetic signals, but results have not yet come in. These signals track the orientation of the earth's magnetic field at the time the rock and its minerals are deposited. The "frozen" paleomagnetic signals can then be matched against a chronology of reversals in the earth's field. Paleomagnetic data would therefore provide an independent source for estimating the age of the Gobi rocks.

In yet another ironic twist, the rocks of the Gobi appear to be missing precisely those strata that currently hold the greatest public interest: no sections found thus far include the Cretaceous-Tertiary (K-T) boundary, when the dinosaurs became extinct. Although the Gobi is richly endowed with early Tertiary mammal faunas, there seems to be a gap of at least several million years between these and the late Cretaceous dinosaur faunas. Whatever cataclysm wiped out the dinosaurs (and many other species then on the earth), its mark on Central Asia seems to have been erased. If a continuous sequence could be found somewhere in the desert's vastness, it would make a formidable contribution to our knowledge concerning the dinosaur extinction and the subsequent rise of mammals.

The notion of finding the K-T boundary in the Gobi is not just wishful thinking. Satellite navigation has already made a tremendous difference in the effectiveness of our work. We can plot the precise location of fossil sites and the routes that lead to them. We have also used *LANDSAT* and *SPOT* satellite images as a prospecting tool. After we returned from Ukhaa Tolgod in 1993, Evan Smith of the Yale University Center for Earth Observation enhanced red and brown spectral bands on computer-based satellite images by matching colors from photographs of the rocks there. The result is a map that shows with high precision the extent and contours of fossil-bearing strata.

During the 1994 season, we used these images as a field guide and simply drove to the latitude and longitude of a telltale cluster of red pixels. Some of these computer-targeted spots proved productive. Satellite and computer technology have provided us with a useful paleontological atlas in a region where detailed topographic or geologic maps are virtually lacking. We now also have something that might have cost Andrews his most important but serendipitous discoveries: a fairly decent road map of the Gobi.

Despite our new technology and the decades of insights into the evolution of vertebrates, exploration of the Gobi has much the same quality that Andrews and his colleagues experienced nearly 70 years ago. The Flaming Cliffs we encountered on that first joyful day in 1990 were as Andrews described them—imposing, brilliant red in color and replete with fossils. Nearby are *gers* much like the one Andrews visited to ask for directions on his day of discovery. Sandstorms that engulfed the 1920s expeditions returned to wreak havoc with our fragile campsites.

When the sandstorms clear, one can see from the top of the cliffs the mauve, furrowed mountains of the Gurvan Saichan. Beyond the mountains are hundreds of square miles of fossil-rich badlands whose existence Andrews could only have imagined. The Gobi is and will be for some time a great wilderness. It will continue to hold many secrets of prehistory, of the rise and fall of dinosaurs and other biological empires.

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Earth from Sky

Radar systems carried aloft by the space shuttle Endeavour *provide a new perspective of the earth's environment*

by Diane L. Evans, Ellen R. Stofan, Thomas D. Jones and Linda M. Godwin

Soon after launch on Friday, September 30, the crew of the space shuttle *Endeavour* were treated to a dramatic sight. The Kliuchevskoi volcano in Kamchatka, Russia, was spewing plumes of ash 65,000 feet into the air. After 49 years, the volcano had chosen to erupt that very day. *Endeavour* was carrying a sophisticated radar system designed to study the earth's geology and environment. The equipment had flown only once before, the preceding April. The radar planning team quickly changed the schedule during the next few orbits to capture the fiery peak on film.

Nor was that the only natural event to coincide with *Endeavour*'s 12-day flight. On Tuesday, October 4, an earthquake struck near the island of Hokkaido in Japan. Some hours later *Endeavour* was able to scan the coastline for damage from tsunamis.

Radar systems, such as the one on board *Endeavour,* emit radiation of relatively long wavelengths—ranging from a few to tens of centimeters—and record the echo returned by a surface. Comparison of the original and the reflected ray tells researchers the distance, size, orientation, roughness and other characteristics of the reflector. For example, an object tends to reflect that wavelength of radar that matches its own size.

If the surface is oriented so that it reflects the radar right back to the source the way a mirror does, it will look bright. If oriented at some other angle, it will look dark. Features that are rough on the same scale as the wavelength scatter the radiation in all directions, rather than reflecting it back. Thus, plowed fields look bright with shorter-wavelength radar and dark with longer wavelengths, whereas forests look bright at most wavelengths. And whereas a long wavelength can pass right through a hurricane, a short one might divulge details of a storm system's core.

SPACE SHUTTLE *ENDEAVOUR* views the earth with radar. Visible on the shuttle are flat antenna panels that emit three wavelengths of radar, accompanying electronics (*marked "JPL"*) and an apparatus for measuring atmospheric pollution from satellites (*marked "LaRC"*).

American and European scientists worked together for years to build the radar systems on board *Endeavour.* We used three wavelengths—of three, six and 24 centimeters—called X-band, C-band and L-band, respectively. The two longer wavelengths of radiation were emitted by the Spaceborne Imaging Radar-C (SIR-C, pronounced "sirsee") instrument. Scientists at the National Aeronautics and Space Administration's Jet Propulsion Laboratory (JPL) developed this equipment and the data processor in Pasadena, Calif., where the information is retrieved and studied.

The radiation from SIR-C is polarized, so that its electric field vibrates either in the vertical or in the horizontal direction. The reflected rays may be received either vertically or horizontally polarized, giving scientists another means of discrimination. For example, vertical tree branches may reflect one polarization better than the other, allowing investigators to distinguish between different types of vegetation.

The other radar, X-Band Synthetic Aperture Radar (X-SAR, pronounced "exsaar"), operates at three centimeters, emitting and detecting only vertically polarized light. It was developed by the German Aerospace Establishment and the companies of Dornier in Germany with Alenia Spazio in Italy, for the Italian and German space agencies.

On its April and October flights, *Endeavour*'s orbit was inclined at 57 degrees to the equator. Drifting slightly on suc-

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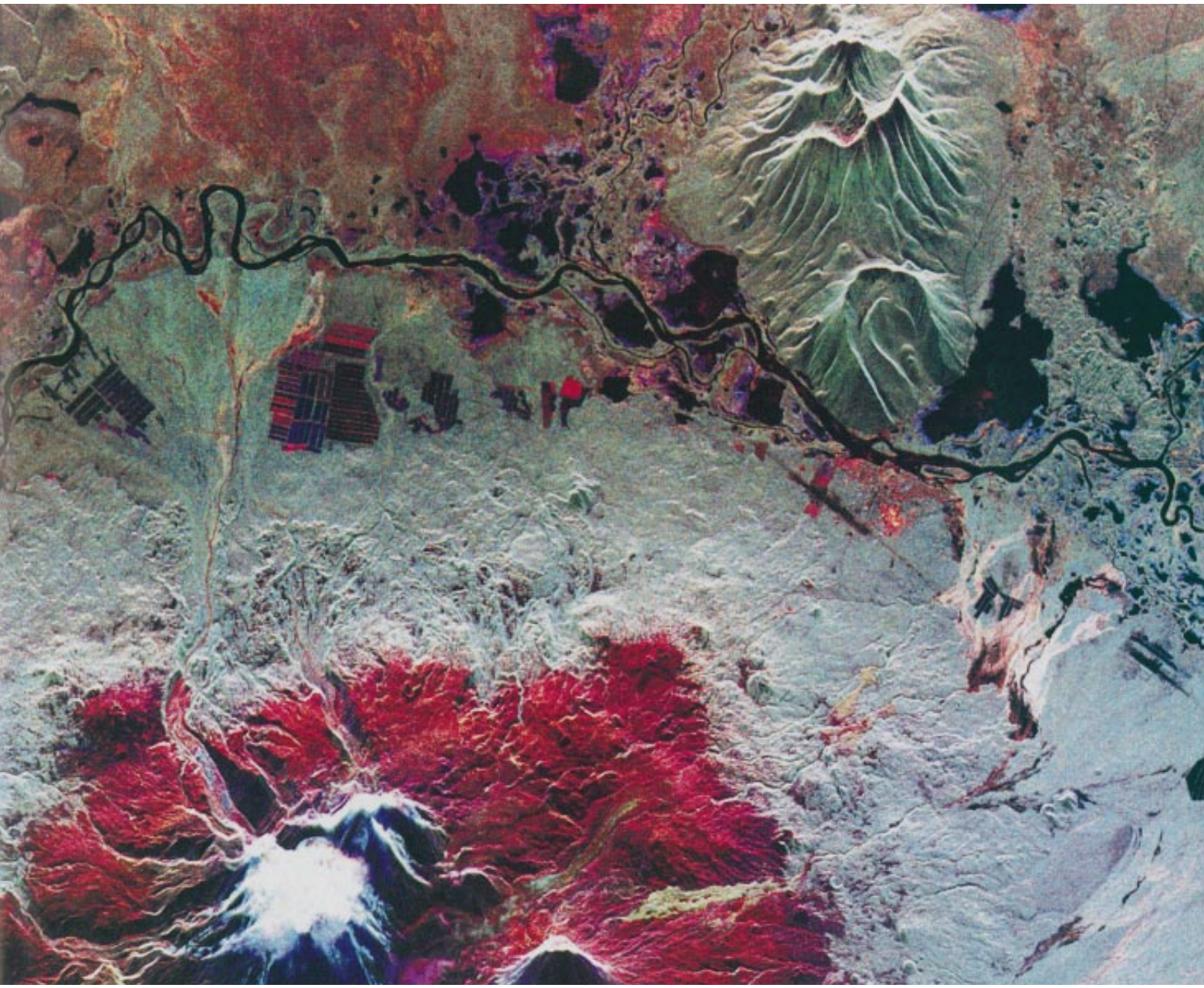
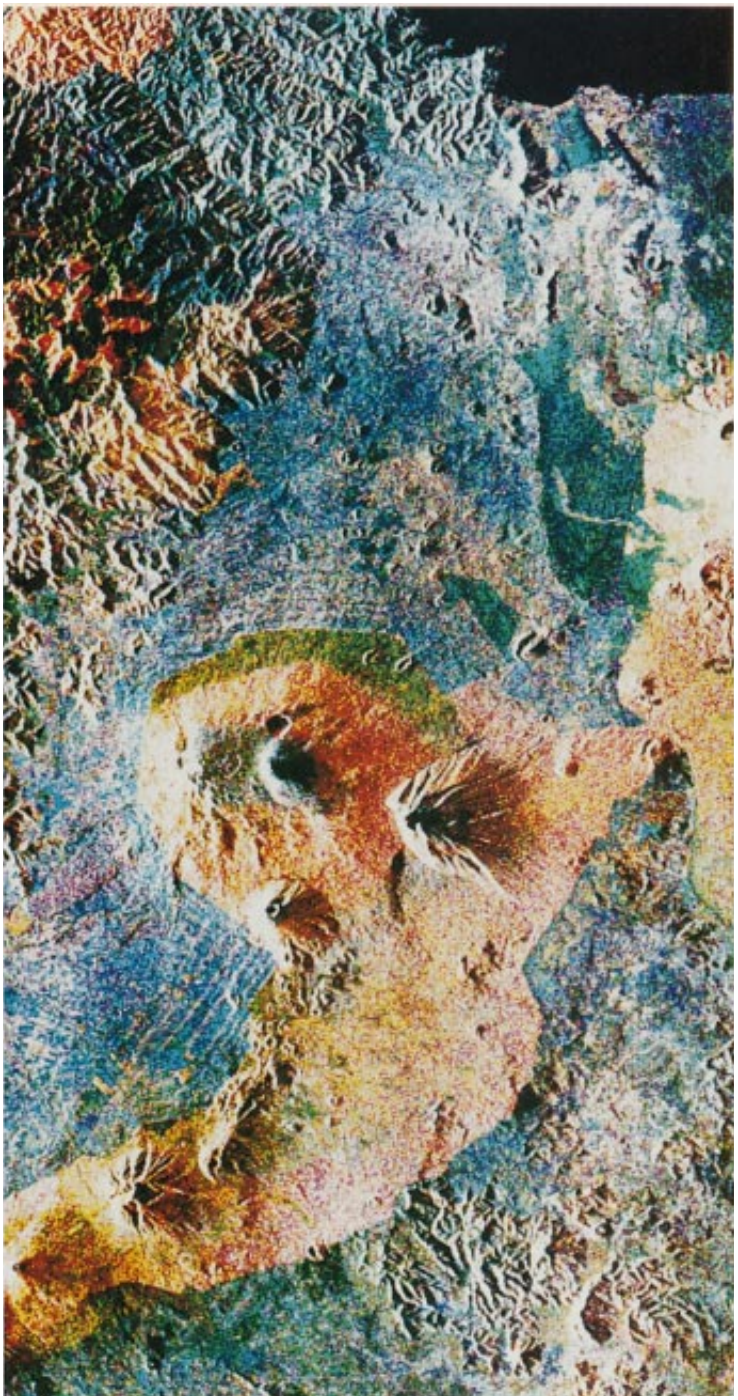


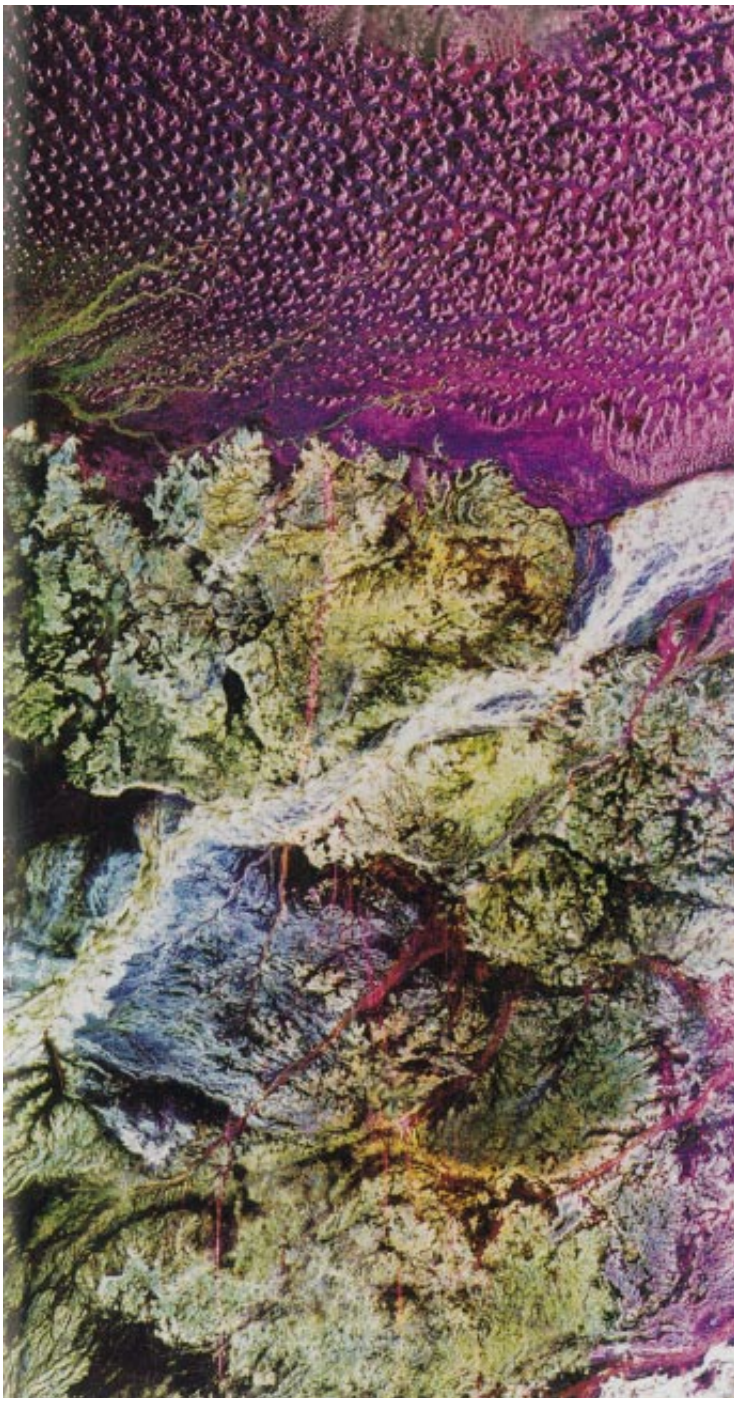
KLIUCHEVSKOI VOLCANO (*red area*) in Kamchatka, Russia, erupted on September 30. Its last major outbursts had been in 1737 and 1945. The Kamchatka River (*top*) flows across this volatile region where the Pacific plate is sinking under the Eurasian plate. North of the river are dormant volcanoes (*green*); south of it are agricultural settlements (*lines*). Streaks (*yellow-green*) on Kliuchevskoi's slopes indicate new lava flows. For this 18.5- by 37-mile image, the transmitted radiation was polarized horizontally. L-band radiation (24-centimeter wavelength) was received horizontally and vertically polarized, called LHH (*red*) and LHV (*green*), respectively. Also displayed is the vertically polarized component, called CHV (*blue*), of the reflected C-band radiation (six-centimeter wavelength).

DIANE L. EVANS, ELLEN R. STOFAN, THOMAS D. JONES and LINDA M. GODWIN worked on different aspects of *Endeavour*'s April and October flights. Evans, of the Jet Propulsion Laboratory, is the project scientist for the SIR-C radar. She has worked on space-borne radar systems since earning her Ph.D. in geology from the University of Washington in 1981. Evans also conducts research on geologic remote sensing. Stofan is the experimental scientist for SIR-C. She studied the geology of Venus for her Ph.D. at Brown University in 1988 and is also the deputy project scientist on the Magellan mission. Jones flew on both flights of *Endeavour*. A 1977 graduate of the U.S. Air Force Academy, he served in the Air Force for six years. To pursue an interest in planetary science, Jones obtained a Ph.D. from the University of Arizona in 1988. In 1991 he became an astronaut. Godwin, deputy chief of NASA's Astronaut Office, served as a mission specialist on *Endeavour*'s April flight, her second visit to space. A condensed matter physicist who received a Ph.D. from the University of Missouri in 1980, Godwin enjoys flying small planes.

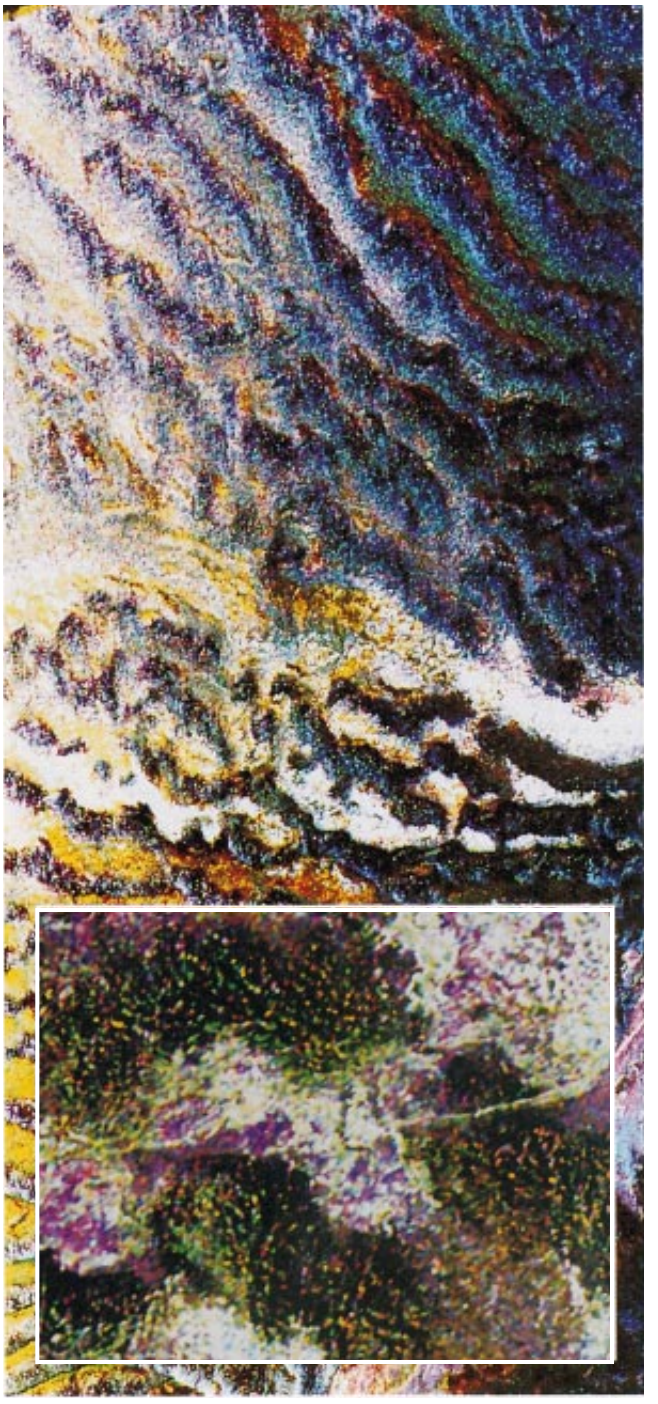
DINOSAUR EXTINCTION, 65 million years ago, may be linked to the Chicxulub crater in the Yucatán, Mexico. The meteoritic impact crater is now buried under 300 to 1,000 meters of limestone, but fracture patterns and water flow reveal the crater's structure. To the left is a mangrove swamp (*yellow and pink band*). The spots (*blue*) indicate tropical forests watered by springs, most abundant near the crater rim, which runs across the center of the image. Data from *Endeavour* may help determine the diameter of the crater (between 110 and 180 miles), a topic of much debate. (L-band total power is red; C-band total is green; and the difference between C- and L-band is blue.)



MOUNTAIN GORILLAS that were studied by Dian Fossey live in the bamboo forest (*green crescent*) on the slopes of Mount Karisimbi (14,800 feet). Its neighboring peaks are Sabinyo (12,000 feet) and Muhavura (13,500 feet). These belong to the Virunga volcano chain along the borders of Rwanda, Zaire and Uganda. The volcanoes endanger the town of Goma, Zaire, and nearby Rwandan refugee camps (*white*) on the shores of Lake Kivu (*dark patch at top*). Researchers are using similar images to produce vegetation maps. These maps could be critical to helping the world's last mountain gorillas survive. (35 by 20 miles; LHV red, CHH green, CHV blue.)



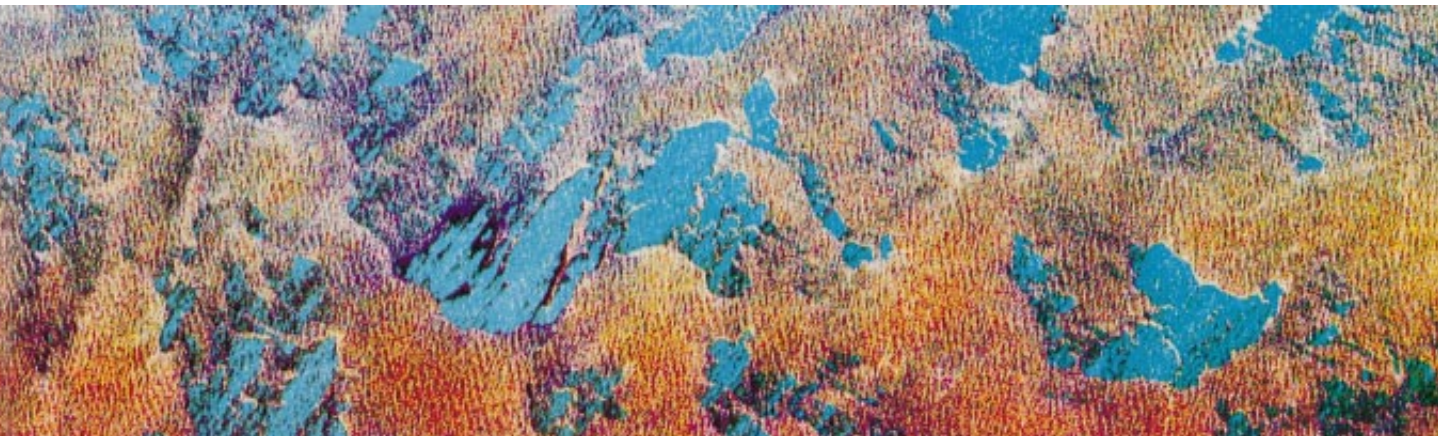
LOST CITY OF UBAR in southern Oman was uncovered in 1992 using *LANDSAT*. As in the original data, the city itself is too small to show up in this image by *Endeavour*. But streaks (*pink*) just below the old riverbed, or wadi (*white gash*), reveal buried roads converging on the site. Ubar, one of the enchanted cities of *Thousand and One Arabian Nights,* was a decadent outpost where caravans assembled before ferrying frankincense across the desert. Long believed to be mythical, it probably flourished from about 2800 B.C. to A.D. 300. North of the river are sand dunes (*magenta*); south are bare limestone rocks (*green*). (31 by 62 miles; LHH red, CHH blue, LHV green.)



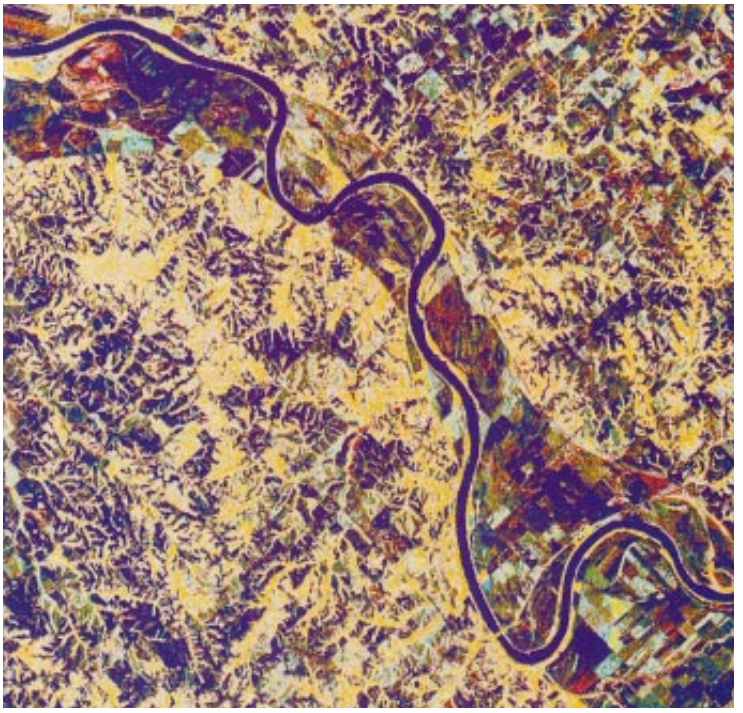
SILK ROAD may have traversed this corner of the Taklamakan Desert, in China's Xinjiang Province, on its way to Persia, Byzantium and Rome. The image is thought to contain the ruins of Niya, an ancient settlement. The white streak (*middle*) is the Niya River flowing through ridges and dunes (*blue*). Enhancement (*inset*) reveals a linear feature, probably a man-made canal leading off the river. Such images of deserts and dunes can also help predict sandstorms. (22 by 51 miles; CHH red, LHH green, LHV blue.)

RECLAIMED LAND in Flevoland, the Netherlands, is used for agriculture and forestry. This image from *Endeavour*'s April mission shows bare fields (*blue*). Above the canal (*black*) is an old forest (*red*); on the canal's shore is the city of Harderwijk (*white*); and specks in the canal are boats. Such images aid in studies of crops and soil conditions. The pentagon (*lower right corner*) is a reflector for calibrating the radar. (15.5 by 15 miles; L-band total red, C-band total green, X-band vertically polarized and received blue.)

AMAZON FLOODS (*yellow and red*), imaged in April, have since receded. The Rio Negro (*top, blue*) and Rio Solimões (*bottom*) meet a few miles downriver to form the Amazon. A road (*center, thin line*) can be seen connecting a cleared patch (*blue*) in the forest (*green*) to a tributary of the Rio Negro. Researchers use radar to measure the extent of flooding or clear-cutting and the biomass of forests. They can then deduce the carbon dioxide intake, essential to studies of global warming. (5 by 25 miles; LHH red, LHV green, LVV blue.)



ICE FLOES (*brown and white*) ride on swells in the Weddell Sea, Antarctica, creating this rippled image. Stretches of open water (*blue*) harbor areas where new ice is forming (*black wisps*). Sea ice hinders heat flow from the warm ocean to the cold atmosphere, affecting the global climatic system. Radar reveals not only the ice thickness but also the energy and interactions of the waves. It is especially useful in polar regions, which have long periods of darkness and extensive cloud cover. (62 by 18.5 miles; LHV red, LHH green, CHH blue.)



LEVEE BREAKS during the Midwestern floods of 1993 deposited several meters of sand (*blue*) on farmlands along the Missouri River near Glasgow, Miss. These farms may now become a muddy-bottom refuge. Some breaks are visible just below the sharp bend (*top center*). Gullies (*yellow*) from the floods crisscross the terrain. *Endeavour* was able to monitor the April floods of 1994 even as they ravaged parts of Illinois. Radar can also measure the wetness of soil or snow (such as in California's Sierra Nevada) and help manage water resources. (23 by 16 miles; LHH red, LHV green, inverse of LHH + LHV blue.)

Continued from page 70

cessive passes—each orbit took 90 minutes—it eventually imaged 12 percent of the globe. The radar was focused on several hundred sites selected by the 52 scientific teams.

The crew also tested a new technique for making accurate topographic maps. The radiation is emitted in phase (as for a laser). The phase of the returned wave is detected by two separate antennae or by two slightly displaced passes of the shuttle. The difference in phases recorded in the two instances depends on the distance of the feature being imaged. Such interferometry has revealed changes as small as centimeters in the topography of California and Hawaii between the April and October flights.

The bulk of the data was not turned over to JPL until the shuttle landed. But the crew transmitted some images directly to researchers on the ground, along with comments on what they were seeing. This verbal record, together with more than 20,000 frames of film that the astronauts exposed—a record for shuttle missions—is invaluable for interpreting the data. Covering much broader areas than the radar swath, it provides context. It has already helped explain anomalies such as shadowy regions in X- and C-band images taken during heavy rain in the Amazon.

Endeavour landed at Edwards Air Force Base in California on October 11, 1994, having stayed aloft an extra day to finish all its tasks. Its mission showed how the unique perspective of space, combined with the power of radar, can let us explore our planet in a way never before possible. From the images taken, we expect to learn which combination of radar wavelengths and polarizations are optimal for future studies. Launched on board a satellite, such a radar system could become a permanent source of information about the state of the earth's forests, rivers and climate—and potential hazards such as earthquakes, volcanoes and floods.

FURTHER READING

THE DISPLACEMENT FIELD OF THE LANDERS EARTHQUAKE MAPPED BY RADAR INTERFEROMETRY. D. Massonnet et al. in *Nature,* Vol. 364, No. 6433, pages 138–142; July 8, 1993.

THE SHUTTLE IMAGING RADAR-C AND X-SAR MISSION. D. L. Evans et al. in *Eos* (*Transactions of the American Geophysical Union*), Vol. 74, No. 13, pages 145–158; March 30, 1993.

ADDITIONAL IMAGES are available from the World Wide Web at http://spacelink.msfc.nasa.gov or ftp to spacelink.msfc.nasa.gov

The New Genetic Medicines

Synthetic strands of DNA are being developed as drugs. Called antisense and triplex agents, they can potentially attack viruses and cancers without harming healthy tissue

by Jack S. Cohen and Michael E. Hogan

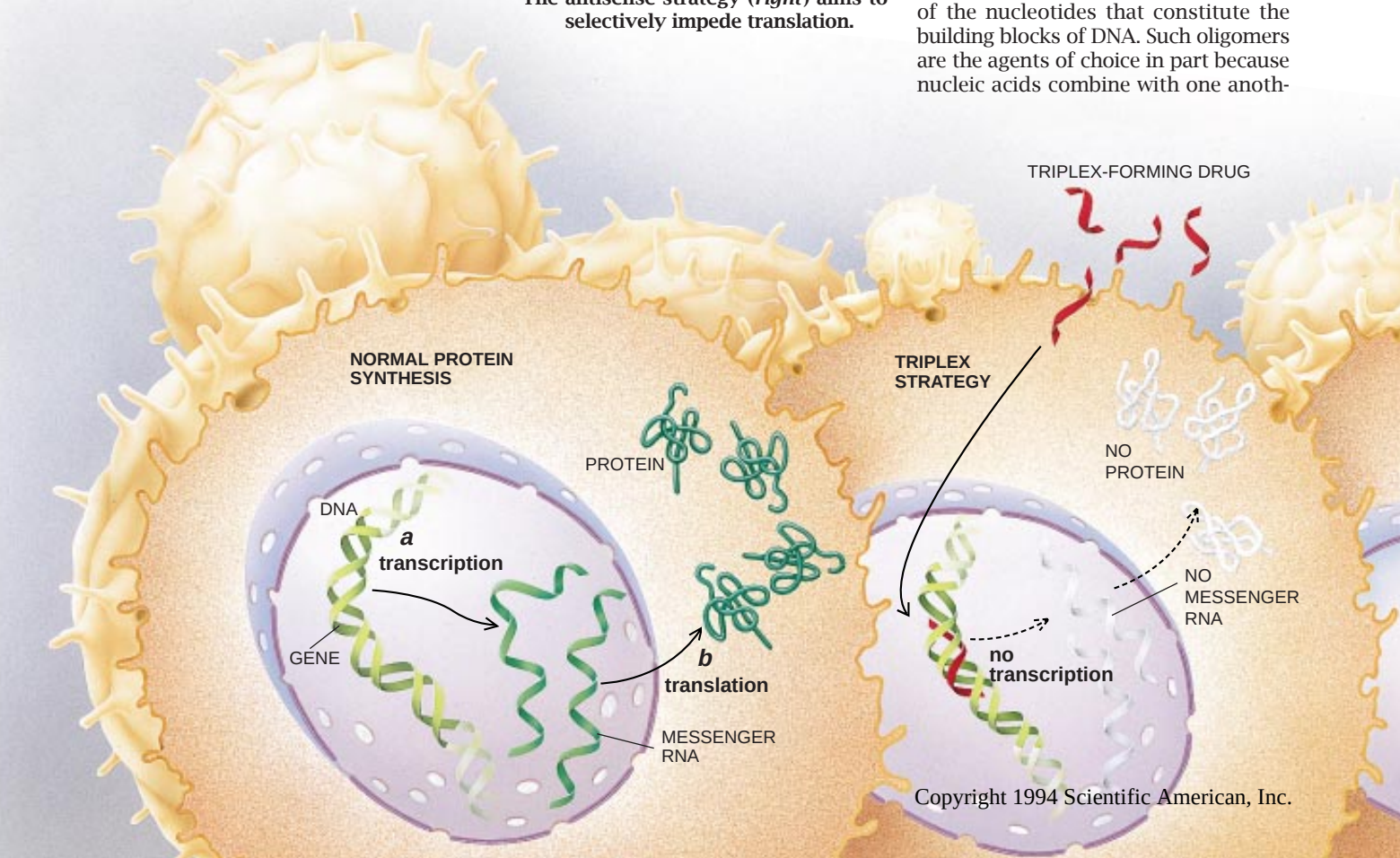
To someone interested in curing a disease, nothing would be more gratifying than discovering a "magic bullet"—a drug able to reverse the illness without producing side effects. For most of the 20th century, researchers hoping to find magic bullets thought in terms of agents able to combine with the active sites of proteins that contribute to disease. By filling these active sites, which differ from one protein to another, the drugs would presumably inhibit the activity of the targeted proteins but would not interfere with needed ones.

Work on proteins is ongoing. Recently, however, a number of investigators have turned their attention to an exciting new class of targets. Following what are known as the triplex and antisense strategies, those researchers are attempting to design drugs that will bind to selected sites on the nucleic acids (DNA and RNA) that direct the synthesis of disease-related proteins.

The rationale is straightforward. For a protein to be made, the unique gene that specifies its composition must be expressed. That is, the gene must be transcribed, or copied, from double-strand DNA into individual molecules of single-strand messenger RNA. Then the RNA molecules must be translated into the specified protein. Investigators hope the new drugs, by attaching to chosen segments of DNA (in the triplex approach) or messenger RNA (in the antisense approach), will impede transcription or translation of selected genes—be they microbial genes or aberrant forms of human varieties. In so doing, the compounds will not merely disable deleterious proteins, they will prevent them from being made at all.

The nucleic acid binding agents receiving the most study are DNA oligonucleotides, or oligomers: short strings of the nucleotides that constitute the building blocks of DNA. Such oligomers are the agents of choice in part because nucleic acids combine with one anoth-

TWO INNOVATIVE STRATEGIES are being tested for inhibiting the production of disease-related proteins. For any protein to be synthesized (*left*), the gene that specifies its composition must be transcribed from DNA (*a*) into molecules of messenger RNA. Then the RNA must be translated (*b*) into copies of the protein. The triplex strategy (*center*) aims to stall production of an unwanted protein by selectively inhibiting transcription of its gene. The antisense strategy (*right*) aims to selectively impede translation.



er according to well-understood rules. As a consequence, the compounds can be designed to recognize a unique site on a chosen gene or on its messenger RNA transcripts. They therefore have the potential to achieve the specificity required of a magic bullet.

A number of obstacles to the routine use of triplex and antisense therapies remain. Still, there is good reason for enthusiasm. Indeed, several oligonucleotide drugs have already demonstrated enough promise to justify clinical trials. They are being tested in patients suffering from leukemia, AIDS and other diseases in need of improved treatments.

Because oligonucleotide drugs are essentially snippets of genetic material, they are often referred to as genetic therapies. We should note, though, that such treatments differ markedly from standard gene therapies. Most gene therapies provide full, healthy genes as substitutes for versions that are missing or unable to direct adequate synthesis of a needed protein. Oligonucleotides cannot give rise to proteins. Their virtue lies in their ability to block the expression of existing genes.

Use of an oligonucleotide to stall transcription is known as the triplex strategy simply because the oligomer winds around double-helical DNA, forming a three-strand helix. The logic behind calling the translation-blocking strategy "antisense" is less apparent. But it can be grasped easily if one knows a bit about the structure of RNA and the way one RNA molecule combines with another or with DNA.

RNA molecules are strings of nucleotides. These nucleotides consist of the sugar ribose, a phosphate group (PO_4) and any of four nitrogen-containing bases—adenine (*A*), guanine (*G*), cytosine (*C*) and uracil (*U*). (DNA nucleotides are similar, except that the sugar is deoxyribose and the base thymine, *T,* takes the place of uracil.) When RNA or DNA nucleotides are assembled into a single string, the sugar and phosphate groups become the backbone of the resulting strand, and the bases protrude from that backbone. As James D. Watson and Francis Crick showed for DNA in 1953, two nucleic acids combine into a double-strand structure by forming hydrogen bonds between their bases; adenine on one strand combines with thymine or uracil on the other strand, and guanine combines with cytosine. Hence, if one strand of RNA consisted of the sequence *AUCCGUG,* it could pair with a second string of nucleotides having the complementary sequence—*UAGGCAC* in the case of RNA; *TAGGCAC* in the case of DNA.

Because the sequence of bases along a messenger RNA molecule spells out the series of amino acids that must be strung together to make a protein (in other words, carries information needed by a cell), the sequence is said to make sense. To produce a molecule able to bind to the sense strand, one must construct a string of nucleotides having the complementary, "antisense," sequence. So it is that the practice of inhibiting translation with oligonucleotides is called the antisense strategy.

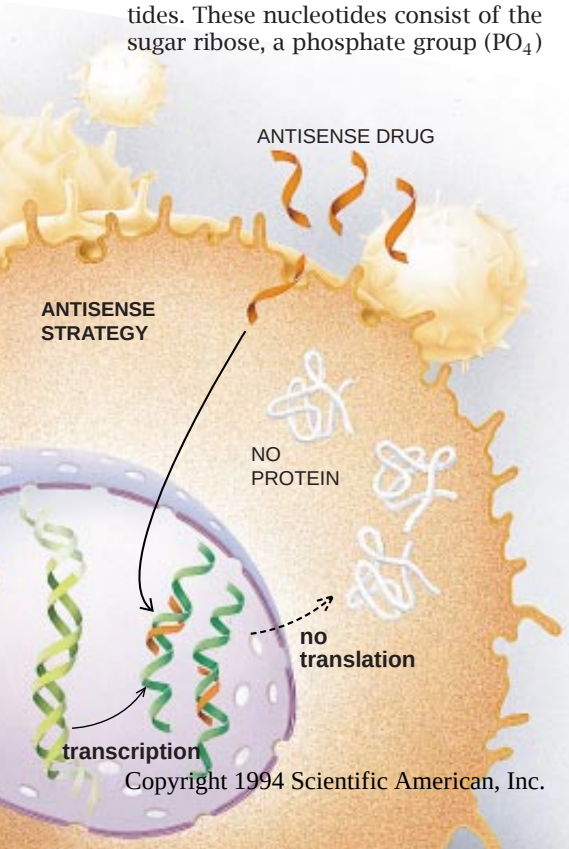
Antisense oligonucleotides are the first of the new genetic medicines to have reached clinical trials. One of the initial clues that they could have therapeutic merit emerged in the early 1980s, when scientists discovered that certain microbes, in addition to making messenger RNA, naturally produce antisense RNA. The most logical explanation for this behavior seemed to be that the organisms used antisense molecules as a previously unrecognized tool for regulating gene expression. If the antisense RNA paired with its complementary messenger RNA molecule, it would presumably interfere with the ability of the organism's translation machinery to act on the sense strand and produce the specified protein.

It is now clear that plant and animal cells, in common with microbes, sometimes employ the antisense strategy to control gene expression. But back then, workers were still trying to find out whether their hypothesis was correct. With the help of recombinant-DNA technology, they created genes that would give rise to antisense versions of selected messenger RNA species. Then they put the genes into cells. Sure enough, the procedure sometimes led to dampened manufacture of proteins coded for by the targeted RNA strands.

The results suggested that antisense molecules could be designed to serve as drugs that would selectively impede translation. For broadest application, however, the drugs would have to be delivered to cells in the body easily and efficiently. That is, in most cases the best approach would be to administer short strings of synthetic antisense nucleotides instead of entire, cumbersome genes—although some researchers continue to work with antisense genes.

By the mid-1980s tools for readily synthesizing DNA oligonucleotides had become available, but whether the oligomers could be enlisted as drugs was another question. Some years before—in 1978—Paul C. Zamecnik of the Worcester Foundation for Experimental Biology and Mary L. Stephenson of Harvard University had laboriously constructed a 13-nucleotide oligomer designed to recognize a base sequence in many messenger RNA molecules made by the Rous sarcoma virus. This oligomer reduced replication of the virus in cells, indicating that it had blocked production of proteins needed for elaborating new viral particles. Nevertheless, two potential problems worried investigators.

First, unmodified oligonucleotides carry a negative charge on each phosphate group. Charged molecules often have difficulty diffusing across the uncharged membranes of cells. Hence, most researchers assumed that the multicharged oligomers would be unable to enter cells efficiently. Second, cells abound in enzymes that cleave foreign DNA; it was thought likely that oligomers that managed to enter cells would, in most cases, be degraded promptly.



JACK S. COHEN and MICHAEL E. HOGAN concentrate their efforts on antisense and triplex research, respectively. Cohen is professor of pharmacology and of biochemistry and molecular biology at Georgetown University Medical Center. He is also program director of molecular biochemistry at the National Science Foundation. In 1990 he helped to found PharmaGenics, Inc., in Allendale, N.J., and served on its scientific advisory board until 1993. Hogan is professor at the Center for Biotechnology and in the department of cell biology at Baylor College of Medicine. He is also chief scientific adviser to Triplex Pharmaceutical Corporation and to Genometrix, Inc., both in The Woodlands, Tex., and an adviser to Lark Sequencing Technologies in Houston.

To address these drawbacks, Paul O. P. Ts'o and Paul S. Miller and their associates at Johns Hopkins University explored the value of modifying standard oligonucleotides. As part of that effort, they replaced an oxygen atom in each phosphate group with a methyl group (CH_3). In so doing, they converted the negatively charged phosphates into noncharged units known as methylphosphonates. This step helped to increase the cellular uptake of oligonucleotides and enabled them to resist being broken down by enzymes. Regrettably, eliminating the charges on oligomers renders them hydrophobic (water-hating) and thus rather insoluble in aqueous solutions. Lack of solubility can make mass production difficult.

Kazuo Shinozuka and Gerald Zon of the U.S. Food and Drug Administration, working with one of us (Cohen), then at the National Cancer Institute, later introduced an alternative to the methylphosphonate oligonucleotides. They exchanged an oxygen atom in normal phosphate groups with a negatively charged sulfur atom. These phosphorothioate oligomers—better known as "S-oligos"—are water soluble, easy to produce automatically and resistant to enzymatic breakdown. Perhaps for these reasons, most antisense drug research today employs the S-oligos.

Ironically, it is now apparent that cells take up S-oligos and unmodified oligonucleotides more easily than was originally thought. These charged agents seem to enter cells not only by direct diffusion across the cell membrane but by endocytosis as well. In this process the cell membrane engulfs the compounds and then folds in on itself, giving rise to a small vesicle that is subsequently drawn into the cytoplasm. What is less clear is whether the contents of such endosomes are released readily.

In addition to lowering some of the initial barriers to the therapeutic uses of antisense oligonucleotides, investigations conducted over the past 15 years have revealed a number of other important factors that must be taken into account in designing antisense drugs. For instance, oligomers must be at least 15 nucleotides long in order to bind tightly to target sites and avoid associating with nontarget sites. Related analyses have also established that antisense oligonucleotides can stall translation by at least two methods. As predicted, they interfere with the ability of cells to "read" sense RNA. In addition, by binding to messenger RNA, they can stimulate an enzyme (ribonuclease H) to cleave, and thereby destroy, the bound messenger RNA.

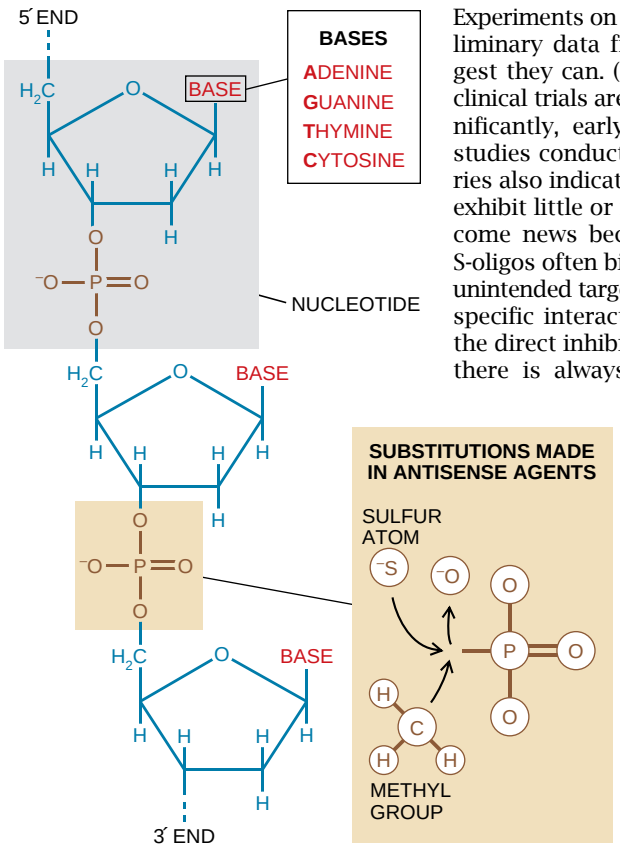
The collected findings fuel confidence that the antisense strategy holds promise for therapy. But can antisense DNA in fact retard production of proteins known to be involved in diseases? Experiments on cells in culture and preliminary data from human trials suggest they can. (To our knowledge, the clinical trials are all using S-oligos.) Significantly, early reports from animal studies conducted in several laboratories also indicate that antisense agents exhibit little or no toxicity. This is welcome news because in cultured cells S-oligos often bind to proteins or other unintended targets. At times, these nonspecific interactions actually augment the direct inhibition of translation. But there is always a concern that they could have unwanted consequences.

The first antisense oligomers to reach the market will probably be applied to combat viral infections. ISIS Pharmaceuticals in Carlsbad, Calif., is conducting a large-scale clinical trial of an oligonucleotide targeted to transcripts of a viral gene important for replication of the human papillomavirus. This virus is a cause of genital warts. Such growths have reportedly disappeared or become smaller in many patients who have received injections into the skin under the warts.

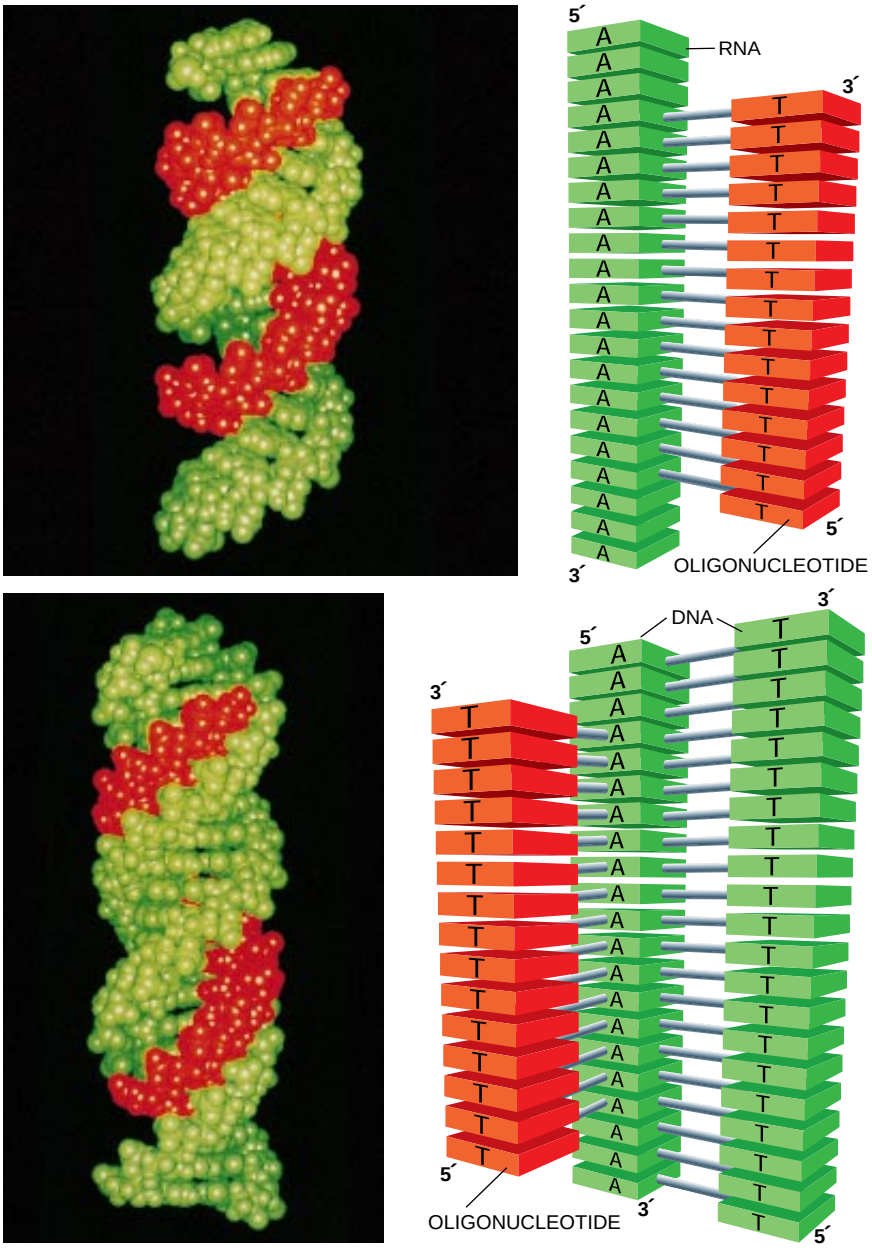
A more preliminary clinical trial is under way in patients infected with the human immunodeficiency virus (HIV), the cause of AIDS. Scientists at the National Agency for AIDS Research in France, Hybridon in Worcester, Mass., and elsewhere are evaluating an oligomer directed against the RNA product of the HIV *gag* gene, which the virus requires in order to replicate.

Clinical trials of cancer-fighting oligonucleotides are beginning, too. One of these tests is being carried out in patients afflicted with acute myelogenous leukemia, a rapidly progressing cancer of the blood. In the experiment, a group at the Nebraska University Medical Center is collaborating with scientists at Lynx Therapeutics in Hayward, Calif., to examine the ability of an antisense oligonucleotide to destroy cancer cells in the body and in a procedure known as ex vivo bone marrow purging. In the latter approach, physicians remove bone marrow from a patient and treat it with an agent that selectively kills cancerous cells. Then, after administering chemotherapy to the patient, they return the "purged" cells to the body. The oligomer in this study is targeted to RNA generated by the *p53* gene. This gene is usually considered to be a tumor suppressor, but it is apparently overexpressed in patients with acute myelogenous leukemia.

Lynx is simultaneously collaborating with Alan M. Gewirtz of the University of Pennsylvania in analyzing an antisense drug for treating chronic myelogenous leukemia. This trial, which is again evaluating the ability of an antisense drug to eliminate cancer cells during ex vivo bone marrow purging, targets messenger RNA transcribed from a gene called *c-myb*. In its healthy state, *c-myb* promotes the normal proliferation of blood cells. Abnormal regulation of the gene has been implicated in caus-



NUCLEOTIDES ARE BUILDING BLOCKS of the new genetic medicines, which typically consist of 15 to 20 units. The nucleotides in the drugs, like those in natural DNA, consist of a sugar (*blue*), a phosphate group (*brown*) and any of the four nitrogen-rich bases (*red*) listed at top right. In the antisense agents, one oxygen atom in each phosphate group is often replaced by a sulfur atom (S) or a methyl group (CH_3) (*box at bottom right*). Such changes help the drugs to resist breakdown by enzymes in cells.



BINDING OF OLIGONUCLEOTIDES (*red*) to nucleic acid targets (*green*) is represented by space-filling models (*left*). One oligonucleotide, an antisense agent, twists around a messenger RNA strand (*top*), creating a double helix. The other oligonucleotide winds around the deep major groove of the DNA double helix, producing a triple helix (*bottom*). The nucleotides (identified by the first letter of their bases) in the binding agents and their targets are indicated next to the models.

ing human leukemias and other diseases. Gewirtz is also beginning to test the efficacy of infusing the antisense agent into leukemic patients directly.

Clinical trials are under way or planned against additional viruses and cancer-related genes. Even if the results are positive, in the long run antisense agents will probably be administered with other anticancer or antiviral drugs. Two or more compounds that operate by different mechanisms are likely to prove more effective than any single agent administered alone.

As might be expected of any emerging technology, many difficulties still have to be resolved before the full promise of the antisense strategy can be realized. For one thing, oligonucleotides are expensive to produce (although costs are dropping). The stability of the compounds must be improved. And workers interested in employing oligonucleotides as drugs must find better methods for delivering them to cells in quantity. The triplex research we discuss below shares these same concerns.

Potency needs to be enhanced as well. To this end, some investigators are attaching RNA-degrading agents to the molecules. In another approach, Claude Hélène and his colleagues at the National Museum of Natural History in Paris have made oligomers that carry chemical groups able to insert themselves between successive bases pairs on the RNA-DNA duplex; such intercalation should stabilize binding and prolong antisense activity. Cohen's group and others are using molecular modeling to design oligonucleotides with novel backbone structures, in the hope of improving both potency and specificity.

Meanwhile a very different antisense approach is making impressive headway. RNA molecules known as ribozymes are deployed instead of DNA oligonucleotides. These molecules recognize specific base sequences in messenger RNA and cut the RNA at those sites, thereby destroying the transcripts. In the next few months Flossie Wong-Staal of the University of California at San Diego expects to start a clinical trial of a ribozyme targeted to the RNA transcripts of a gene in HIV.

The other new genetic strategy—the triplex approach—has received less attention until recently, but intimations of its possibilities emerged in the 1950s. Four years after Watson and Crick discovered the structure of double-helical DNA, Gary Felsenfeld and Alexander Rich, then postdoctoral fellows at the National Institutes of Health, began conducting their own explorations of multiple-strand structures formed by nucleic acids. They synthesized RNA polymers of uracil-containing nucleotides and mixed them with complementary strands—synthetic polymers of adenine-containing nucleotides. Predictably, they were able to retrieve *AU* double helices. To their surprise, they also found *UAU* triple helices, in which an additional strand of uracil-containing nucleotides bound to the *AU* double helix.

Subsequently, Michael J. Chamberlin and his colleagues at the University of California at Berkeley showed that the corresponding DNA polymers, consisting exclusively of thymine or of adenine nucleotides, could be assembled into *TAT* triple helices. And Richard A. Morgan and Robert D. Wells, then at the University of Wisconsin, produced yet another kind of all-DNA triple helix. They established that a string of cytosine nucleotides could bind to a *GC* double helix. In this case, the triple helix arose only when the molecules were placed in a slightly acidic solution, in which protons were abundant. The acidity was needed because the triple

helix could form only if the extra cytosine-bearing strand acquired an additional proton. The resulting structure is known as a $C^{+}GC$ triplex.

For about a decade, the various triplexes seemed little more than intriguing curiosities, without obvious significance for the design of agents able to regulate native genes in cells. After all, the genes of living organisms are not fashioned from simple "homo" polymers, carrying one, endlessly repeated, nucleotide. If triple-helix-forming nucleic acids were to be put to practical use, they would have to be able to recognize genes whose strands carried more than one kind of base pair.

In the late 1960s Morgan and Wells established that triple helices containing *TAT* and $C^{+}GC$ units could be formed by combining an oligomer containing thymine and cytosine with a double helix containing *AT* and *GC* base pairs. They thus produced the first strong indication that triple-helix formation might well be able to occur on natural genes, not solely on simple synthetic double helices. Unfortunately, the tools needed to pursue this notion were not yet available. For instance, the technology for cloning genes and synthesizing DNA oligonucleotides automatically had not yet been invented.

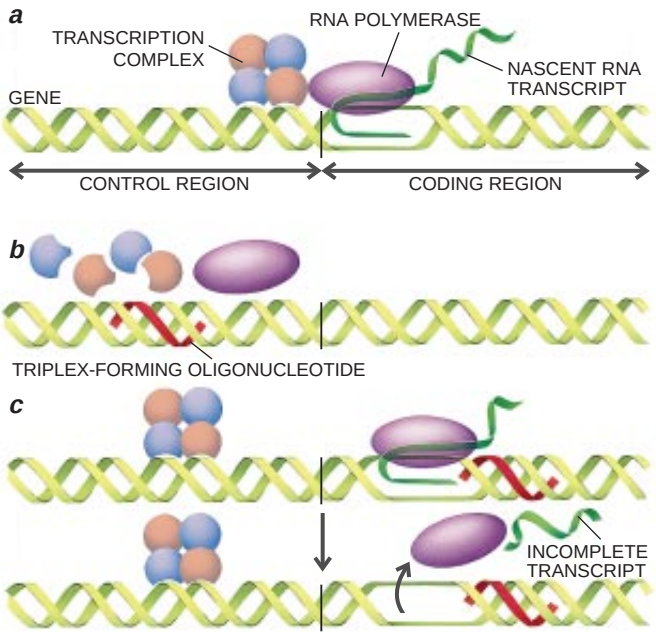
By the late 1980s, though, these problems were history. Furthermore, investigators had learned a great deal about how gene transcription is regulated. They discovered that genes basically consist of two elements: one is a regulatory region that controls the rate of transcription; the other is a coding region that specifies the amino acid sequence of the corresponding protein. Genes are transcribed when proteins known as transcription factors bind to specific sites on the control region. After such binding occurs, an enzyme known as RNA polymerase attaches to the coding region and produces messenger RNA copies of the information stored in that region. The coding segments of genes are usually covered with protective proteins and are inaccessible to drugs, but parts of the regulatory, or control, regions are often significantly more accessible.

These insights suggested that researchers would be well advised to concentrate effort on designing oligonucleotides that would bind to the control region of a chosen gene, thus keeping transcription factors from initiating transcription. But first, scientists needed more evidence that synthetic oligonucleotides could recognize selected base-pair sequences on natural genes.

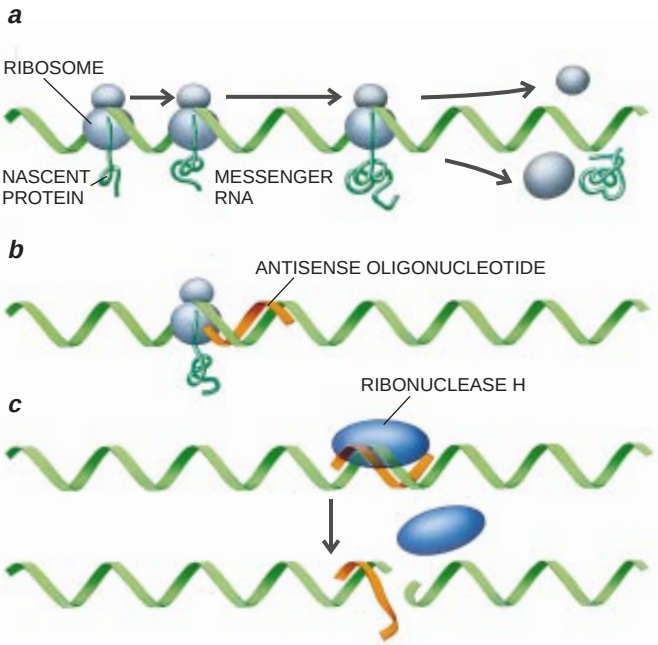
Such proof came in 1987. Peter B. Dervan of the California Institute of Technology and Hélène separately confirmed what Morgan and Wells had earlier shown with synthetic strands of double-helical DNA. Under certain conditions, natural genes that contained sites rich in *AT* and *GC* base pairs could indeed combine with an oligonucleotide designed to form *TAT* and $C^{+}GC$ triplets. In these experiments the triplexes arose when one strand of the targeted DNA duplex carried mainly purine bases (adenine and guanine), leaving the pyrimidine bases (thymine and cytosine) for the other strand. It is now evident that the oligonucleotides studied to date typically bind to just one strand of the double helix and only to the purine bases on that strand.

Dervan's and Hélène's findings were tantalizing. Yet a serious roadblock to therapeutic application of the triplex strategy persisted. As was expected from the results of Morgan and Wells, their triplexes did not appear at physiological levels of pH; they arose only when the solutions were acidic.

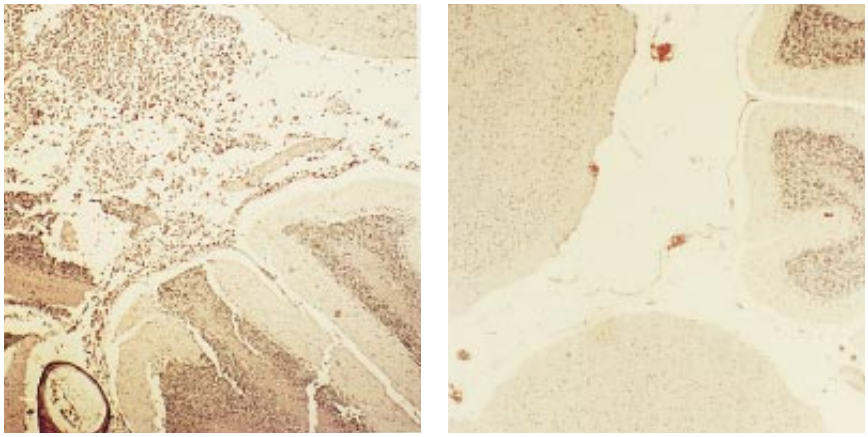
Dervan was able to bypass the problem partially by adding an iodine atom or a methyl group to standard oligonucleotides. In 1988 one of us (Hogan) and his collaborators at Princeton University succeeded with a different approach—one that also increased the affinity of oligonucleotides for their targets and generated a new variety of



GENE TRANSCRIPTION OCCURS (*a*) after proteins attach to the control region of a gene, forming a transcription complex. This complex directs the enzyme RNA polymerase (*purple*) to copy the instructions in the coding region into messenger RNA (*dark green*). Most triplex-forming agents (*red*) are targeted to the control region, to prevent RNA polymerase from attaching to a gene (*b*). Drugs targeted to the coding region might also halt transcription midstream (*c*).



TRANSLATION IS ACCOMPLISHED (*a*) by structures called ribosomes, which travel along RNA transcripts, constructing proteins as they go. Binding of an antisense drug (*orange*) to messenger RNA can inhibit translation in at least two ways. It can prevent the ribosomes from beginning or completing their journey (*b*). It can also induce an enzyme, ribonuclease H, to cut the RNA at the site of drug binding (*c*). Cleaved RNA cannot be translated and is rapidly degraded in cells.



CANCER CELLS (*dark spots*) have markedly infiltrated the cranial cavity (*whitish area*) of a leukemic mouse (*left*). But the cells have not spread to that area in a leukemic mouse treated with an antisense oligonucleotide directed against *c-myb* (*right*)—a cancer-related gene. Researchers at the University of Pennsylvania are now conducting human trials of the same drug in patients who have leukemia.

triplex. They determined that the need for an acidic pH level could be eliminated by inserting guanine-containing nucleotides where cytosines had previously been placed in triplex-forming oligonucleotides. These revised oligomers generated *GGC* triplets instead of the $C^{+}GC$ kind. The guanine in the synthetic strand connects with the guanine in the double-strand DNA.

Hogan's team and others later showed that oligonucleotides built to form *TAT* and *GGC* triplets on the regulatory regions of genes sometimes bound about as tightly as the proteins that normally recognize those sites. This similarity fanned rising expectations that oligonucleotide drugs could be constructed to prevent genes from being bound by regulatory proteins.

To create triplex drugs, designers have to understand exactly how a given oligonucleotide will interact with its target. They now know that triplex-forming oligonucleotides do not interfere with the hydrogen bonds that hold the original double helix together. Rather each base in the oligonucleotide establishes two new hydrogen bonds with a purine base in the targeted region of the duplex. It turns out as well that some oligonucleotides orient parallel, and some antiparallel, to their targets. DNA strands are asymmetrical. One tip is designated as the 5′ end and the other as the 3′ end. In a classic double helix the strands are antiparallel: the 5′ terminal of one strand lies next to the 3′ terminal of the other strand. Oligonucleotides that contain cytosine and thymine tend to lie parallel to the purine-rich strand of the duplex target. Those containing guanine and thymine tend to be antiparallel. If these differences are not taken into account, an oligonucleotide will fail to recognize its DNA target.

In 1988 Edith H. Postel and Michael Cooney in Hogan's laboratory, working with the cancer-related *c-myc* gene, provided the first evidence that an oligomer designed to make a triple helix on the control region of a gene could inhibit initiation of messenger RNA synthesis. They did it in a cell-free transcription assay: the gene and the oligonucleotide were mixed together with various cell components in a test tube instead of in an intact cell. Subsequently, Dervan showed, again in a cell-free system, that triplex formation can prevent transcription of selected viral genes.

Equally promising results have been obtained for other genes. Thus, it is now well accepted that, at least in the test tube, triplex-forming oligonucleotides can be designed with the ability to home to the control region of a chosen gene and selectively block its transcription into messenger RNA. Recent evidence also indicates that triplex agents targeted to the coding regions of genes can interrupt RNA polymerase's efforts to construct messenger RNA transcripts. This discovery implies that when initiation of transcription cannot be prevented, triplex drugs might be able to cut off transcription in midstream.

Studies of living cells add weight to the probability that triplex compounds can eventually be used against disease-related genes. Hélène has established that oligonucleotides targeted to the control region of the gene coding for the interleukin-2 receptor can inhibit expression of that gene. Postel and others in Hogan's laboratory have likewise shown that an oligonucleotide targeted to the regulatory region of the human *c-myc* gene can inhibit the gene's transcription in a human tumor-cell line. Other laboratories have similarly demonstrated that oligonucleotides can reduce transcription of various cancer-related and viral genes in living cells. So far no data from animal trials have been reported, and no human trials are under way. But that picture is likely to change in the next few years.

This is not to say the road ahead will always be smooth. Along with the difficulties faced by anyone interested in developing oligonucleotide-based drugs, triplex researchers are confronting special challenges of their own. For instance, the oligonucleotides that manage to stall transcription in cells today do so only when relatively high concentrations are delivered. Designs that might lower the required doses are being pursued.

A more major limitation is the requirement that targets carry virtually all their purines on the same strand. Few deviations from this ideal can be accommodated at present. Yet more than half of the potential targets on duplex DNA contain a mixture of purine and pyrimidines on each strand. As a first solution to this problem, Dervan and his colleagues have replaced the phosphate groups in oligomers with a chemical grouping that allows the oligonucleotides to "hop" from one strand to the other. Even more sophisticated structural changes are being investigated. Undoubtedly, some of them will extend the range of DNA targets available to triplex-forming oligonucleotides.

Antisense and triplex technologies may be far from perfect now. But if the successes of the past few years are any guide, antisense and triplex agents will be improved rapidly. We expect that such drugs will one day be common as treatments for illnesses, such as many viral and genetic diseases, for which no effective therapies yet exist.

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The Duality in Matter and Light

In quantum mechanics, objects can behave as particles or as waves. Studies now emphasize that such complementary features are more fundamental than has generally been appreciated

by Berthold-Georg Englert, Marlan O. Scully and Herbert Walther

In the microcosmos of quantum mechanics, phenomena abound that fly in the face of common sense. Many of these effects are a consequence of the principle of complementarity. Its most popular manifestation is the wave-particle duality. A microscopic object, such as a photon, an atom or an electron, can appear to behave as a water wave in one instance and as a discrete particle in another. Both features complement one another as a complete description of the object. Since the idea of complementarity was first enunciated more than 70 years ago, a belief common among many physicists has been that it is simply a consequence of the uncertainty relation. According to this rule, two complementary variables, such as position and momentum, cannot simultaneously be measured to less than a fundamental limit of accuracy. The uncertainty relation normally prevents one from learning everything about the behavior of a quantum object. As a result, we can never see the object acting both as a particle and as a wave.

Recently we and our colleagues have worked to show that uncertainty is not the only enforcer of complementarity. We devised and analyzed both real and thought experiments that bypass the uncertainty relation, in effect, to "trick" the quantum objects under study. Nevertheless, the results always reveal that nature safeguards itself against such intrusions—complementarity remains intact even when the uncertainty relation plays no role. We conclude that complementarity is deeper than has been appreciated: it is more general and more fundamental to quantum mechanics than is the uncertainty rule.

Wave and particle behaviors manifest themselves distinctly when tested. The wavelike aspect shows itself in interference patterns. Throw two stones at the same time into a quiet lake, and you will see how the emerging circular waves will eventually overlap. They reinforce one another where crest meets crest or extinguish one another where crest meets trough. The same effect appears if we shine light through two slits, which act as the two stones. The light wave travels through both slits, so that two smaller waves come out from each slit. These waves interfere, producing a series of light and dark fringes when projected onto a screen [*see illustration on page 88*]. The particlelike aspect, in contrast, always appears as photons, which are invariably seen as indivisible entities. Rather than registering a continuous intensity, a suitable detector counts a discrete number of photons.

A more impressive demonstration of particle and wave attributes takes place if we send photons through the slits one at a time. In this case, each photon produces a spot on the screen. But when we collect the results of many such events, an interference pattern emerges. (Specifically, the interference pattern represents the probability of the photon hitting one point or another.)

Niels Bohr and Albert Einstein analyze the two-slit experiment.

This counterintuitive dual nature of both wave and particle does not exhaust complementarity. Most quantum objects (a silver atom, say) have an internal structure that can result in magnetic properties. Measurements may find the "poles" of this "magnet" to point either up or down, or right or left. But we can never find the poles to point "up and left." Thus, the property of being up or down is complementary to that of being left or right, quite analogous to wave versus particle behavior.

A more striking, or even mysterious, aspect of complementary features concerns their predictability. Suppose a measurement found that our microscopic magnet points up. We then perform a second experiment to decide whether the magnet points left or right. What we find is that there is nothing predictable about the outcome: left or right occurs with a probability of 50 percent each. Are we lacking some knowledge that would allow us to make a prediction? No, the case is more serious than that: the result of the left-right measurement cannot be known beforehand.

The reason for this ignorance is the principle of complementarity. It states that one cannot simultaneously know the values of two related (that is, complementary) variables, such as whether the magnets point left or right and up or down. In fact, absolutely precise information about one variable means that nothing can be known about the other. Textbooks often illustrate the law using the position and momentum of a moving particle as the two complementary properties. The more accurate the position measurement, the less accurate the momentum information, and vice versa. The precise numerical statement is Heisenberg's uncertainty relation.

The principle of complementarity implies that in the microcosmos, complete knowledge of the future, in the sense of classical physics, is simply not available. If one of a pair of complementary properties of a quantum object is known for sure, then information about the second complementary property is lost.

In the two-slit setup, if we discover by any means whatsoever through which slit each one of the photons traveled (thus acquiring "which-way" information), we lose the interference pattern on the screen. The possession of which-way information means that at the slits the particlelike nature of the photons must be manifest, rather than the wavelike aspect necessary for interference fringes. We can have either which-way information or the interference pattern, but never both together. (Although we stated earlier that the particle nature is always recognized when the photons are detected on the screen, the information does not tell us anything about the state of affairs at the slits where the interference pattern originates.)

This complementarity is a fact of life, and we have to live with it. The Danish physicist Niels Bohr, more than anyone else, insisted on just that, and he deserves the lion's share of the credit for making us accept complementarity as a fundamental truth. It did not come easily, and the resistance put up by devil's advocates as prominent as Albert Einstein himself was formidable. The thrust of their arguments centered on whether complementary properties could be measured simultaneously. Here is an imaginary transcript of one of their many clarifying debates:

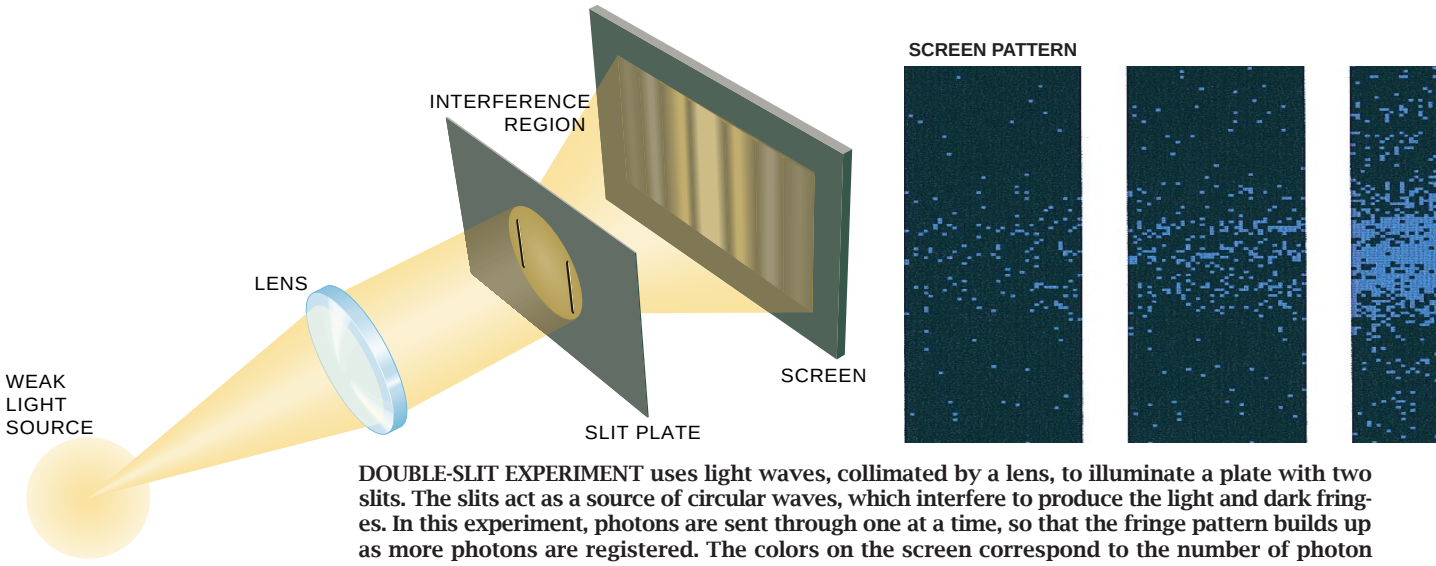
Bohr: I see you are once more sketching a two-slit experiment. What are you heading for this time?

Einstein: Just wait, Niels, until I have finished. Here you go [*see box on page 89*]. A plane light wave illuminates a plate that has two slits through which the light can reach a screen. Provided the geometry of the setup is right, an interference pattern appears on the screen—a series of light and dark bands.

B: That's what we teach our students. What's new?

E: Be patient, please. Before presenting the new thought, let me state the old affairs to make sure that we agree on those. You will not object to the statement that the interference pattern demonstrates the

BERTHOLD-GEORG ENGLERT, MARLAN O. SCULLY and HERBERT WALTHER entertain a great curiosity about the fundamental aspects of quantum mechanics. Englert received his doctorate from the University of Tübingen and is currently a member of the University of Munich. He holds an appointment at the Max Planck Institute for Quantum Optics in Garching and has been a visiting scientist at universities in New Mexico, Poland, Hungary and France. Scully, who received his Ph.D. from Yale University, has won numerous awards in quantum optics. He is a professor at Texas A&M University and has research appointments at the Houston Advanced Research Center and the Max Planck Institute for Quantum Optics. Walther, who earned his doctorate from the University of Heidelberg, is vice president of the Max Planck Society and directs its quantum optics institute. A recipient of many awards and honorary degrees, he serves on the boards of several journals and scientific societies.



DOUBLE-SLIT EXPERIMENT uses light waves, collimated by a lens, to illuminate a plate with two slits. The slits act as a source of circular waves, which interfere to produce the light and dark fringes. In this experiment, photons are sent through one at a time, so that the fringe pattern builds up as more photons are registered. The colors on the screen correspond to the number of photon

wave nature of light?

B: Of course not.

E: You will also agree that what you call complementarity implies here that there is no way of knowing through which slit any one of the photons reached the screen to deliver its contribution to the interference pattern.

B: Quite right so.

E: Well, you know I always found it hard to believe that the Lord took recourse to throwing dice. Let me now come to the new twist. Contrary to what was just said, I can tell through which slit the photon came. Say we saw the photon hitting the screen at the site of the first side maximum—that is, one of the bright bands closest to the center of the pattern. To get there, the photon needed to be deflected by the slit it traversed through.

But as Isaac Newton taught us, there is no action without reaction. So when the slit plate gives a jolt to the photon, a corresponding jolt is delivered by the photon to the plate. And the strength of the jolt depends on the slit through which the photon went. By suspending the slit plate sensitively, I can in principle register its recoil. The amount tells me through which slit the photon came.

B: Aha. You would then have "which-way" information for each individual photon and in the same experiment observe an interference pattern.

E: Yes.

B: But that is inconsistent with complementarity.

E: Yes.

B: Nice try, but I'm afraid you overlooked something—namely, the quantum properties of the slit plate. I can explain the reasoning with mathematics [*see box on opposite page*]. But the gist of the matter is that in order to observe the interference pattern, the position of the slit plate must be fixed rather precisely.

E: Certainly, because otherwise the two-slit fringe pattern cannot build up, and we would observe the scatter pattern of a single slit.

B: Now to distinguish one path from the other, we must know the momentum of the recoiling slit rather precisely. In fact, I can show that the interference pattern appears only when the uncertainties in both the position of the slit plate and the momentum of its recoil are so small that they would be inconsistent with the uncertainty relation.

E: Okay, okay, Niels, you win. I agree that one cannot have which-way information and the interference pattern in the same experiment. You are quite right in insisting that the slit plate must also respect the laws of quantum theory. I must with pleasure compliment you on this demonstration of complementarity.

B: Hold it. Do you think that Heisenberg's relation—as above or a variant thereof—is always the mechanism that enforces complementarity?

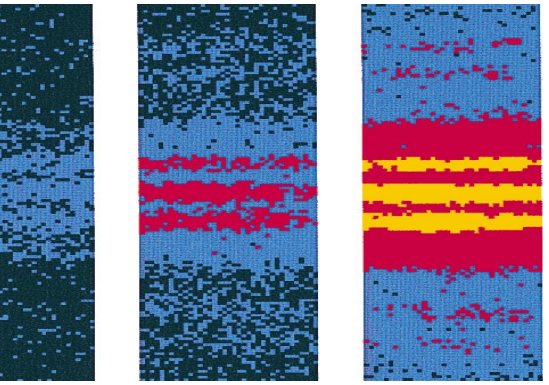
We can only speculate as to what might have been Einstein's response to the last question. For us, the answer is no. The constraints set by the uncertainty relation are not the only mechanism by which nature enforces complementarity. The negative answer is justified because we recently found that it is possible to construct which-way detectors that do not affect the motion of the observed objects significantly. That is, we envisage which-way detectors that get around the uncertainty relation.

The concept of the new which-way detector derives from a variant of the two-slit arrangement. The late Richard Feynman discussed one such variation in his admirable introduction to quantum mechanics contained in the third volume of his *Lectures on Physics.* He made the interesting observation that if one were to use electrons rather than photons, one would have another handle on interfering particles. Here he had in mind the fact that electrons themselves have wavelike aspects to their personality, just as light does. And so they would display an interference pattern in a double-slit experiment. Because electrons are charged, however, they react to electromagnetic fields, including light. As a result, we may scatter light off them to gain which-way information.

Feynman proposed a specific method to obtain such information: place a light source symmetrically between the two slits. The photons would bounce off the electrons. The direction of motion of the scattered photons would tell the experimenter whether they originate near the upper or the lower slit.

Feynman's analysis of the electron-photon collision process focuses on two variables. One is the jolt of momentum delivered to the electron. The second is the uncertainty in the precision with which the electron's position is determined. Quite similar to Einstein's recoiling-slit scenario, both quantities need to be very small if both which-way information and the interference pattern are desired, smaller indeed than permitted by Heisenberg's uncertainty relation.

The new which-way detector follows Feynman's proposal, but we devised our setup to get around the momentum jolts. Our thought experiment uses atoms rather than electrons as interfering particles. We place a small cavity—essentially a box—before each slit, so that each atom must pass through one of them before reaching the slits [*see*



hits: one to nine photons (*blue*), 10 to 99 (*red*) and 100 or more (*yellow*). The experiment was done by Gerhard Birkl of the Max Planck Institute for Quantum Optics in Garching.

top illustration on next page]. Experimenters at Munich University, the Max Planck Institute for Quantum Optics in Garching, Yale University and the École Normale Supérieure in Paris have made tremendous progress in developing the necessary experimental techniques in recent years. They can now conduct experiments in which single atoms routinely traverse cavities.

We would tune the laser beam so that each atom passing through it becomes excited. That is, the atom absorbs a short-wavelength photon from the laser and thus moves to a state of higher energy. The geometry of the cavities is such that the excited atoms are forced to release a longer-wavelength photon. (These wavelengths are comparable to that of the radiation in a microwave oven.) Locating the longer-wavelength photon would indicate the cavity, and hence the slit, through which that particular atom traversed. This setup does not fall prey to Heisenberg's uncertainty relation, given that the release of the cavity photon does not perturb the motion of the atom. To minimize extraneous signals, the cavities in real experiments would be kept ultracold. They would also have superconducting walls to guarantee a long storage time of the photons within.

Inasmuch as the detection mechanism does not affect the motion of the atoms, one might surmise that the atom would still possess its interference capability. In other words, we would have which-way information, indicating the atom's particlelike nature, and a fringe pattern, signaling its wavelike property.

This naive guess is wrong. Our analysis reveals that the which-way information and the interference pattern remain mutually exclusive. Once we obtain which-way information, the fringe pattern on the screen disappears. Instead we are left with a large splotch in the middle of the screen. We can get around Heisenberg's uncertainty relation but not around Bohr's principle of complementarity.

The way in which complementarity is upheld is rather subtle. It lies in the correlations between the atom's motional freedom and the cavity photons that effect the loss of the interference pattern. It is as if the atoms carry labels indicating through which slit they came, and atoms moving through the upper slit do not interfere with those going through the lower one. The label is the telltale photon left behind—one that has been stripped off, but a label just the same. The screen on which the interference properties could manifest themselves may be any distance away from the which-way detector cavities. That, however, does not matter. Once the correlations between a labeled atom

Upholding Complementarity with Uncertainty

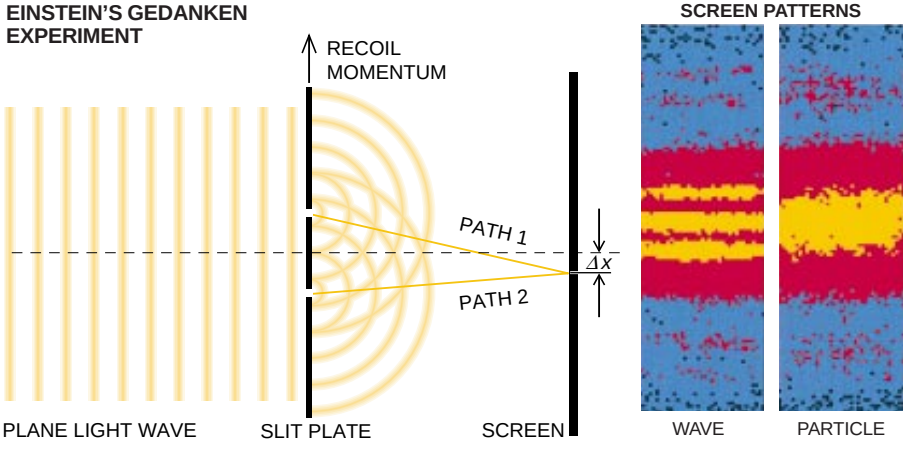
In their imaginary conversation, Niels Bohr explains to Albert Einstein why his alleged "which-way" detector could not work: it would be inconsistent with the uncertainty relation. Here we derive the quantitative reason.

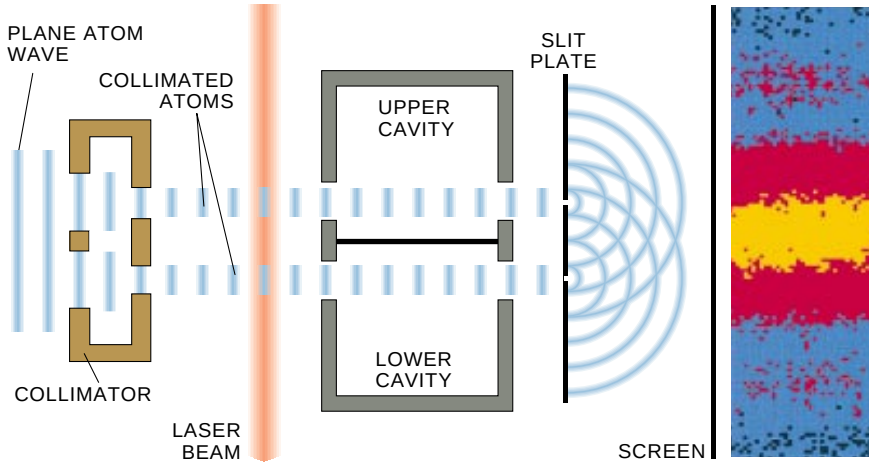
First, we denote the distance from the central bright band to the first side band by Δx. Then the position of the slit plate to the screen must be fixed rather precisely—that is, with an uncertainty, δx, markedly smaller than Δx. Otherwise the two-slit fringe pattern would not build up, and only the scatter pattern of a single slit would appear.

Einstein wanted to observe the recoil of the slit plate to glean which-way information. A photon has a momentum equal to $h\nu/c$, where h is Planck's constant, ν is the frequency of the photon and c the speed of light. (This photon momentum has three spatial components, but we are concerned here with the change in the component parallel to the slit plate.) The amount of recoil momentum the photon gives to the slit plate would depend on the slit through which the photon traversed (since the photon would have to be deflected by a greater amount from one slit than the other to reach the first side maximum). A bit of algebra will show that the momenta given to the two slits differ by $h/\Delta x$.

To identify the photon's path, we must know the momentum of the slit plate to a precision, δp, markedly smaller than this difference. We express the relation in mathematical form as $\delta p < h/\Delta x$. Because δx and δp have to be much less than Δx and $h/\Delta x$, respectively, the product $\delta x \delta p$ must be much less than Planck's constant h, symbolically, $\delta x \delta p << h$. And so we arrive at a requirement that cannot be met in view of Heisenberg's celebrated uncertainty relation $\delta x \delta p \geq h/4\pi$, which has to be obeyed under all circumstances.

In conclusion, either δx must be too large to allow for an interference pattern to form, or δp must be too large to distinguish one path from the other. The argument is particularly convincing because the final requirement $\delta x \delta p << h$ does not depend on the details of the interference pattern, even though the quantity Δx—the spacing between the fringes—enters the reasoning at the intermediate steps.





WHICH-WAY DETECTOR uses a laser beam to excite collimated atoms (manifested as waves). The atoms drop to a lower-energy state by yielding a photon in the cavity through which they traverse. Because this emission does not affect the atom's motion, the uncertainty relation does not apply. Nevertheless, analysis indicates that the which-way information precludes interference fringes.

and the cavity it enters become established, they remain intact.

At this point, the classical intuitionist, CI, can no longer control his temper. He turns to his friend, the quantum mechanic, QM.

CI: I have been listening patiently so far, but this is simply too much. I am willing to accept the previous arguments based on Heisenberg's uncertainty relation and agree that the presence of which-way information excludes the interference pattern. But surely that is so because in gaining the which-way information the experimenter disturbs the motion of the particle, which in turn loses its capability of interfering.

QM: When you say disturbs, do you think of something like an uncontrollable jolt?

CI: Yes, of course.

QM: Then you are wrong. The example of the cavity detectors demonstrates that you can have which-way information without such mechanical disturbances.

CI: I can follow your reasoning. But please help me understand the outcome. How can it be that the particle no longer interferes, although its motion has not been affected?

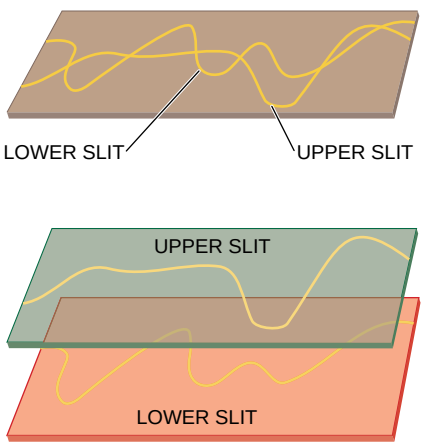
QM: The correlations that get established do the trick.

CI: I'm sorry, but the catchword "correlations" doesn't help me.

QM: Well, then, an analogy might be useful. Symbolize the two alternatives—the atom goes through either the upper slit or the lower slit—by two squiggly curves drawn on a horizontal plane [*see illustration at left*]. We say the curves interfere with each other whenever they cross each other. We draw the curves so they do so many times.

CI: Okay, go on.

QM: Now an additional degree of freedom is introduced—the third dimension in this analogy. The correlations are symbolized by lifting one of the curves to another plane, a few inches above the first one. Then the two curves no longer intersect—that is, they no longer interfere. And note that disregarding the correlations, achieved by ignoring the third dimension and projecting both curves onto a common plane, makes the curves appear to intersect, although they really run past each other.



CURVES ON A PLANE represent whether an atom passes through the upper slit or the lower one (*top*). Interference fringes correspond to the intersection points. But if correlations are established (*bottom*), the two curves are found to reside on different planes. They no longer intersect, and there is no interference.

CI: Aha, now I think I have a much better intuitive feeling for what is going on. In summary, the interference pattern gets lost because which-way information has become available, and this is not at all because of an uncertainty in the position of the slits or an uncontrolled jolt delivered to the atom.

QM: Yes, nothing of a random character enters.

In view of the subject's history, with its many textbook discussions invoking the uncertainty relation, many thoughtful colleagues have remained skeptical of our analysis. They have raised subtle objections to the conclusion that the motion of the atom is not perturbed. But careful calculations and a recent experiment performed in David J. Wineland's laboratory at the National Institute of Standards and Technology (NIST) in Boulder, Colo., have demonstrated convincingly that all these objections are invalid. The principle of complementarity is certainly more fundamental than is the uncertainty relation.

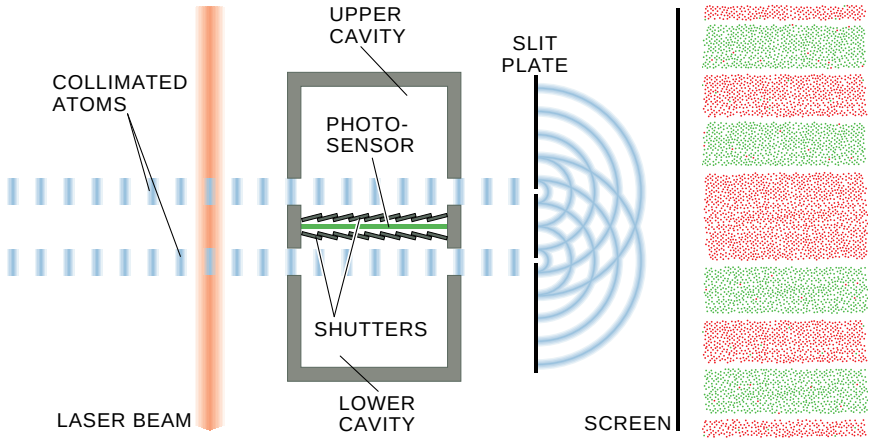
Given that which-way information precludes interference patterns, we can pose a converse question about complementarity. Suppose we erase the which-way information by absorbing the telltale photon somehow. Should not the interference pattern reemerge?

Quantum erasure would seem to make sense, although simply deleting information would not suffice in bringing back the interference pattern. It is true that an interference pattern indicates the lack of which-way information; likewise, which-way information precludes an interference pattern. But the conclusion that the lack of which-way information implies the presence of an interference pattern is a non sequitur. The answer to the question of whether the interference pattern will reemerge is therefore yes, provided that the erasure results in new correlations. Thus, the erasing has to happen under well-controlled circumstances.

The experimental realization of a quantum eraser is extremely difficult and has not yet been achieved. Instead we present a thought experiment that involves various idealizations while correctly containing all important features.

In the imagined setup, a photosensor sits between the cavities. Shutters shield the cavities from each other [*see illustration on page 92*]. As long as the shutters are closed, we have the which-way detector discussed earlier.

The experiment starts with the cavities empty and the shutters closed. We



QUANTUM ERASER is a variation of the which-way detector. After an atom hits the screen, the shutters are opened. If the sensor absorbs the cavity photon, the spot on the screen is marked red. Otherwise, it is marked green. The red spots produce interference fringes; the green ones generate a complementary pattern.

send an atom through the apparatus, which leaves behind a photon in one of the cavities. Of course, the chances that a particular cavity has the photon are 50–50. As the photon remains in one of the cavities, the atom reaches the screen, where it leaves a spot. Once that happens, we open the shutters simultaneously, turning the two separate cavities into a single, larger one.

Opening the shutters has an unusual effect on the photon. One might assume that the photon can now be anywhere, so that the sensor would always record a signal. But the photon is a quantum-mechanical beast. It has wave properties. Recall that before the shutters are opened, the photon has an even chance of being in either cavity. Another way to look at the situation is to say that the wave associated with the photon consists of two partial waves, one in each cavity. Now, when the shutters are opened, the photon wave is altered to fit into the new, larger cavity. The alteration can be pictured as a "melting" of the two initial, partial waves into a final, single one.

This melting can occur in different ways. If the two partial waves reinforce each other at the site of the photosensor, the instrument picks up the photon. In contrast, if the partial waves extinguish each other there, the sensor does not detect the photon. Either case is equally likely and is impossible to control or predict. Hence, the sensor has a 50 percent probability of detecting the photon left behind after the shutters are opened.

If the sensor absorbs the photon, the spot on the screen is marked red to indicate that the cavity photon has been erased. If the sensor fails to record anything, we mark the spot green. Then we start all over with the next atom. Half of the atoms will contribute to the set of red spots, half to the green ones.

What kind of pattern should emerge on the screen? Eventually all the red spots together exhibit the interference pattern that one would obtain by the two slits alone, without the which-way detector cavities. Thus, erasing the telltale photon returns the interference pattern. In contrast, the collection of green spots shows the complementary pattern: green crests at the location of red troughs, and vice versa. A black-and-white photograph of the screen would not show the interference pattern. Only by correlating the atoms to the reaction of the photosensor is the interference pattern literally brought to light.

In using QM's analogy of intersecting curves on a plane, one could state that during erasure it is recognized that the upper and lower curves consist of red and green branches. These branches are displaced to corresponding planes, so that the red branches interfere with each other. The same holds for the green ones. But because the red ones do not interfere with the green ones, one must keep them apart in order to identify the interference pattern.

Because it takes place after an atom hits the screen, erasure certainly can have no influence on the atomic motion. The choice falls to the experimenters: Do we want to know whether we registered an "upper slit" atom or a "lower slit" one, or are we interested in the complementary property of having excited the microwave-photon sensor (red) or not (green)? Both at the same time are not available: attaching labels like "upper slit" and "red" is impossible, just as the description "up and left" is unavailable when describing the magnetic properties of a silver atom. Complementarity is at work again.

The erasure scheme just described has the advantage of being readily laid out and analyzed. The experiment itself is a different matter and is still a couple of years away. The primary hurdle is the fragility of the excited atoms, which are easily destroyed.

The first erasure experiment may not use atoms as interfering objects at all. In fact, many of the most advanced interferometers do not even rely on slits. Researchers are using photon pairs as the interfering objects to study these ideas. They include investigators in the laboratories of Raymond Y. Chiao of the University of California at Berkeley, James D. Franson of Johns Hopkins University, Leonard Mandel of the University of Rochester, Yanhua Shih of the University of Maryland and Anton Zeilinger of Innsbruck University. The recent NIST experiment mentioned earlier involves a recoil-free which-way detector for light scattered by two atoms, rather than by two slits. A modification of this setup could yield a quantum erasure experiment.

Yet we do not expect the results to confound quantum mechanics. The quantum world has carefully protected itself against internal contradictions, and an unexpected finding would more likely indicate that something is wrong with the apparatus than with quantum mechanics. Despite human experimental ingenuity, nature will undoubtedly stay at least one step ahead.

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Making Environmental Treaties Work

Many agreements aim to protect the global environment. But actually making them do so requires innovative approaches

by Hilary F. French

According to international law, the environment appears quite secure. Some 170 treaties, most of them drafted in the past 20 years, safeguard virtually every aspect of life on the earth. Air, land and sea and their myriad creatures are protected from hazardous waste, deforestation, overfishing, overhunting and most other possible threats to their well-being.

This perfect world remains largely the province of paper. Inherent weaknesses in rules of international diplomacy render many environmental treaties virtually meaningless. Because a systematic overhaul of the intergovernmental system—specifically the modus operandi of the United Nations—is unlikely, many negotiators have sought creative ways to toughen these accords.

The effectiveness of environmental agreements is perhaps hindered most by the tradition that international decisions be unanimous. Thus, the final draft of treaties often satisfies the wishes of the most reluctant countries. For instance, more than 100 governments at the U.N. Conference on Environment and Development (UNCED) held in Rio de Janeiro in June 1992 agreed on paper to battle climatic change. But at the insistence of the U.S., negotiators reworded the document so that it only urged—but did not require—countries to stabilize their carbon dioxide emissions at 1990 levels by the year 2000.

So that a few recalcitrant countries do not undermine the good intentions of others, some treaties include innovative voting mechanisms. When a consensus cannot be reached, they allow a qualified majority to add stronger measures. Often the amendment need not be ratified. All members are legally bound to it unless they expressly object, and in a few cases dissonant countries are not even afforded the option to withdraw.

The Montreal Protocol, drafted in 1987 to halt the destruction of the ozone layer by chlorofluorocarbons (CFCs), includes provisions governed by such rules. The agreement permits two thirds of the 140 participating nations—who together constitute majorities of both developed and developing countries—to vote stricter controls into the protocol. In 1990 the agreement was strengthened to eventually prohibit all members from producing CFCs.

The outright ban, which responded to new scientific information on the rate of ozone depletion, replaced the protocol's original requirement that production of CFCs be merely cut in half. Two years later the target date for this goal was moved from the year 2000 to January 1, 1996. In both cases, consensus was reached. Undoubtedly, though, the fact that reluctant countries knew they would be outvoted heavily influenced their decisions.

Reaching strong accords in this way, while not easy, is often less difficult than monitoring and enforcing them. Most international treaties provide for few penalties—and those that do rarely impose them. But simple methods such as peer pressure have recently emerged as powerful enforcement tools. Some treaties ask nations to report on how they have tried to fulfill their promises and how well these attempts have worked. When this information is made available, nongovernmental organizations (NGOs) can use it to embarrass remiss governments publicly. Peter M. Haas, a political scientist at the University of Massachusetts at Amherst, found that the environmental group Greenpeace used such data to expose Britain's discharge of coal ash into the North Sea in January 1990, a violation of the spirit (if not the letter) of the 1972 Oslo Convention on ocean dumping.

Beyond moral persuasion and public embarrassment, trade incentives can secure compliance. Members of the Montreal Protocol are forbidden to purchase CFCs or products containing them from nations that have not agreed to the treaty. These provisions were an important factor in convincing more than 100 countries to join in the accord.

World trade rules, however, threaten to jeopardize this use of economic restrictions. In October 1991 and again in May 1994, panels convened under the General Agreement on Tariffs and Trade (GATT) concluded that provisions set by the U.S. Marine Mammal Protection Act—namely, an embargo on importing tuna from Mexico, whose fishermen were killing many dolphins while netting the commercial fish—violated GATT. The ruling sets a dangerous precedent: if GATT can preclude countries from

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PAWS, SKULLS, TEETH, horns and antlers from endangered species, including tigers and bears, are still sold at Taichilek Market in Burma. Across the border in Thailand, traffic of these illegal goods incurs strict punishment. Officials in Thailand imposed tougher penalties on traders in 1991, after the Convention on International Trade in Endangered Species (CITES) banned the purchase of wildlife products from that country.

restricting trade with nations that harm the global environment, then there are few means of inducing offending countries to change their ways.

"Soft laws" are one alternative to the options just described. These declarations can sometimes bring about more rapid action than do hard, binding agreements. Paradoxically, because countries are not legally obligated to adhere to these commitments, they are often more willing to make them. International agencies, sympathetic nations and NGOs can encourage soft laws through funding decisions and public campaigns. Soft laws tend to establish certain expectations—or create an international mindset—that can then form the basis for more permanent agreements.

Agenda 21, a document more than 500 pages long on sustainable development that emerged from the Rio conference, is one example. It offers policy recommendations on such daunting issues as alleviating poverty and providing clean water around the globe. The ambitious guidelines challenge the financial and technical resources of many nations, but the hope is that they will inspire national governments and international agencies to make sweeping policy changes whenever they can. Already more than 100 nations have set up sustainable development commissions designed to translate Agenda 21 into action. The U.N. has formed a Commission on Sustainable Development charged with overseeing the implementation of the Rio accords.

Agenda 21 also strongly encourages the work of citizens' groups, business coalitions and other NGOs. Because such groups do not use the obfuscating jargon of diplomacy, they can often explain failures in compliance and in negotiations more clearly than can government representatives. They also frequently have access to crucial information that governments overlook or lack. For these reasons, such groups have played an increasingly important role in international environmental talks. In light of the contributions NGOs made at the Rio conference, the new Sustainable Development Commission has accredited more than 500 organizations to participate in its activities.

Whether an agreement be soft or hard, developing nations often find it impossible to act on the accords they sign. Redressing this imbalance will depend in large part on providing financial and technical assistance to developing nations—and ensuring that funds are well spent.

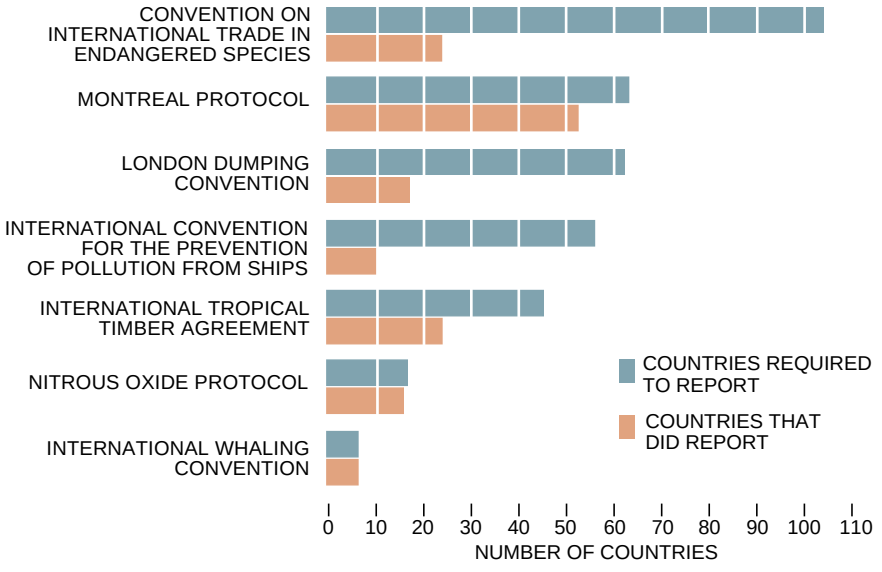
Before that can happen, however, the international community needs to develop better means for securing and dispensing such help. The UNCED secretariat estimated in 1992 that developing countries would need a total of $125 billion in aid every year to implement Agenda 21—more than twice the amount of current development assistance. In Rio, industrial governments promised to give top priority to Agenda 21 goals when figuring their existing aid budgets, but they offered scant new funding.

To administer help to protect the global environment, the Rio signatories voiced support for expanding the Global Environment Facility (GEF), an institution formed as a pilot project in 1990 under joint management of the World Bank, the U.N. Environment Program and the U.N. Development Program. In fact, they designated the GEF as an interim funding mechanism for the climate convention and the treaty to protect biological diversity that were forged in Rio. Governments agreed this past March to make the GEF permanent and to replenish it with $2 billion over the next three years.

All the same, the GEF is a controversial operation. Many developing countries and NGOs have distrusted its close association with the World Bank. NGOs maintain that the bank has long ignored local people in its large development projects. In addition, developing countries resent the fact that the bank distributes voting power according to monetary contributions. In the hope of overcoming these limitations, the March agreement altered the facility's governance arrangements so that it will enjoy greater independence from the World Bank than it did in its pilot phase. The GEF's voting system now gives greater weight to recipient countries as well. Nevertheless, given these reforms, members of the biodiversity and climate conventions are likely to agree to use the GEF as their permanent funding arm.

Funding, soft laws, trade incentives, peer pressure and majority voting practices could all be used more effectively if individual governments were willing to recognize a single international authority charged with negotiating and implementing most environmental treaties. Organizations such as the U.N. Environment Program or the Commission on Sustainable Development could be granted this task, or a new agency could be formed. A centralized operation could promote constructive cooperation between different treaty bodies that share similar goals and enable NGOs to participate more fully in negotiations—benefits hindered by the current process.

Indeed, the existing system for designing and implementing environmental treaties involves a diffuse collection of U.N. offices and quasi-independent government environmental committees scattered around the globe. The General Assembly tends to create an international committee—such as the International Negotiating Committee on Climate Change—every time a major agreement is up for discussion. The results are then passed on to other institutions to be administered. A group of treaty members, called the Conference of the Parties, meets periodically and formal-



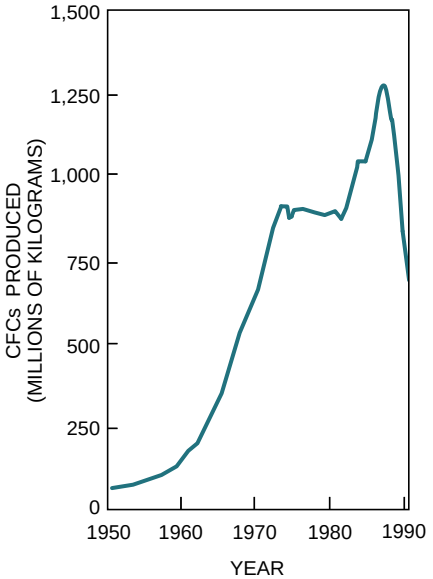
SELF-REPORTING by individual countries about their own progress in adhering to environmental treaties is not a sufficient monitoring tactic. Few nations submit the reports or data that any one treaty demands from them. Even when they do, the accounts frequently include very few details.

Curbing Chlorofluorocarbons

Under the Montreal Protocol, global consumption of ozone-destroying chlorofluorocarbons (CFCs) dropped from 1.3 billion kilograms in 1988 to some 510 million kilograms in 1993 (*graph, left*). To encourage this trend, the treaty has banned CFC use in the industrial world after January 1, 1996. As a result, many scientists are investigating less harmful alternatives. Thermoacoustics, a technique that uses sound to produce cooling, may be one replacement for CFCs used in refrigeration. The photograph (*right*) shows Steven Garrett of the Naval Postgraduate School displaying his prototype of a thermoacoustic refrigeration system.

Chemical substitutes, including hydrofluorocarbons, show some promise as well. Because these substances do not contain chlorine, they do not damage the ozone layer. But they may be greenhouse gases, as are CFCs.

The protocol signatories further established a $240-million fund in 1990 to help developing countries implement alternatives to CFCs before 2006, an extended deadline. An additional $510 million was pledged two years later. So far only $226 million has been collected. Still, had the treaty not provided this money, countries such as India and China most likely would not have participated—and their use of CFCs would have continued to rise.



SOURCE: Du Pont,Worldwatch estimates

ly oversees the implementation of their agreements. A smaller "implementation committee" often reports to this group.

Secretariats, too, provide crucial support to these governmental groups, but they are hampered by insufficient funds and staff. For instance, the Montreal Protocol secretariat employs just five people and has a total budget of $2.5 million, less than 1 percent of the amount allotted to the U.S. Environmental Protection Agency for air-quality operations. In some cases, this diffusion may have contributed to success. Small offices can sometimes tackle specific jobs better than can large bureaucracies. But more often this administrative structure—or lack thereof—has led to inefficiency and delays.

As nations contemplate ways to consolidate and strengthen this system, they can borrow strategies from other fields of international relations. The International Labor Organization offers a sound model. The organization provides a forum where participants can negotiate international standards on issues such as workplace safety, and it reviews whether members are complying with these standards. Furthermore, its unusual tripartite governing structure gives equal standing to business, government and union representatives.

Creating international treaties and institutions strong enough to reverse the relentless momentum of global ecological decline is no simple task. To do so, sovereign nations must overcome their long-standing reluctance to cede power to international organizations, and these organizations must open their doors to nongovernmental participants. In the final analysis, though, it is in the self-interest of all countries to take these steps, given that nothing less than the habitability of the planet is at stake. Just as the world has been transformed by the border-erasing effects of technology, pollution, trade and travel, so must be the process of international governance itself.

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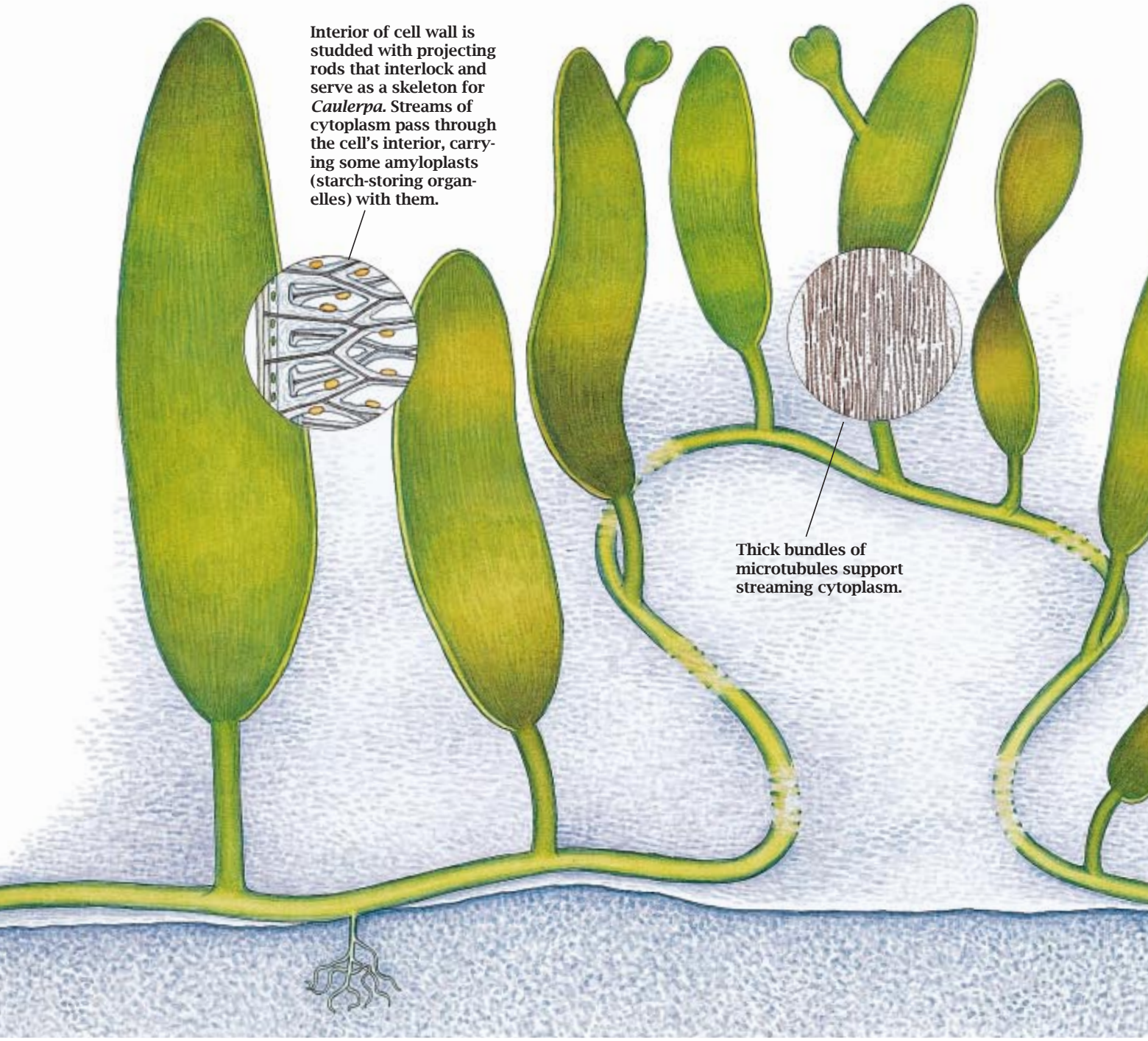
Caulerpa

This tropical alga is the world's largest single-celled organism. Yet it differentiates into a complex structure of leaves, stems and roots

by William P. Jacobs



Swimming with faceplate and snorkel over a lagoon where *Caulerpa* grows, you would be unlikely to notice anything unusual about this green plant protruding from the coral sand. It looks much like the sea grasses that also thrive in warm, shallow seas around the world. The horizontal stem and branched, leafy form of *Caulerpa* resemble those of many higher plants, such as the bracken fern or the strawberry plant. But an internal examination reveals the alga's uniqueness. *Caulerpa* is the largest, most differentiated single-celled organism in the world. No cell wall or membrane separates each of the many nuclei and their adjacent cytoplasm from the others.

This unusual, unexpected organism remains unknown to most biologists, although it was first described almost 150 years ago. By its very existence, *Caulerpa* is a gauntlet flung in the face of biological convention. No single cell should be capable of growing to a length of two or three feet, much less differentiating into separate organs, such as a stem, roots and leaves. The questions raised by *Caulerpa*'s peculiar structure have intrigued the few biologists who have investigated its development.

All other organisms of such size and complexity consist of hundreds of thousands of microscopic cells. In each cell, a membrane encloses a limited volume of cytoplasm and a single nucleus. Most plants also secrete a cell wall outside the membrane. So ubiquitous is this organization that between 1838 and 1839 Matthias Schleiden of the University of Jena in Germany and Theodor Schwann of the University of Louvain in Belgium enshrined their observations in the form of the "cell theory." They posited that the cell is the basic unit of biological structure and function in both plants and animals. In the many decades since then, thousands of observations have converted the cell theory into a broadly accepted generalization that forms the basis of current ideas about biological development. Those ideas attribute the microscopic size of the average cell to the limited range of influence of the enclosed nucleus over its surrounding cytoplasm.

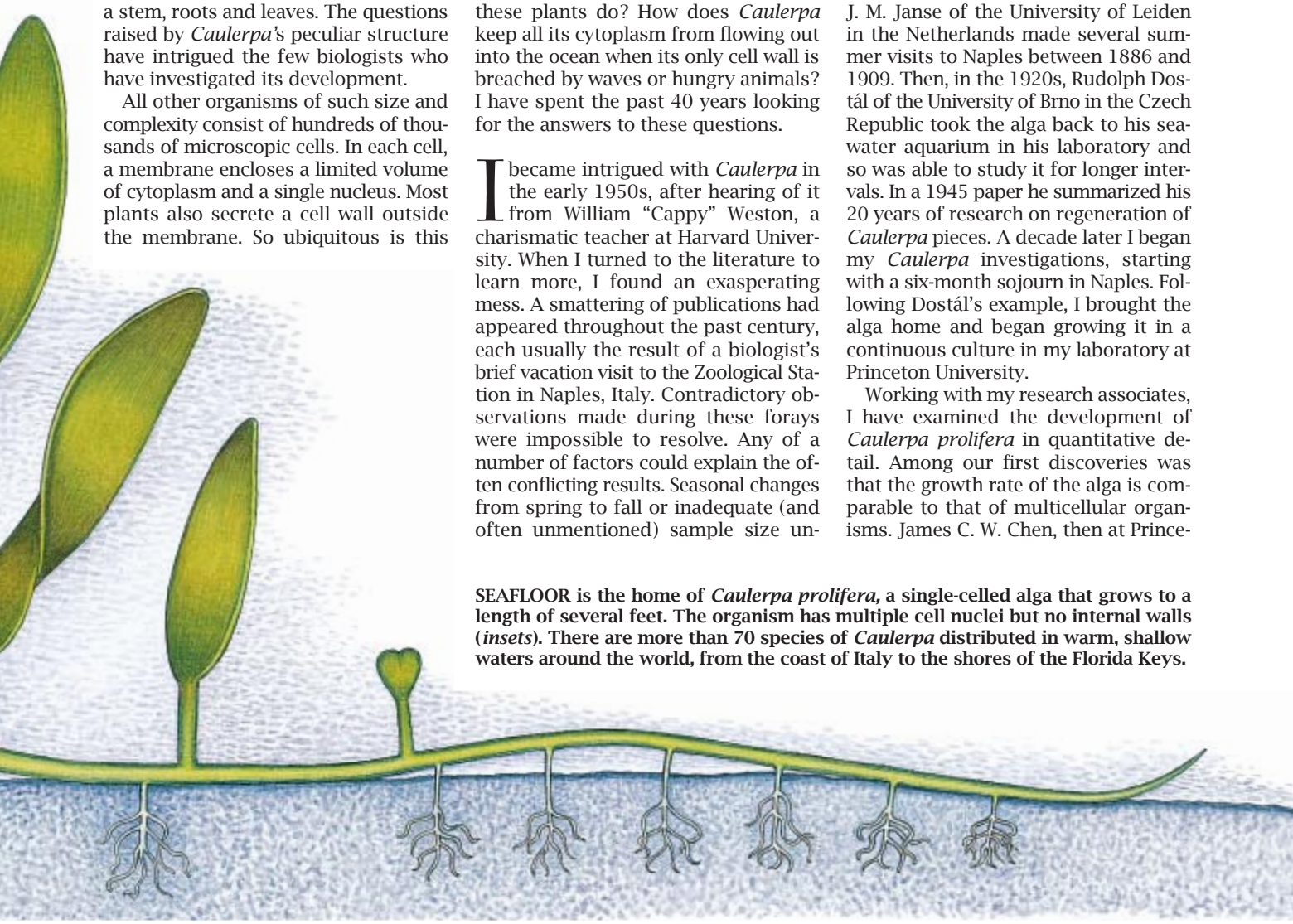
So how can *Caulerpa* grow to its macroscopic size and complexity without the compartmentalization that other organisms seem to need? Is *Caulerpa* handicapped by its single-celled form? Do hormones coordinate its development and regeneration, as they do in higher plants? If so, does *Caulerpa* employ the same chemical messengers as these plants do? How does *Caulerpa* keep all its cytoplasm from flowing out into the ocean when its only cell wall is breached by waves or hungry animals? I have spent the past 40 years looking for the answers to these questions.

I became intrigued with *Caulerpa* in the early 1950s, after hearing of it from William "Cappy" Weston, a charismatic teacher at Harvard University. When I turned to the literature to learn more, I found an exasperating mess. A smattering of publications had appeared throughout the past century, each usually the result of a biologist's brief vacation visit to the Zoological Station in Naples, Italy. Contradictory observations made during these forays were impossible to resolve. Any of a number of factors could explain the often conflicting results. Seasonal changes from spring to fall or inadequate (and often unmentioned) sample size undoubtedly affected the findings. The visitors rarely had time to repeat any experiment. And, of course, many worked before the days of statistical analyses, leaving the reader to guess at the reality of differences reported.

Only after two European biologists decided to investigate *Caulerpa* over longer periods could one have some confidence in the published reports. J. M. Janse of the University of Leiden in the Netherlands made several summer visits to Naples between 1886 and 1909. Then, in the 1920s, Rudolph Dostál of the University of Brno in the Czech Republic took the alga back to his seawater aquarium in his laboratory and so was able to study it for longer intervals. In a 1945 paper he summarized his 20 years of research on regeneration of *Caulerpa* pieces. A decade later I began my *Caulerpa* investigations, starting with a six-month sojourn in Naples. Following Dostál's example, I brought the alga home and began growing it in a continuous culture in my laboratory at Princeton University.

Working with my research associates, I have examined the development of *Caulerpa prolifera* in quantitative detail. Among our first discoveries was that the growth rate of the alga is comparable to that of multicellular organisms. James C. W. Chen, then at Prince-

WILLIAM P. JACOBS has written a dozen or so papers on giant single-celled organisms. He has also studied the hormones of land plants, their transport in shoots and roots, and their role in controlling differentiation, regeneration, growth and longevity. He received both his A.B. and Ph.D. from Harvard University. In 1948 he started as an assistant professor of biology at Princeton University, and he is now professor emeritus there. A Guggenheim Fellow, Jacobs has served on numerous committees, including advisory panels for the National Aeronautics and Space Administration.



SEAFLOOR is the home of *Caulerpa prolifera,* a single-celled alga that grows to a length of several feet. The organism has multiple cell nuclei but no internal walls (*insets*). There are more than 70 species of *Caulerpa* distributed in warm, shallow waters around the world, from the coast of Italy to the shores of the Florida Keys.

ton, and I took daily photographs to measure its growth. We found that the rhizome (the cylindrical stem of the plant) grew roughly 4.6 millimeters a day, a rate similar to that observed for stems of several multicellular plants.

The pattern of *Caulerpa*'s development, however, differs from the more complex growth seen in higher plants. Most multicellular plant organs mature at rates that vary with time, but *Caulerpa* elongates at a constant speed. In multicellular plants, some individual cells that contain multiple nuclei (as *Caulerpa*'s large cell does) also demonstrate this pattern. Thus, extended periods of constant growth may be typical of multinucleated cell structure, common both to *Caulerpa* and to certain cells in higher plants.

We were surprised to find that the elongation rates of all three organs of *Caulerpa*—stem, root and leaf—do not differ significantly from one another. In higher plants, the speed of growth varies from organ to organ. Our results from *Caulerpa* suggest that whatever factor limits development of the stem must pervade the entire plant so that it also limits the growth of the other two types of organs.

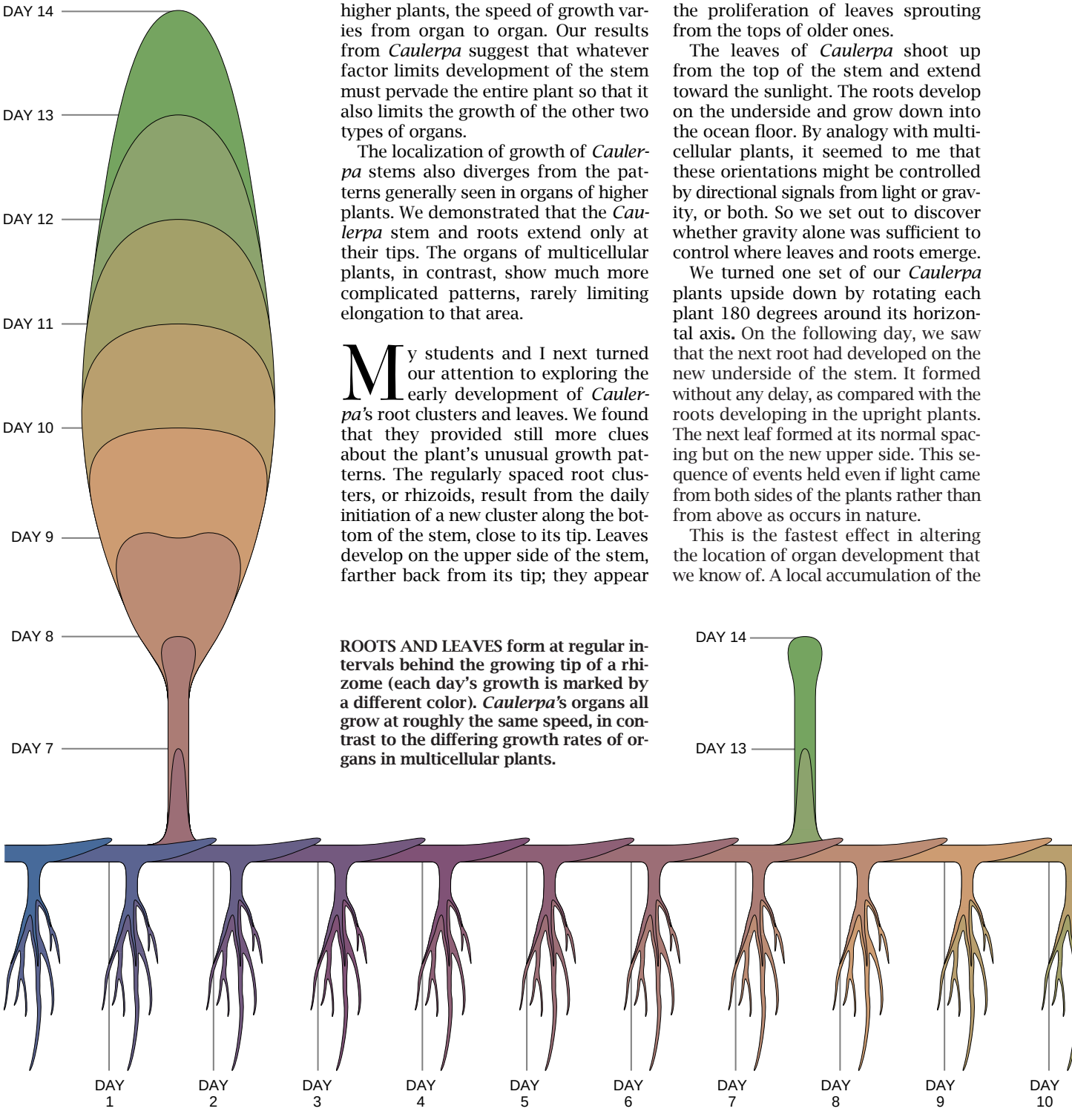
The localization of growth of *Caulerpa* stems also diverges from the patterns generally seen in organs of higher plants. We demonstrated that the *Caulerpa* stem and roots extend only at their tips. The organs of multicellular plants, in contrast, show much more complicated patterns, rarely limiting elongation to that area.

My students and I next turned our attention to exploring the early development of *Caulerpa*'s root clusters and leaves. We found that they provided still more clues about the plant's unusual growth patterns. The regularly spaced root clusters, or rhizoids, result from the daily initiation of a new cluster along the bottom of the stem, close to its tip. Leaves develop on the upper side of the stem, farther back from its tip; they appear less often and with less regularity than do root clusters. In my cultured *C. prolifera* sample, collected from the Florida Keys, a new leaf formed every five or six days. The leaf initially resembled the pointed cylinder of a new root or stem, but the tip soon grew a flattened, heart-shaped blade and unfolded into a roughly rectangular form four to five inches long. Often another new leaf started growing near the top of the primary one once it had matured. In fact, the species name *prolifera* derives from the proliferation of leaves sprouting from the tops of older ones.

The leaves of *Caulerpa* shoot up from the top of the stem and extend toward the sunlight. The roots develop on the underside and grow down into the ocean floor. By analogy with multicellular plants, it seemed to me that these orientations might be controlled by directional signals from light or gravity, or both. So we set out to discover whether gravity alone was sufficient to control where leaves and roots emerge.

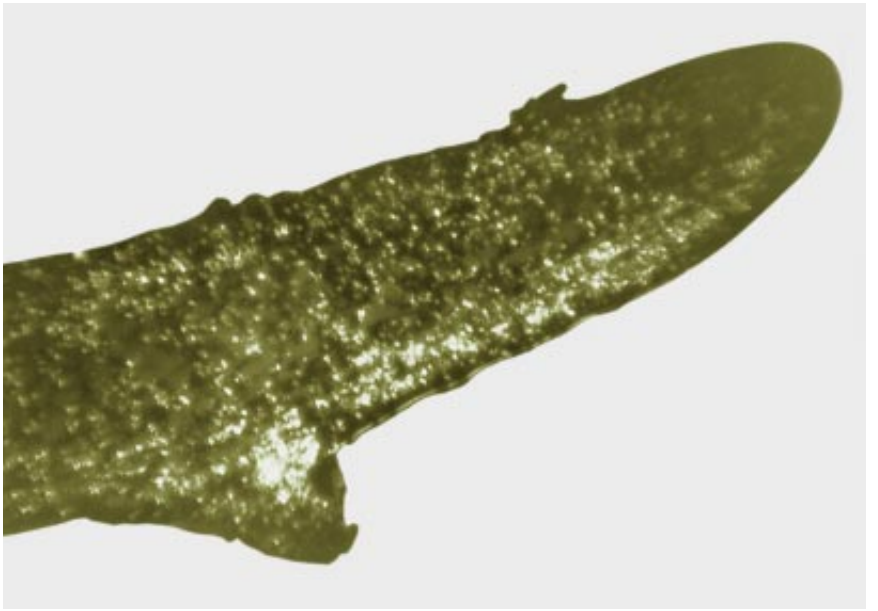
We turned one set of our *Caulerpa* plants upside down by rotating each plant 180 degrees around its horizontal axis. On the following day, we saw that the next root had developed on the new underside of the stem. It formed without any delay, as compared with the roots developing in the upright plants. The next leaf formed at its normal spacing but on the new upper side. This sequence of events held even if light came from both sides of the plants rather than from above as occurs in nature.

This is the fastest effect in altering the location of organ development that we know of. A local accumulation of the



ROOTS AND LEAVES form at regular intervals behind the growing tip of a rhizome (each day's growth is marked by a different color). *Caulerpa*'s organs all grow at roughly the same speed, in contrast to the differing growth rates of organs in multicellular plants.

starch-storing structures inside cells known as amyloplasts apparently triggered the change. Michael B. Matilsky, then at Princeton, and I found that within six hours of inverting the plants there were 54 percent more amyloplasts on the new underside of the stem tip than before. We also noticed that the increased number of these organelles accumulated where the new root cluster would later develop. A corresponding decrease in the number of amyloplasts occurred on the upper side of the stem tip. Apparently the amyloplasts drifted down through the cytoplasm and settled to the bottom of the stem. Farther back from the tip, in the areas where roots do not develop, there was no redistribution of the organelles after inversion. Our results indicate that *Caulerpa* uses amyloplasts to respond to gravity just as higher plants do. Yet its reaction to gravity is somewhat different. Instead of changing only the direction of growth, gravity initiates the development of organs in novel locations on *Caulerpa.*



GROWING SHOOT (shown here in a thin section illuminated by polarized light) orients itself by means of amyloplasts. These starch-storing structures (visible as bright spots) settle onto the bottom side of the shoot as a result of gravity, and root clusters form in response to their accumulation.

Any laboratory study of *Caulerpa* originally required the removal of some alga from the ocean. How does the single-celled plant withstand being torn open by grazing fish or sadistic biologists such as myself? As soon as a leaf or stem is cut, some cytoplasm does stream out into the seawater as one would expect. But a wound plug forms, and a new wall is laid down behind it, sealing off the remainder of the cell. Such self-sealing allows *Caulerpa* to survive substantial loss of leaf area and permits the process of regeneration to begin. Indeed, regeneration of an entire *Caulerpa* plant from a piece of leaf or stem is not uncommon.

Regenerating pieces of *Caulerpa* can often be found in the sea. For many years, the lack of any evidence for other forms of reproduction led biologists to consider regeneration as perhaps the only way the plant reproduced. But in the late 1920s Dostál observed that old leaves formed tiny projections from which cytoplasm oozed. Along with the cytoplasm, the plant released flagellated cells capable of movement. By the end of the 1930s several people had observed sexual reproduction—the fusion of pairs of such cells—in different *Caulerpa* species. Nevertheless, tearing and subsequent regeneration still appear to be the most probable way that *Caulerpa* reproduces in nature.

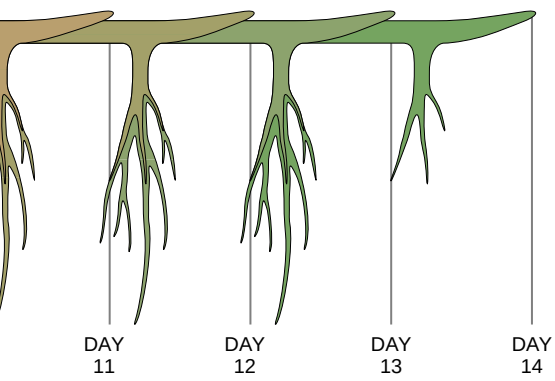
An experimental version of a wound plug permits closer study of *Caulerpa*'s regeneration mechanisms. In 1904 Janse discovered that pressing together opposite walls of the cell and clamping them would lead in a few days to the development of a new cell wall known as a pressure wall. More recently I have found that this protective response happens much faster, on the order of minutes. We can then cut the alga apart at pressure walls with little loss of cytoplasm and observe the regeneration of small pieces of *Caulerpa.* Such pieces cannot regenerate otherwise, because there is not enough cytoplasm remaining to reorganize the cellular material and trigger growth.

Regeneration of the whole plant from large pieces occurs naturally; laboratory studies indicate an unexpected directionality to the process. For example, when we cut a 50-millimeter-long piece from a *Caulerpa* leaf, an entire plant regenerated in a particular polar sequence [*see illustration on next page*]. First, roots developed at the cut mad closer to the stem. Later, a new stem grew only a few millimeters away from this cut. On the outer half of the leaf section, a new leaf began to regenerate. Most organisms exhibit such polarity in normal development as well as in regeneration (if they are capable of that). But in multicellular plants, such regeneration is usually attributed to the polar movement of growth substances through thousands of cells. Demonstration of a similar trait in single-celled *Caulerpa* surprised many.

We also used pressure walls to alter developmental pathways in regenerating pieces of *Caulerpa.* A transverse pressure wall made just below a growing leaf places the bud physiologically above the base of the section. Because the sprout sits near the bottom of its stem, the little nubbin that would have grown out as a leaf will adjust to become a root. Similarly, a bud starting as a root can often be induced to change to a leaf instead.

In view of the striking effect of gravity on the development of the stem tip, we also wondered how gravity might affect regeneration. Because leaves also contain the starch-storing amyloplasts, perhaps their gravity-induced resettling could alter regeneration patterns as well. But the pattern and number of regenerated organs were unchanged by inverting the leaf pieces. For instance, roots regenerated exclusively on the original stem end of the leaf piece, whether that end was up or down relative to gravity.

It is still unclear what determines the



directionality of regeneration of pieces of *Caulerpa.* The most likely candidate is the striking cytoplasmic streaming. Strands of moving cellular material are easily visible in the leaves, even under the low magnification of a dissecting microscope. The broad channels run roughly parallel to the long axis of the leaf, and the direction of the flow can be opposite in adjacent strands. The streams may move organ-forming substances in a particular direction, thus substituting for the myriad direction-specific transporting cells of higher plants.

If one ignored the fact that these regenerating fragments are simply multinucleated pieces of a single cell, *Caulerpa*'s polar regeneration seems much like the well-known regeneration of pieces of other plants. Do *Caulerpa* species—and by extension do other algae—use hormones to coordinate development and regeneration? If so, are the hormones chemically related to those used by presumably more highly evolved plants?

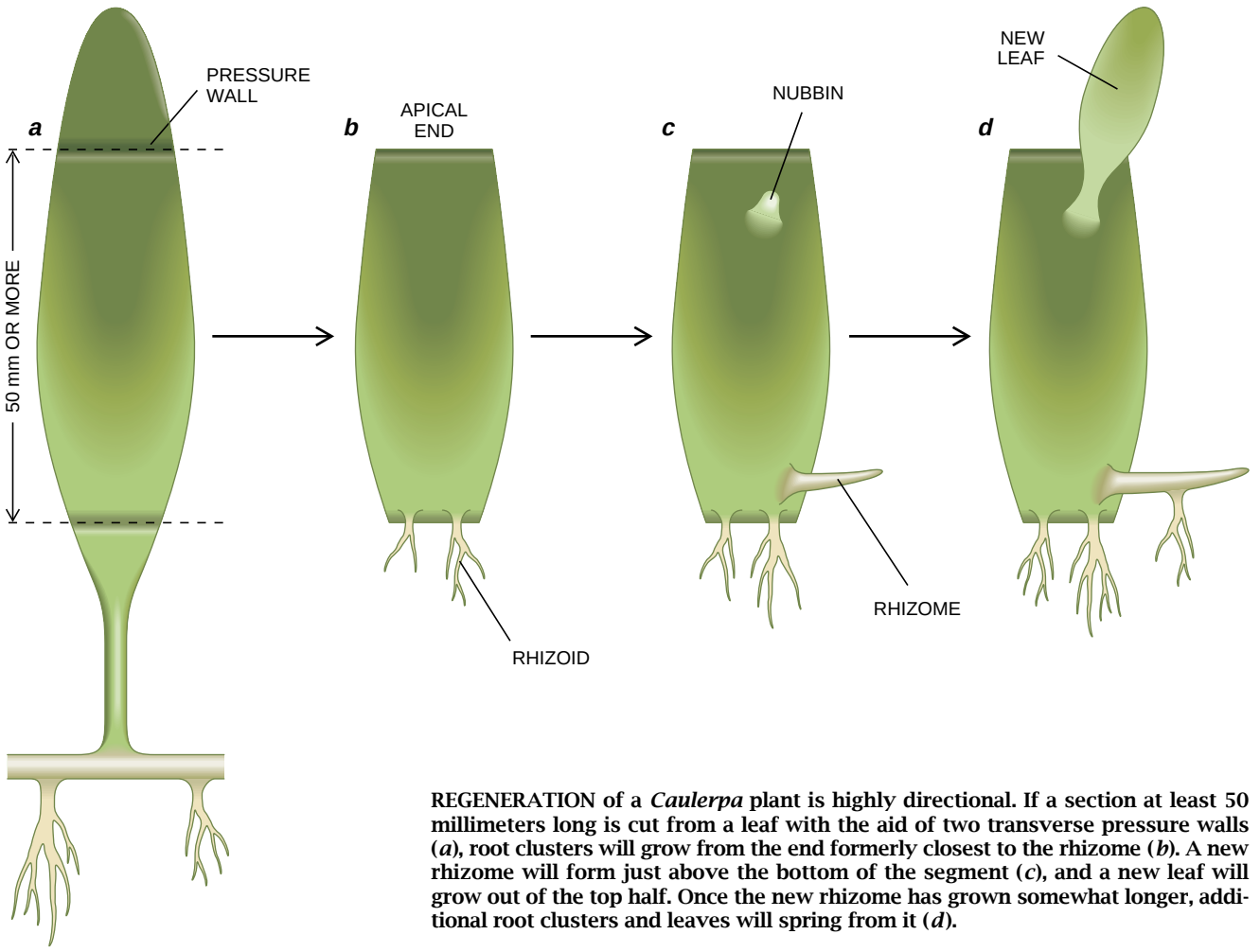
The hormone indole-3-acetic acid (IAA) helps to control regeneration in multicellular plants. We have recently documented conclusively, using gas chromatography and mass spectrometry, that IAA is present in *Caulerpa.* Work done earlier by Ned Kefford and Arun Mishra of the University of Hawaii, Clinton J. Dawes of the University of South Florida and Henry Augier of the University of Aix-Marseille II in France showed that addition of IAA to the seawater in which *Caulerpa* thrives stimulates its growth patterns. But even with evidence that IAA is present and active in *Caulerpa,* we still wondered if the action of IAA depended on selective distribution of the hormone, as it does in multicellular plants. No evidence exists for the formation of pockets of IAA within *Caulerpa.* To the contrary, if IAA labeled with radioactive carbon is added to the tip of a *Caulerpa* leaf, the radioactivity—and presumably IAA—spreads uniformly along the stem.

Gibberellins are another class of growth hormones active in many multicellular plants. Early studies reported that extracts of *Caulerpa,* when added to higher plants, triggered growth patterns just as pure gibberellins do. But my recent, more extensive analysis using mass spectrometry revealed no known gibberellin or gibberellin metabolite in such *Caulerpa* extracts. Was the gibberellinlike activity seen in *Caulerpa* caused by a chemical that did not have the basic structure of the compound but that happened to show similar activity? Or was the activity from yet another, as yet unknown, gibberellin that could be added to the already long list of more than 70 of these compounds?

We surmise that hormones produce their effects in *Caulerpa* by interaction with substances or organelles whose distribution does vary. For example, the amyloplasts that accumulate at the bottom of the growing stem tip may promote root formation by working in concert with either IAA or the gibberellinlike substance. The interaction maintains gravity-directed growth and initiates root formation at specific sites.

Although the details of many of *Caulerpa*'s hormonal interactions are unclear, most of its organelles are known and resemble those of higher plants. In the peripheral cytoplasm, chloroplasts used in photosynthesis and many small nuclei stream along with the starch-storing amyloplasts. A large cytoplasmic sac, or vacuole, of convoluted shape sits in the center of the cell.

The only visibly unusual features are



REGENERATION of a *Caulerpa* plant is highly directional. If a section at least 50 millimeters long is cut from a leaf with the aid of two transverse pressure walls (*a*), root clusters will grow from the end formerly closest to the rhizome (*b*). A new rhizome will form just above the bottom of the segment (*c*), and a new leaf will grow out of the top half. Once the new rhizome has grown somewhat longer, additional root clusters and leaves will spring from it (*d*).

***CAULERPA MEXICANA* is one of several species of the alga whose leaves are deeply fringed. The roots attach to coral fragments or rocks on the bottom of lagoons. Global distribution of *Caulerpa* species (each recognizable by its distinctive form) makes it clear that a single-celled structure is no bar to successful competition with "higher" plants.**

numerous rods that project in from the cell wall that encloses the whole plant. The rods run both perpendicularly and parallel to the long axes of the organs, forming a dense, interconnecting network. Janse counted 850 rods per square millimeter in the older part of the leaf and five times as many in the tip. The rods are sheathed in cytoplasm, and their density throughout the organism partially compensates for the lack of cell membrane surface. They appear to serve as a supporting skeleton for the huge cell. A few investigators have suggested that they also serve as conduits to and from the surrounding sea.

Dinkar D. Sabnis, working with me at Princeton, looked at *Caulerpa* with an electron microscope and found a similarly unusual distribution of tiny fibers known as microtubules. We determined that sheets or thick bundles of microtubules, evenly spaced and uniformly oriented, were arrayed in the internal layer of cytoplasm where streaming occurs. Our suggestion that microtubules were related in some way to streaming was later confirmed by other researchers. Inoculating the plant with the alkaloid compound colchicine disassembled the microtubules (as expected from research on various multicellular organisms) and stopped the streaming.

Many of the riddles posed by *Caulerpa*'s existence are now understood. Despite its uniquely large, single-celled organization, *Caulerpa* competes successfully with multicellular organisms that inhabit the world's warmer seas. It grows as fast as many of its land-based, multicellular, distant relatives. *Caulerpa* has proved so hardy that one species is raised commercially in seawater pens in the Philippines for use in fresh green salads. It readily regenerates entire plants from pieces of stem or leaf and does so in a temporal and spatial pattern resembling that seen in more highly evolved, multicellular plants. The fact that 73 species of *Caulerpa* exist around the world, making them far from rare in the tropical algal flora, suggests that their single-celled construction is not a great handicap.

Musing over the current knowledge we have about *Caulerpa* and the many questions still remaining, I find that evolution has provided more possibilities than we have tended to expect. If *Caulerpa* is this prominent as a large, highly differentiated, multinucleated single cell, what are the ultimate lengths to which this structure could be carried? I can see nothing that would preclude an even larger unicellular organism so long as it lives in the sea. There the buoyant water substitutes for the internal support provided to land plants by their cell walls. Might we one day discover a huge algal equivalent of "Audrey II," the outrageously large Venus flytrap of *The Little Shop of Horrors*?

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The Speed of Write

by Gary Stix, *staff writer*

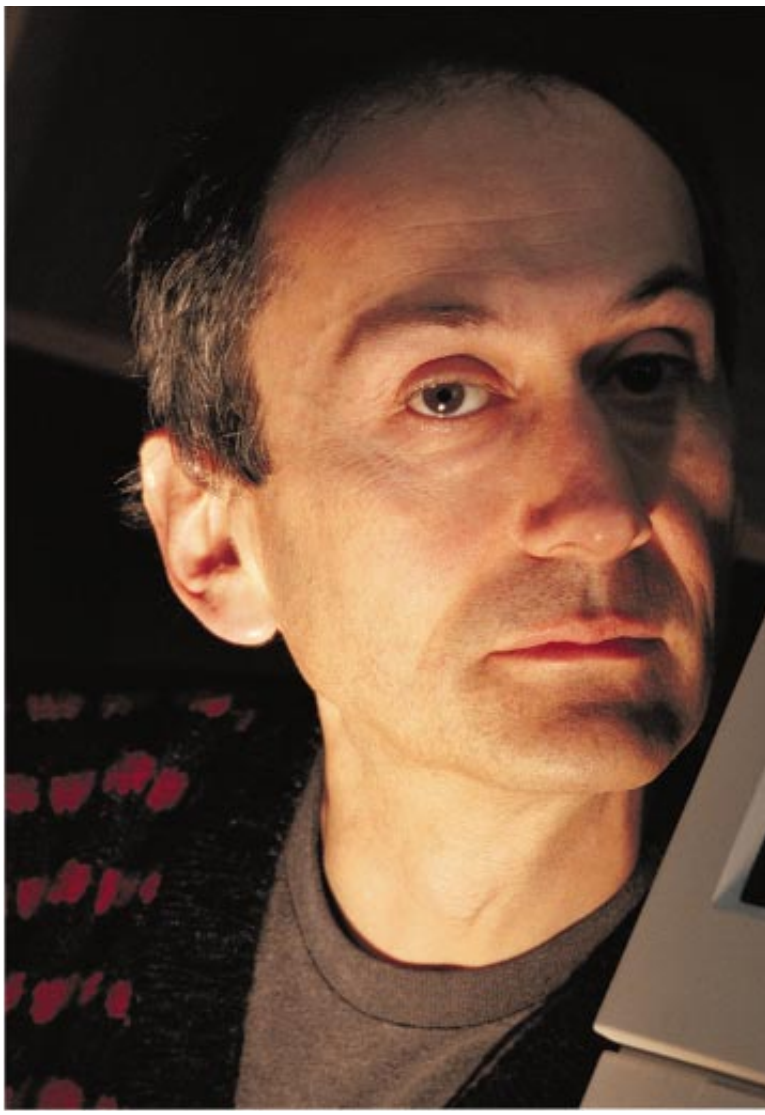
Under a table in a corner of Paul H. Ginsparg's office at Los Alamos National Laboratory, surrounded by piles of scientific papers, a squash racket, dated magazines and the occasional soda can, sits a machine that is quietly changing how science is being done. To the casual observer, it looks like a spare workstation, a Hewlett Packard 9000 not unlike those found in engineering laboratories throughout the country. Yet tens of thousands of scientists around the world pay attention to it every day.

Running on this machine is the product of a project that the bearded 38-year-old physicist has been working on in his spare time for the past three years. Ginsparg, whose loves in life extend to string theory and two-dimensional gravity (reduce space to one dimension, add gravity and stir), has written software that lets other researchers transfer to his computer by way of the Internet the unrefereed copies of research papers, or preprints.

That computer, known by its cryptic Internet address, "xxx.lanl.gov," has become, in effect, a daily wire service for high-energy physics theorists as well as researchers from more than 10 other disciplines, primarily in the physical sciences and mathematics. Every day 20,000 or so electronic-mail messages carry the abstracts of new papers stored in the computer's databases to more than 60 countries. Readers of the summaries then download thousands of copies of the full papers. "It has completely changed how people in the field exchange information," says Steven B. Giddings, an associate professor of physics at the University of California at Santa Barbara. "The only time I look at the published journals is for articles that predate the Los Alamos physics databases."

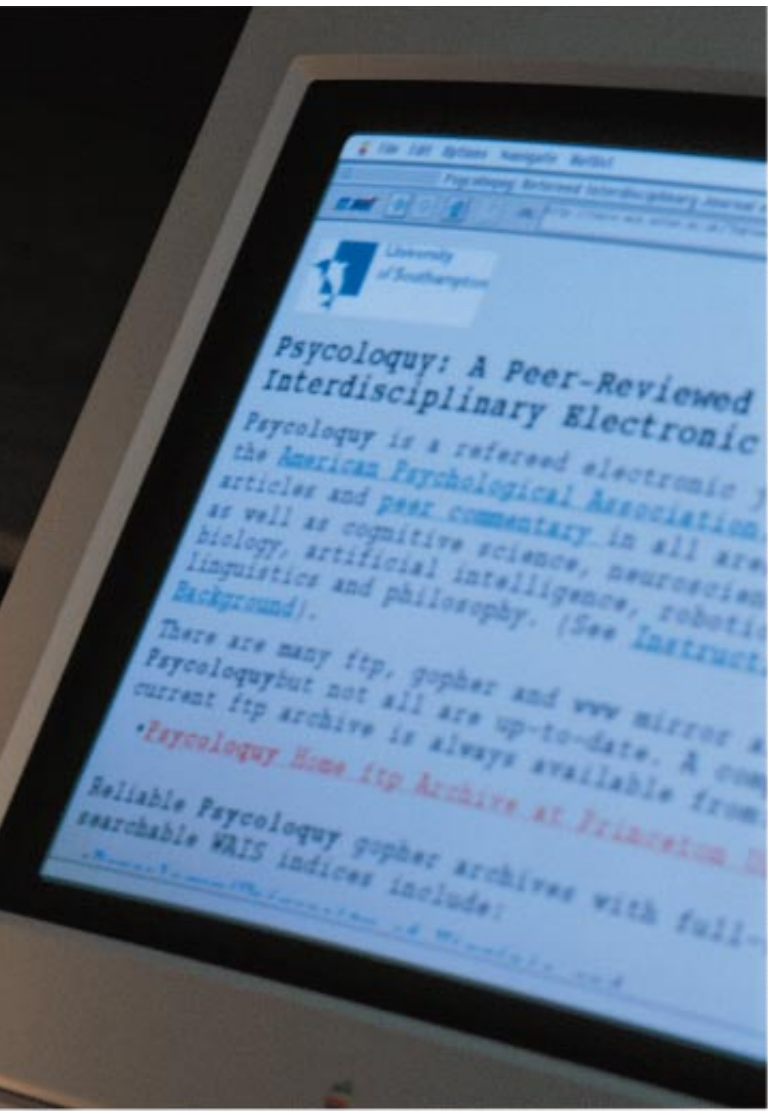
The under-the-desktop machine at Los Alamos represents just one manifestation of what may be a major shift in the way scientists and engineers communicate with one another. The Internet—comprising about 40,000 connected computer networks—has become the world's biggest blackboard.

On subjects from cold fusion to a purported proof for Fermat's Last Theorem, the Internet serves as the medium of choice for conveying news flashes, gossip and quibbles about scientific findings both serious and whimsical. More than just scuttlebutt and self-advertisements travel the network. The Los Alamos machine may represent the future of scientific and technical publishing. If Ginsparg can channel the flood of preprints through some form of peer-review process—one of his next extracurricular undertakings—the traditional paperbound physics journal could become an anachronism.



ELECTRONIC PUBLISHER AND EDITOR Stevan Harnad has become a proponent of low-cost dissemina-

Scientists now transmit reports of their research—from first inspiration to final result—over electronic networks. Even live experiments can be witnessed on-line. Publishers and libraries may never be the same



***tion of scientific and other scholarly work over the Internet. His electronic journal is* Psycoloquy.**

Established publishers could find their livelihoods threatened, if they fail to react quickly.

These developments suggest that scientific communication is becoming less a historical account and more a live record of how thinking on a research problem evolves. It can transcend the bureaucratic publication process of the paper journal in which an article appears months or even years after researchers have moved on to their next project. "Paper is necessary and important but depressingly and maladaptively slow," says cognitive psychologist and electronic journal publisher and editor Stevan Harnad. "A scholar's work could be inspired to much greater heights if it had a faster response, closer to the speed of thought."

In this view, software running on geographically dispersed computers will be able to link together an entire research corpus, from electronic-mail notification of first results to the actual peer-reviewed article to any commentary that follows.

As this phenomenon emerges, the definition of scientific collaboration may change. Commentators on articles virtually become members of research teams. The network even opens the possibility of broader participation in experimental activity itself. Investigators from throughout a discipline can witness an experiment as it takes place—and register their comments for future perusal by other workers.

The growth of the Internet as a means for researchers to distribute their findings is particularly fortunate in light of what some observers think may be a crisis in the traditional system for scientific publication. As scientific disciplines grow and splinter into subdisciplines, each new area of study requires its own journal. Libraries are having trouble keeping up with this information glut.

The wealth of scientific information doubles about every 12 years; stacks of journals can dwarf even a national monument [*see illustration on next page*]. In a widely distributed electronic paper on the demise of the traditional journal, Bell Laboratories mathematician Andrew M. Odlyzko makes the extraordinary estimate that nearly half of the one million papers ever published in mathematics have found their way into print only during the past 10 years.

The costs of producing the journals to hold all these papers are recovered from a tiny subscriber base that consists mostly of university libraries. There are sometimes only a few hundred subscribers, so prices remain high. Journal publication, moreover, can be painfully slow: it can take a year or more to get into print.

The cost and time lag have become a bottleneck for scholarly communication. Subscription

prices for journals more than doubled from the 1985–86 to the 1992–93 academic year [*see right illustration below*]. Percentage increases well outpaced both inflation and library budgets. A year of some journals can now cost about as much as a Ford Escort. Librarians have cut back on subscriptions over the objections of faculty and graduate students. "There is a process of deacquisition by dozens of libraries," says Nobelist Joshua Lederberg of the Rockefeller University, a longtime proponent of electronic distribution of scientific literature. "Soon, one institution will get a publication, and everyone else will borrow it by interlibrary loan. It's an absurdity. There'll be just one copy, and you'll have to pay $1 million for a subscription."

An alternative has emerged. Professors and researchers can compose and typeset their own papers and then distribute a periodical directly through their institution's connections to the Internet, thereby circumventing traditional publishers. The 1994 edition of the *Directory of Electronic Journals, Newsletters and Academic Discussion Lists,* published by the Association of Research Libraries, listed 440 electronic journals and newsletters, up from 110 in 1991, for the first edition of the directory. During the past two years, the number of peer-reviewed titles has quadrupled to about 100. "The figures tell us that in the real world where 'hard choices' must be made, scholars and scientists are in fact mastering the challenge of providing high-quality scholarly information to a very wide audience at no or virtually no charge to the end user," writes Ann Okerson of the Association of Research Libraries.

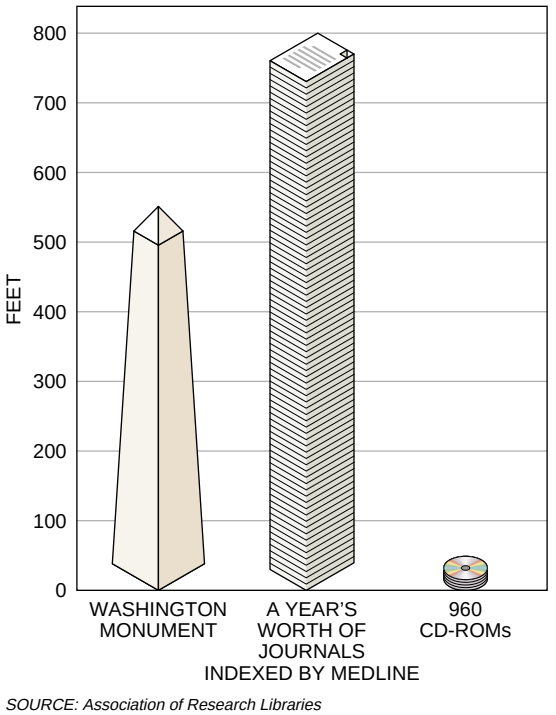
With names like *Postmodern Culture,* most of these journals address themes in the humanities, not the sciences. But scientists and engineers are starting to take their turn. Neil J. Calkin, a professor of mathematics at the Georgia Institute of Technology, and Herbert S. Wilf, a professor of mathematics at the University of Pennsylvania, decided to become members of this new breed of publisher after Wilf read Odlyzko's writing on the demise of traditional journals. The peer-reviewed *Electronic Journal of Combinatorics* has published since April, gaining enthusiastic backing from a number of prominent mathematicians. Calkin estimates that besides his time, which might be donated anyway if he were running a print journal, the project consumes only 25 megabytes of computer hard-disk storage space (worth less than $50).

Electronic publications benefit as well from a growing number of public-domain software tools that make it simpler to display complex equations, chemical models and other graphics. Three English researchers, for example, have proposed a set of technical standards that would let pictures of molecules be transmitted over the Internet as readily as an E-mail text message.

Henry Rzepa, a computational chemist at Imperial College in London, Benjamin J. Whitaker of the University of Leeds and Peter Murray-Rust of the pharmaceutical maker Glaxo have worked on this dial-a-molecule project. Rzepa made his contribution because of the difficulty he had in trying to act as a referee of scientific papers without being able to visualize the results of the work presented.

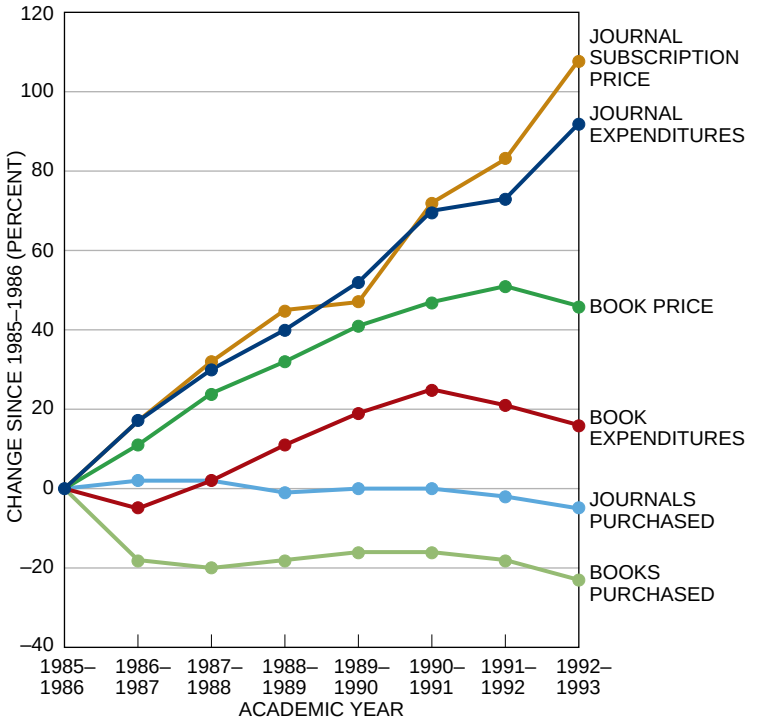
The proposed standards, called Multipurpose Internet Mail Extensions, or more simply MIMEs, specify a uniform format for sending chemical data over a network. Examples of these transmittals might be the spatial coordinates for display of a molecule or the mathematical variables for its spectral analysis. A chemical-modeling software package can then use a MIME to display, manipulate and even annotate a molecule. "Chemists and biologists can now exchange molecules in a virtual sense, rather than just words," Rzepa says.

The so-called E-journal movement



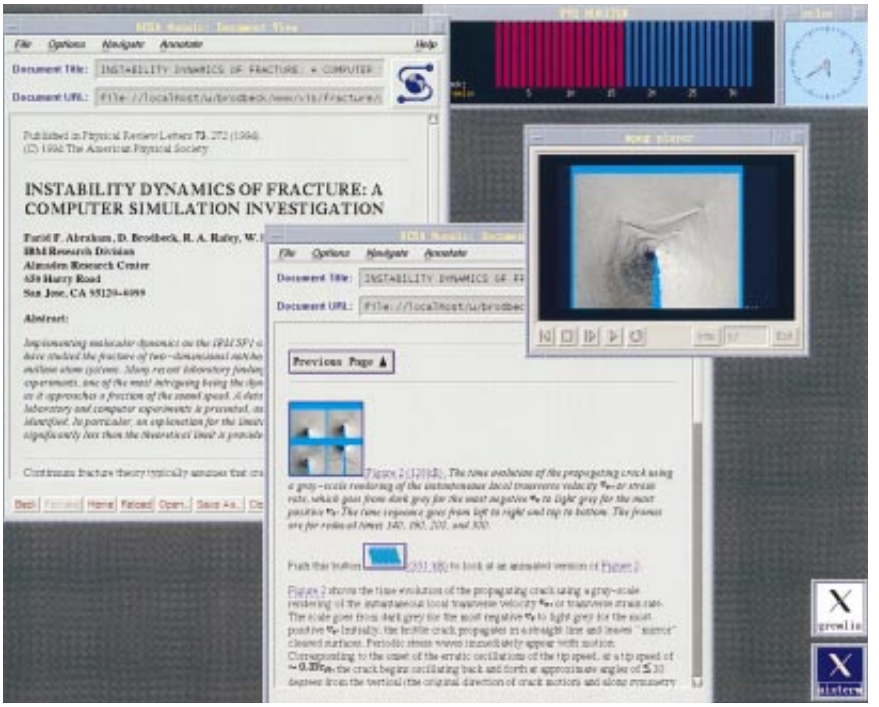
SOURCE: Association of Research Libraries

TOWER OF JOURNALS beside the Washington Monument shows a pile of these publications referenced in the Medline bibliographic database of biomedical literature during just one year. Capturing this material on CD-ROMs or in an on-line database could help libraries cope with the deluge of information.



LESS FOR MORE is a persistent trend in subscription and book purchasing at major university libraries. Costs for journals more than doubled during the past eight academic years, whereas the number of subscriptions actually dropped. Yet publishers continue to bring out more journals.

MULTIMEDIA JOURNALS are presaged by projects of individual scientists. Researchers at IBM placed on the Internet an article they had published in *Physical Review Letters;* they added two computer simulations of a crack getting larger.



could readily be dismissed as the biggest vanity press effort of all time. Few on-line journals have yet achieved the prestige and standing that translates into a line on a résumé for securing tenure and promotion. Calkin, in fact, acknowledges that he will also have to publish in well-known print journals to further his career.

The egalitarianism and "anything goes" sensibility of the Internet could work against attempts to raise the status of E-journals. The Usenet, a vast miscellany of bulletin boards accessible to the network's millions of users, represents the antithesis of the selectivity exercised by the editors and referees of a journal. The unfettered discussion there ranges from genetic experiments carried out by UFO aliens to legitimate debate about an advance in robotics or gene therapy. Some academics fear that the sheer volume of literature and a growing inability to distinguish the good from the bad in what gets published may lead to an overall decline in standards. "There will be far more trash than there is today," says Frank S. Quinn, a professor of mathematics at the Virginia Polytechnic Institute and State University.

Imposing a rigorous system of quality control could change these perceptions. Perhaps the most vocal proselytizer of the network as a scholarly vehicle is Stevan Harnad, a Hungarian-born cognitive psychologist who is a professor at the University of Southampton in England. He is best known as the founder and editor for more than 15 years of *Behavioral & Brain Sciences* (a journal whose acronym, *BBS,* is appropriately enough the same one used to designate computer bulletin-board systems).

At *BBS,* an article first goes through review by five or so referees drawn from at least three different disciplines, which may include behavioral biology, computer science, linguistics, philosophy, robotics or machine vision. If an article passes muster, it then goes to up to 100 people in those fields for a critique. As many as 30 commentaries appear with the original submission.

BBS bears remarkable similarities to the facile exchanges that take place over computer bulletin boards—with one big difference. Harnad is no populist. Unlike Internet evangelists who view the network as the ultimate equalizer for dismantling hierarchy, Harnad is an unabashed academic snob. The best thinkers in a field, he believes, should have access to one another, undisturbed by the noise of crowds milling outside the ivory tower.

Global Graffiti Board

Despite this elitist stance, Harnad discovered the potential for electronic scholarly discourse during the mid-1980s in, of all places, an electronic bulletin board on artificial intelligence on the Usenet. He found that the frenzy of activity on this "global graffiti board for trivial pursuit" spurred his own thoughts on why the mind does not behave like a computer. This experience resulted in a paper he later published in the journal *Physica D* as "The Symbol Grounding Problem." "I realized that I came on this as a result of jousting with pygmies," Harnad says. "I asked myself what would happen if the people I was talking to had been real scholars."

Harnad coined the phrase "scholarly skywriting" to describe the speed and breadth of dissemination that would result if academics eschewed the paper medium to publish over the network.

He practices what he preaches. Five years ago Harnad started an electronic journal, *Psycoloquy,* that is identical to *BBS* in the topics it covers and in its editorial practices, except that the papers are somewhat shorter. The journal is free; Harnad supports it on a $15,000-a-year stipend from the American Psychological Association that covers the expense of a part-time editorial assistant and a clerk to maintain a mailing list. The journal is sent to computers all over the world and is even available on the Usenet. (Amateurs, Harnad says, should be allowed to observe and emulate scholars' work from the bleachers.)

This past summer Harnad sent to an electronic mailing list a "subversive proposal" that suggested that authors and institutions should try to undermine the present publishing system by posting preprints to the network. This action would, he hopes, provoke the type of mass migration to the electronic medium from throughout academia that has already been experienced in the high-energy physics community.

At about the same time, Harnad, Lederberg and others met with a high-ranking UNESCO official for a broad-ranging discussion of electronic distribution of biomedical information to developing nations. They suggested, among other recommendations, that the agency endorse low-cost electronic publishing of scientific articles. "I think this will get the ball rolling," Lederberg says. "If you get a few institutions doing this, then others will feel that they have to be on the bandwagon."

Commercial scientific publishers are feeling the pressure to enter the electronic arena. Many, however, have yet to determine ways to smooth the transition. Simultaneous print and electronic distribution could, if anything, cause subscription rates to rise. Illustrations, graphs and equations do make scien-

tific publishing more difficult than providing an all-text database. More than a decade after the first market tests of electronic newspapers, many scientific editorial houses are drafting their plans for moving into the new medium. "Publishers are still trying to figure out how they can recover their costs," says David Rodgers, a research scientist at the University of Michigan and the former director of electronic products and services for the American Mathematical Society.

Both professional societies and for-profit science and technical publishers have started to piece out initial strategies. The American Physical Society, for one, has plans to circulate the electronic *Physical Review Letters* along with the printed version.

Reed Elsevier, the $4.3-billion British-Dutch company, recently made a major commitment to electronic publishing by buying the Lexis legal database and the Nexis news service. Yet the company is only beginning to make its 1,100 science and technical journals available on-line. It has an experimental program to provide image files of its 43 materials science journals to nine universities. Next year it will test-market all its journals in an electronic format but as yet has no firm plans as to when its entire suite of publications will become available as fully searchable databases.

In January, Elsevier Science, the company's science journal publishing division, did unveil its first electronic journal. The event was an indirect tribute to the work of Paul Ginsparg. *Nuclear Physics Electronic* (NPE) is an on-line compilation of already reviewed papers that are being readied for print in *Nuclear Physics,* a $12,000-a-year set of paper journals.

Elsevier had considered creating this type of on-line system for a decade, given that high-energy physicists were distributing paper preprints of their work through the mail. But physicists told Elsevier they were not interested—until Ginsparg's database began to gain a following. "Clearly, the market was ready; Ginsparg more than proved that," says Karen Hunter, an Elsevier vice president.

Many of the non-peer-reviewed versions of the papers that appeared in *NPE* are available in virtually identical form on the Los Alamos computer long before they appear on the Elsevier system. The range of topics on the Los Alamos databases is much broader.

Elsevier has not yet requested that papers be withdrawn from the Los Alamos databases once they appear in their copyrighted form in *NPE,* an action that would surely alienate physicists. For his part, Ginsparg may eventually need the help of mainstream publishers—he will have difficulty instituting a peer-review system for the papers in his databases while remaining a practicing physicist. He did, in fact, meet with officials from the American Physical Society in mid-October to discuss how a review process for the databases might work. If Ginsparg is brought into the fold, though, journal publishing could still change: costs could remain dramatically lower than for paper journals; reviews could proceed more quickly and with a broader base of contributors to evaluate manuscripts.

The library, the usual repository for journals, would also be affected by these shifts. The computers that store electronic publications may reside in a laboratory, not a library building. The librarian will remain, but the job will not be the same. Librarians, along with publishers, have traditionally been entrusted with the responsibility to make order out of scholarly chaos. Yet so far computer scientists, not librarians, have usually been the ones to create the tools for navigating the Internet.

Career Changes

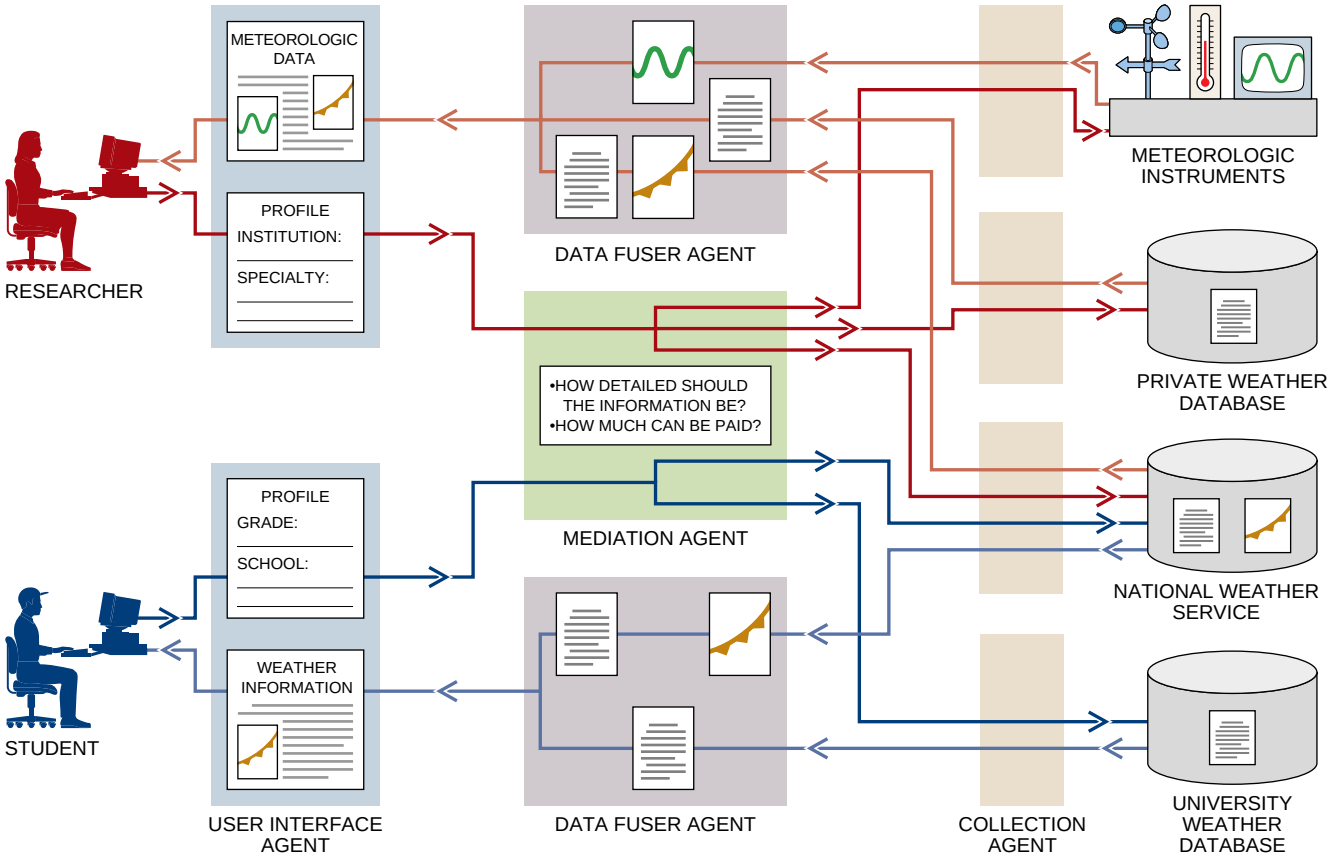
Daniel E. Atkins wants the School of Information and Library Studies at the University of Michigan to turn that trend around. Atkins spent the better part of his career tweaking high-powered computers as a professor and dean of engineering before coming to his present position as dean of the library school in 1992. His current mission is to redefine the job of the librarian. Atkins envisages an "information professional" who will combine the skills of the computer scientist, the business graduate and even a little of the old-school librarian.

One of the jobs of the new librarian will be to help make sense of the labyrinth of different information sources available on the Internet. "You can waste 24 hours a day browsing," Atkins comments.

In September the University of Michigan was awarded one of six grants in a digital library initiative sponsored by the National Science Foundation and two other federal agencies. Michigan's grant is for the development of technology to help students and scholars wade through the limitless store of information available on the earth and space sciences.

The NSF program also includes the New York Public Library, Stuyvesant High School in New York City, the Ann Arbor public school system and a number of corporate participants, among them Elsevier and IBM. Atkins and team will attempt to exploit "agents," the much publicized (though still rarely implemented) software tools from artificial-intelligence research that can retrieve information or perform other automated tasks. These agents would try to replicate in software some of the

DESK-BOTTOM PUBLISHER Paul H. Ginsparg of the Los Alamos National Laboratory sits in his office beside a Hewlett Packard 9000 containing a series of databases that have become, for a growing number of physical scientists, a substitute for the paper journal.



DOING THE BIDDING of research scholar or student, a network of software "agents" under development at the University of Michigan is intended to operate like an experienced reference librarian. After receiving a question—"What is the weather in Travers City?"—the user interface agent extracts a profile of the user from information in its database. The request is channeled to the mediation agent, which evaluates the profile to determine how detailed the information retrieved should be and how much the user can pay. The mediation agent decides what information resources should be allocated to what type of user. The researcher may get access to real-time meteorologic data and both public and private weather databases, whereas the student is relegated to less expensive public information sources. A collection agent then executes an actual search of the relevant databases. A data fuser agent assembles the collected information—text, maps, graphs, raw data—before relaying it to the user agent for display as a document on the student's or the researcher's screen.

functions of a reference librarian [*see box above*].

The digital library project is also exploring ways of combining information retrieval with laboratory tools accessible to researchers over the Internet. Atkins heads another NSF-funded project, the Upper Atmospheric Research Collaboratory (UARC), that has been examining how scientists can make use of research tools located in remote environs. A "collaboratory" uses electronic networks so that investigators around the globe can witness the results of an experiment as it progresses. Besides space physics, collaboratory projects are being pursued in molecular biology and oceanography—the Human Genome Project and a decade-long research effort to characterize the El Niño ocean currents are two examples.

For two years, the UARC has given scientists at various institutions (SRI International, Lockheed, the Danish Meteorological Institute and the universities of Alaska, Maryland and Michigan, among others) around-the-clock access to one another and to readings from instruments on the southwest coast of Greenland for observation of the solar wind. The software lets researchers in these various far-flung locations exchange comments as they observe the trace lines from incoherent scatter radar and other instruments that follow the impact on the atmosphere from the waxing and waning of the solar wind. The NSF digital library project will allow Atkins and his colleagues to expand the UARC. They will evaluate how the massive quantities of instrument readings, bulletin-board conversations and later annotations can be managed and used by the different research teams.

The goal of the librarian in this project will be to organize this information in a form that will let workers replay an experiment six months later. "We're producing a full-fidelity, multimedia transcript of the process," Atkins says.

The electronic network blurs boundaries between experimentalist, author, publisher, reviewer and archivist. As the work of Paul Ginsparg and of Daniel Atkins suggests, there is a need for a new institutional framework—both electronic publishers and collaborators in their collaboratories—to cope with the glut of scientific knowledge and the data from which it is derived.

FURTHER READING

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STEVAN HARNAD'S ELECTRONIC ARCHIVE. Available on the World Wide Web as http://www.princeton.edu/~harnad/

Measuring the Energy Drain on Your Car

Most of us do not bother to consider all the factors that affect the fuel performance of an automobile—that is, how many miles it gets to a gallon of gasoline. If we can measure the ways in which this energy is used, then we can consider how to improve the efficiency of our own car. Designers use similar information in striving to boost the fuel economy of future vehicles. Specifically, we need to examine the frictional forces that must be overcome in driving.

On level ground at constant speed, the engine of an automobile works against three kinds of friction: rolling resistance of the tires, friction within the engine, and air drag. These frictional sources largely determine a vehicle's energy use. Yet the coefficients representing these fuel-wasting forces are rarely published. With care, you can measure the friction and calculate the consequences for fuel economy. Most of the proposed measurements will work only on a manual transmission automobile. Also needed are some space in a parking area, a scale, a stopwatch, and a little-used, level and straight roadway, half a mile or more in length. We did our experiments with a 1989 Honda Civic sedan.

The first variable to measure is the coefficient of rolling resistance of the tires (represented by C_R). The force needed to overcome this resistance is proportional to the car's weight and is roughly independent of its speed. To measure the resistance, place your vehicle in neutral on a smooth, level parking area with the engine off. Pull it horizontally with a rope looped through the windows and attached to a spring scale. A level affixed to the rope may help. Alternatively, push your car from behind with a bathroom scale (protect the vehicle with a heavy cloth). You should find a force roughly between 20 and 40 pounds. Our reading came in at about 25 pounds.

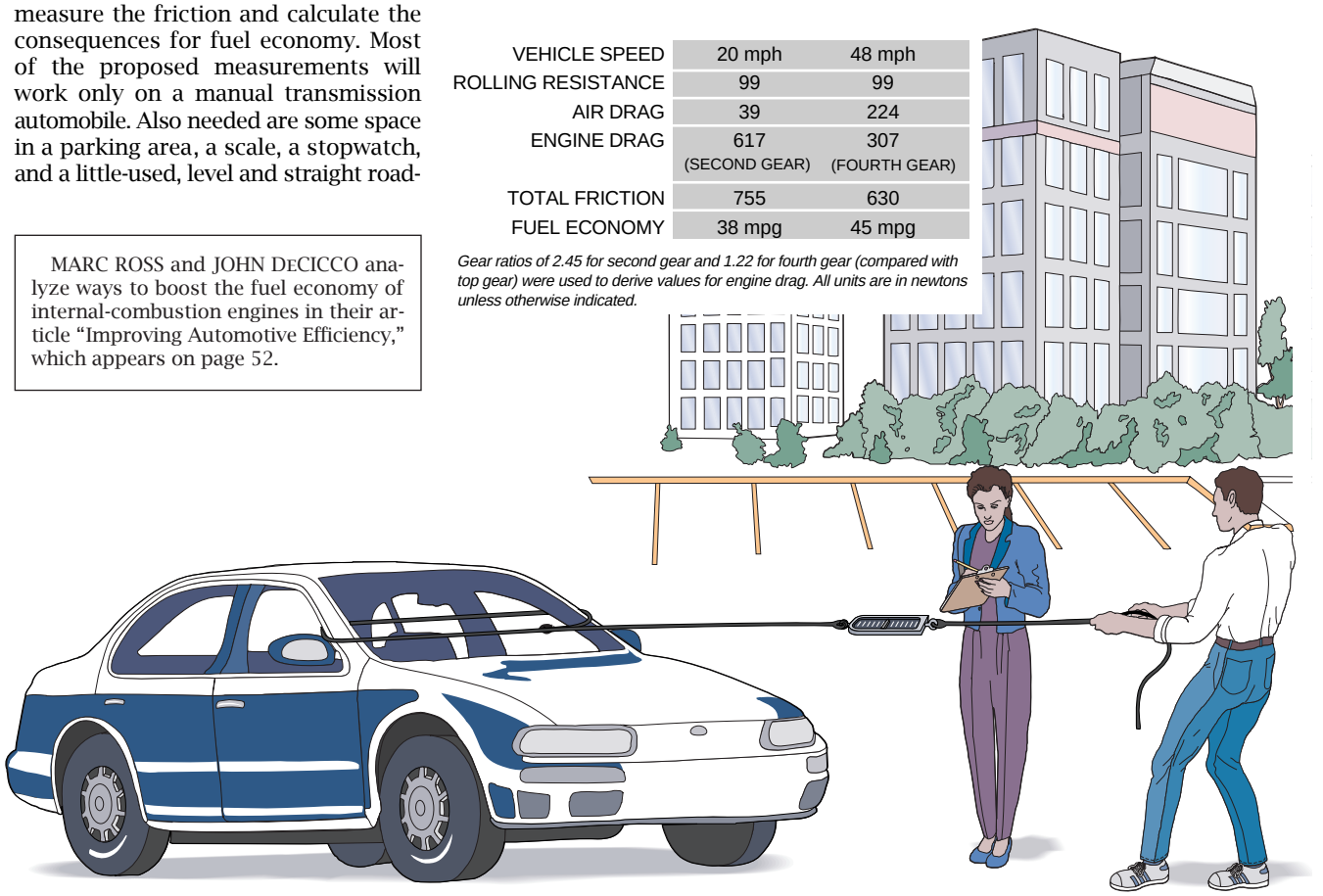
Unfortunately, this measurement is crude. If either the parking surface or the scale is angled by 0.1 degree from the horizontal, it will change the measurement by five pounds for a typical 1,300-kilogram (3,000-pound) vehicle. It is also difficult to move the car at a steady speed, which is necessary to avoid inertial effects. A good idea is to have two people divide the tasks. One pulls, and the other reads the scale. To correct for grade, repeat the experiment in the reverse direction and average the results. To obtain the coefficient of rolling resistance, divide the measured force by the vehicle's weight, which is listed in the owner's manual. With properly inflated original equipment tires, the coefficient should roughly equal 1 percent.

Aside from the effect of inflation pressure, several factors can confound the measurement of rolling resistance. One is bearing friction, which fortunately tends to be much smaller than tire

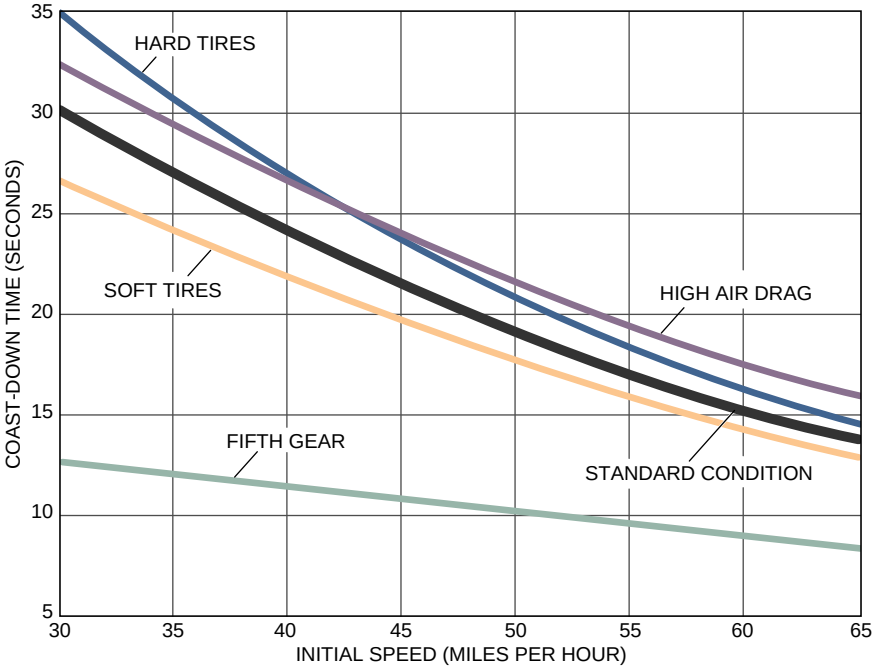
VEHICLE SPEED	20 mph	48 mph
ROLLING RESISTANCE	99	99
AIR DRAG	39	224
ENGINE DRAG	617 (SECOND GEAR)	307 (FOURTH GEAR)
TOTAL FRICTION	755	630
FUEL ECONOMY	38 mpg	45 mpg

Gear ratios of 2.45 for second gear and 1.22 for fourth gear (compared with top gear) were used to derive values for engine drag. All units are in newtons unless otherwise indicated.

MARC ROSS and JOHN DECICCO analyze ways to boost the fuel economy of internal-combustion engines in their article "Improving Automotive Efficiency," which appears on page 52.



ROLLING RESISTANCE and engine drag can be found by pulling your car with a rope attached to a spring scale. The table lists the frictional forces and fuel efficiency the authors calculated from their experiments on a 1989 Honda Civic.



COAST-DOWN TIMES for a typical 1993 car as it drops 10 miles per hour from an initial speed depend on variations from the standard condition (automobile in neutral; average air drag and tire pressure).

resistance. Another is brake drag, which arises from the slight contact between the pads and rotors on the disk brakes. This contact may contribute one to two pounds of drag, amounting to about 5 percent of the rolling resistance. The coarseness of the road surface also affects rolling resistance; smooth, paved surfaces provide the greatest accuracy.

Now measure the engine drag. The procedure is the same as that for rolling resistance, except that the transmission is in top gear. The scale reading provides the combined force of rolling resistance and engine drag. With our Honda Civic, we measured roughly 100 pounds, which means that engine drag is about three times greater than tire drag. (In typical driving, engine drag is somewhat less because depressing the accelerator opens the throttle slightly more than simple coasting does.) But the measurement is rough because the force is uneven as the cylinders go through their strokes.

Deriving the coefficient that characterizes this friction is a bit complicated. We must compare our measurements with the work performed by a "standard engine." By definition, a standard engine generates 100 joules of work to rotate the crankshaft once when the throttle is almost closed—that is, when the accelerator is up, in its rest position.

The actual frictional work is then given as the product of 100 joules and the coefficient of engine friction, C_E (a term coined for this column). To derive this coefficient, you need to know the volume swept through by the pistons (called engine displacement). This value, given in liters, is listed in the manual.

You also need the number of revolutions the engine's crankshaft turns for every meter that the vehicle travels in top gear. We represent this number by *n*. One way to find *n* is to read off the revolutions per minute from the tachometer (if you have one) while driving in top gear. Divide this number by the vehicle speed in miles per hour, then further divide by 60 and by 0.447 meter per second (equal to one mile per hour). (A more involved method, ideal for people who enjoy number crunching, is to look up the overall gear ratio from the manual and use the tire circumference to calculate the distance the car moves and the number of crankshaft revolutions.) As a rough check on your results, note that vehicles are designed so that *n* varies from about 1 with large-displacement V-8 engines to almost 2 for small engines.

In our experiment, we multiplied the measured net force of 75 pounds by 4.45, in order to convert pounds to newtons (the metric unit of force). For this car, $n = 1.68$ revolutions per meter, and the engine displacement is 1.5 liters. Thus, $C_E = 75 \times 4.45/(100 \times 1.68 \times 1.5) = 1.3$. The frictional work is therefore 130 joules per liter per revolution.

The last frictional force with which we must contend is air drag. To find it, we need to get the car on the road. The technique measures the time it takes for a vehicle to drop 10 miles per hour from an initial speed. You need to go back and forth on the same stretch of road and average the times to correct approximately for any sloping in the road and for any wind.

This part of the experiment requires two people. One gives full attention to driving, while the other handles the stopwatch and records the results. Find a straight, smooth, level road with little traffic at the time. Be careful not to interfere with other vehicles and do not make these measurements at night.

To determine air drag, measure the coast-down time with the clutch pedal down in two speed ranges. For example, you might use 50 to 40 mph and then 40 to 30 mph. Just be sure they are safe for the road conditions. The two ranges should be different enough for a good measurement. In our experiment, we found coast-down times of 17.7 seconds and 24.0 seconds for the respective ranges (that is, at average speeds of 45 and 35 mph). Unless you are an expert, you will find considerable variability in the times, even in the same direction. You need to read the speedometer straight on and be highly systematic in using the stopwatch. Practice until you feel you have achieved some reliability.

Using the equations in the box on the opposite page, we found that the difference of air-drag forces at these two speeds was 74 newtons, or 16.6 pounds, for an automobile mass of 1,110 kilograms, which includes the passengers. (The difference measurement eliminates the resistance offered by the tires.) From this value, you can infer the air drag at other speeds. To find the value at, say, 70 mph, multiply the air-drag force just calculated by $70^2/(45^2 - 35^2)$. For the example discussed, the air drag at 70 mph is 102 pounds.

What we want to calculate is the efficiency with which your car cuts through air. It is the product of the frontal area of the vehicle, *A*, in square meters, and the air-drag coefficient, C_D, a dimensionless number describing how streamlined the vehicle is. The box gives the necessary equation. For the Honda Civic sedan, we found the product $C_D A$ to be 0.77 square meter.

To find the drag coefficient itself, you need to determine the frontal area. One way is to make a scale drawing of the vehicle's silhouette as seen from well in front. Include the tires but not the empty space between them. As a check, multiply the width by the height by 0.833, the typical factor for current cars. With the Honda Civic, the frontal area is 1.89 square meters, so the measured C_D is 0.41. The actual drag coefficient is

probably less; estimates in the literature list it at about 0.35.

With coast-down observations and the equations in the box, you can double-check the values derived for rolling resistance and engine friction in the parking-lot measurements. To find the rolling resistance coefficient, substitute one of the coast-down measurements already made into the proper equation in the box. Our Honda Civic produced a coefficient of 0.0086—close to what we found in the parking lot. Note that rolling resistance depends on tire pressure. The coefficient is roughly proportional to the square root of the gauge pressure. For example, if you lower the pressure 20 percent, you should find that the force increases about 10 percent.

Next, measure engine drag during coast-down. Leaving the vehicle in high gear, time the coast-down. Although it muddles the interpretation slightly, leave the engine running during the measurement. That way you will not lock the steering after you turn the engine off and can drive at the end of the coast-down without slowing down further and perhaps interfering with traffic. In our measurements with the Civic, the 50- to 40-mph coast-down time was 9.1 seconds. Using an expression in the box, you can figure that the engine drag is 265 newtons, or 60 pounds. You can check that the corresponding coefficient is equal to 1.0, a reasonable result and probably more accurate than the 1.3 value we found earlier.

The frictional coefficients calculated here can be used to estimate fuel economy without further measurement. Assume that the indicated efficiency of the engine (the efficiency before accounting for frictional losses) is 38 percent, a value typically listed in the literature. This number expresses the ratio of the total work by gases on the piston surface (during the high-pressure strokes) to the combustion energy of the fuel. The fuel economy is then determined according to the equations in the box.

We calculated the fuel economy at two speeds, as shown in the table on page 112. The speeds roughly correspond to the overall average speeds for the official urban and highway driving cycles. The fuel economies agree fairly well with Environmental Protection Agency estimates for this car: 34 and 46 miles per gallon for the urban and highway cycles, respectively. If we consider the energy losses in the brakes during city driving, which decreases the fuel economy by about 10 percent, we obtain even better agreement.

Our results may be misleadingly good. Not only were there experimental errors, but the driving cycles involve various speeds, which complicates the air- and engine-drag calculation. Nevertheless, these methods should enable you to determine where most of the energy is going during a drive.

The analysis presented here offers some hints for improving your fuel economy. Because the total amount of friction an engine must overcome depends on the number of revolutions of the crankshaft, shifting up early to reach a cruising velocity and cruising in high gear will lessen engine friction. Removing roof racks will improve efficiency by decreasing air drag. Keeping tires correctly inflated will reduce rolling resistance.

You can explore several other variables that could affect fuel efficiency. Try coasting down with the windows open or with the air conditioning on to see how much of a difference that makes. You could also check to see if the ambient temperature plays a role. A cold engine should be less efficient than a warm one. With some imagination, you can squeeze a few extra miles out of a gallon of gas.

Coefficients of Friction

The forces of friction, other than brakes and accessories, as they oppose the motion of a vehicle are characterized by dimensionless coefficients C_R (rolling resistance), C_D (air drag) and C_E (engine friction). Rolling resistance is given by $F = C_R Mg$, where F is the force to overcome the resistance and Mg is the vehicle's curb weight (technically, the vehicle mass times the gravitational acceleration).

Air drag can be found from $F = 0.5 \rho C_D A v^2$, where ρ is the density of air, equal to about 1.2 kilograms per cubic meter at low altitude and typical temperature, A is the frontal area of the car, and v is its velocity.

Engine friction can be calculated from $F = C_E (f_0/\varepsilon) n V (R/R_{top})$, where f_0 is the frictional work per liter of displacement to rotate the crankshaft of a "standard engine" through one revolution equal to 100 joules per revolution; ε is the efficiency of the transmission system, approximately equal to 0.95 when the gears are engaged; n is the number of crankshaft revolutions per meter of travel; V is the engine displacement in liters; R is the gear ratio in use; and R_{top} is the ratio in top gear. The owner's manual may show the gear ratios, or check with your dealer.

You can calculate the coefficients from the coast-down measurements. The quantity $C_D A$ is given by

$$C_D A = \frac{0.447 \Delta v M (1/t_1 - 1/t_2)}{[0.5 \rho (v_1^2 - v_2^2)(0.447^2)]}.$$

Here Δv is the (positive) change in speed (in miles per hour) during coast-down, equal to 10; M is the vehicle mass, including passengers, in kilograms; t_1 is the faster coast-down time in seconds and t_2 the slower time; and v_1 is the average speed in miles per hour of the higher range and v_2 that of the lower range. The constant 0.447 is meters per second, corresponding to 1 mph.

The coefficient of rolling resistance can be found by

$$C_R = (0.447/9.8)\,[\Delta v/t - (0.447/2M)\rho C_D A v^2]$$

where either t_1 and v_1 or t_2 and v_2 can be used.

Having determined $C_D A$ and C_R and measured the coast-down time with the vehicle in top gear, you can find the engine friction by

$$C_E = \frac{[0.447\,\Delta v\, M/t - 9.8 M C_R - (0.447^2/2)\,\rho C_D A\, v^2]}{(f_0\, n\, V/\varepsilon)}.$$

Knowing the three frictional forces enables you to calculate the gasoline consumption of your vehicle. Let ΣF be the frictional work to move the vehicle one meter (in joules)—that is, the sum of all frictional forces in newtons. To obtain ΣF, the forces of air drag and rolling resistance on the vehicle must be multiplied by $1/\varepsilon$ and the engine drag on the vehicle by ε. The fuel economy in miles per gallon is then equal to 120,600 kilojoules × 0.38/(1.609 kilometers × ΣF).

Here 120,600 kilojoules is the lower heating value of a standard gasoline, 38 percent is a typical indicated efficiency for modern engines, and 1.609 kilometers is one mile. (The lower heating value of the fuel accounts for the water exhausted as a gas rather than as a liquid.)

BOOK REVIEWS by Philip and Phylis Morrison

Science Books for Young People

Heaven and Earth

EARTHSEARCH: A KID'S GEOGRAPHY MUSEUM IN A BOOK, by John Cassidy. Klutz Press, 1994 (aluminumbound, $19.95).

Once again this author-builder appeals to clever, wary yet eager kids, who will read and respond. Our witty Klutz of the World asks: "Why have we sold you a used sheet of aluminum?" instead of a papery cover or even a brand-new metal one. "Because we only want you to own the best"; recycled aluminum takes the smallest bite out of the planet whereon we all reside.

Once again his book is not only for reading but for *doing.* It is packed with cool activities and exhibits, colorful, movable, wry and hip, as much fun as they are meaningful. They probe everything geographic, "from the tip of your nose" on outward. End the first section on an unusual page: yes, it is toilet paper. "No offense, but your great great great grandmother never used a toilet."

Those pages tell the story of Dr. John Snow and the Broad Street water pump, popular, well located but invisibly sewage contaminated. His maps gave him a superb clue in 1840; he took off the pump handle, and in that London district new cholera cases ended. That famous tale stands for all the measures of public health that have since brought about the modern rise in human population.

A chapter on maps shows how to make a contour map on your own hand, the Knuckle Mountains, able to unfold from flatness to reality as fast as you make a fist. Then check this "dirt we call home," the U.S. in relief, under a neat overlay of features, and learn longitudes by judging the shadows that grow all day across distant playing fields on daytime TV.

A little history leads to recognition of empathy among us, the five billion two-legged creatures who dwell in the big sandbox. Simply enough, a color wheel mixes four colors (halftone dots) to form by the numbers a skin tone to match your own—or any other. We're all right there on the wheel, skin deep. If you can't find a match, "call a doctor."

Going much deeper, a bag bound into the book holds a measured ration of real raw rice, enough for half of a kid's daily food. Cook it up and eat it, but nothing more that day! You will experience the needs of the poorer developing world. The unique package ends with an intimate conceit: your next breath is demonstrably shared, by way of random molecular mixing, with one of Julius Caesar's. Eight real coins from eight lands are inset here; you're to identify them. They unite little everyday purchases around the world. We differ, to be sure, but equally we are one kind, and unlike anything else we know.

IS A BLUE WHALE THE BIGGEST THING THERE IS? by Robert E. Wells. Albert Whitman and Company, 1993 (Morton Grove, IL 60053) ($13.95; paperbound, $6.95).

A blue whale, the biggest thing that ever lived, is a lot bigger than any elephant, horse or lion. The painted page shows that clearly. But it's *not* at all the biggest thing there is.

Imagine a big, big fishbowl that could hold 100 blue whales. You see it here, in a painting, the three animals looking up at it from the dock. Now put a pair of those bowls on a platform, balance a similar shelf on top of the two and pile 10 shelves high, blue whales in plenty. The entire "tremendously tall tower" looks quite small shown on top of snowy Mount Everest. Now think of stacking 100 Mount Everests up, one on the other. Huge, yet only a longish whisker on the broad face of Planet Earth! A net bag packed with 100 Earths is still only a small package next to the Sun. Even 100 Suns in an *immense* orange crate are not much beside one giant star, red Antares.

Step by step we reach the Universe that holds all the galaxies, so amazingly big that no one knows what the *whole* universe looks like. What we *do* know is that it's a lot bigger than a blue whale. Imaginative young readers will surely enjoy this audacious little book. "Will it give you big ideas? You can count on it!"

EXPLORING SPACE. Voyages of Discovery, Scholastic, 1994 ($19.95). **MISSION TO DEEP SPACE: VOYAGERS' JOURNEY OF DISCOVERY,** by William E. Burrows. Scientific American Books for Young Readers, W. H. Freeman and Company, 1993 ($17.95).

The sky that opens to space is dark at night, so that this ingenious book about space, translated from the French, needs only a couple of white pages among its dozens of glossy black ones. The text is in white type, and across the velvety pages half a dozen artists have handsomely arranged a star planisphere, a sky clock and much more. Crowded pages bear a text that moves swiftly from the zodiacal animals out to the edges of space. The words are clear, suited to readers in the middle grades and up.

Past and present art of the sky are here in an agreeable harmony, a figure

from old Appianus not far from the Man in the Moon with a rocket in his eye, a snap from a famous pioneering animated film. A wealth of color inserts fill the pages: Louis XIV in costume as Sun King, a gamma-ray satellite and its map of the Milky Way, four main galaxy types, even little lost E.T. himself. A small foldout booklet is a modest atlas of the structure of the cosmos, and a couple of overlays and some stickers to mount stir up action. Constellation maps viewed via a red-blue stereo viewer show how much chance alignments in depth help to shape the starry patterns. Altogether a success, this is one of a new group of such museumlike books originating with the publisher Gallimard.

The second book, more matter-of-fact and possibly even more amazing, tells the story of two old probes from Pasadena, the Jet Propulsion Laboratory satellites named *Voyagers 1* and *2.* They set out on their Grand Tour of the solar system, bounced around in a game of planet billiards made possible by the planet alignments of the 1970s and 1980s. Never so well lined up since Thomas Jefferson's day, the planets will not be well placed again until 2155.

But NASA did it right on time, with Titan III-E power. It all worked superbly, and this crisp, clear book for kids from age 10 on up shows what the *Voyager* sisters reported over the years by video link. All the big planets are here, spots and bands and shadows, the awry axis of Uranus, the old familiar moons and many newly found, moons frozen and volcanic, wild multiple-ring systems, all simply and sensibly told.

One page deserves special notice: it shows the souvenir pictures *Voyager 1* sent back as finally it swerved past Saturn, to pass far above the plane of the planetary orbits. Looking back to the Sun, it caught Earth from afar, no longer a place, not even a blue marble, only a faint wanderer among background stars. *Voyager* was a fine start; the next ambitious explorers of our system will be drawn from boys and girls who read books like this.

TEN OLD PAILS, by Nicholas Heller. Pictures by Yossi Abolafia. Greenwillow Books, 1994 ($14). **TIGERELLA,** by Kit Wright. Pictures by Peter Bailey. Scholastic, 1993 ($14.95).

Two whimsical books celebrate the long human interest in the sky. A little redheaded farm kid in a yellow cap tells us that he has 10 old pails. We see him get them one by one: the first a dented milk pail the cow kicked, the second a leaky water pail, sixth the sand pail that sat in the barn until Father bought a new red fire extinguisher, and tenth is an empty paint can.

The paint can completed the design: three made a rocket pack, one was for moon rocks, the iron pot was a head cone and the big pail became the launchpad our astronaut stood on. The smallest held flowers and bore a note for his mother: "Gone to the moon back soon." Lift-off here is an inner event.

Poet Wright has told a fiercer tale about a red-haired little girl. Everything Ella did was right. She passed around the sausages and even gave the dog a bite. Good as gold and nice as pie, she sweetly kissed each guest good-bye. But little did they know.

Every midnight Ella awoke *changed,* with a furry growl, a striped hide and a long tail. TIGERELLA she was! TIGERELLA her name! She ran and raced and leapt and bit a piece from the rolling moon. Up and down the Milky Way, at last she found the Bear. The two beasts together finally tumbled down to the garden, Tigerella scratched by an arrow from Hunter Orion. She poured herself through the window as the Bear soared back to his heavenly home.

Ella sat quietly at breakfast and blamed the old tomcat for the little scratch. And little did they know!

It isn't astronomy, but it comes as close to the true nature and origin of the constellations (which belong, of course, not to stars but to *people*) as does many a learned volume.

Life-forms

WHALES, by Mitsuaki Iwago. Photographs in color. Chronicle Books, 1994 ($29.95; paperbound, $17.95).

The sea's edge is sharp against the still unlit wall of the coastal cliff at five on a summer morning south of Alaska. From the visible surface rises a single orange cloud. It is the spout of a humpback, vapors caught in the glow of the rising sun. Sixty-odd more large color photographs, dramatic seascapes printed across the long pages without margins, form this extraordinary book of wildlife photographs. Many catch the creatures close-up, flukes high above water, or huge white pectorals spread, or grouped underwater as mother and calves. They have been made over the years by an intrepid photographer at work in three widely separated areas of the Pacific where humpback whales display. All day long on a small rubber raft bobbing in the seas, his patience longer than his big telephoto lenses, sometimes snorkeling below the surface to catch the animals submerged, Mitsuaki Iwago has brought home a trophy of insightful images.

But his book is not confined to cetacean natural history. What he has done as well is to make a glowing work of art, a portfolio so elegantly composed, so alive to the sea color and the nuances of the fleeting moment, that it transcends the great whales.

MONARCHS, by Kathryn Lasky. Photographs by Christopher G. Knight. Harcourt Brace and Co., 1993 ($16.95).

The large monarch butterflies, whose caterpillars feed solely on the milkweed plant, are beautiful. The tiny fluted egg is beautiful, the voracious caterpillar is beautiful in its three-colored stripes, and the carved chrysalis hangs like a jade and gold lantern, ripening to a transparency that discloses the beauty of the flier folded within. Spotted and striped in its orange, black, white and yellow heraldry, the one-gram flyers ornament our summer breezes coast to coast.

But they are not the fragile homebodies they may appear. Every autumn most of the insects migrate from the Gulf States about 2,000 miles to the high mountain forests in Mexico. They overwinter in a few "magic circles," groves of the tall oyamel trees whose canopy offers them the microclimate they need. Near El Rosario the largest colony hosts 30 or 40 million monarchs packed on tree after tree, the yearly cynosure of awed winter tourists. (The smaller fraction of the creatures who dwell west of the Rockies have a shorter journey to eucalyptus groves near Monterey in California.) This splendidly illustrated chronicle is no clip art; the authors migrated, too, and we can meet the humans—and their excited kids—who know the migrant monarchs well.

We want to draw a reviewer's conclusion: many good books tell such tales as this one, based on a wondrous form in nature. Most of them are by able authors who carefully study written words and collect their images from many sources. They can and do make good books that way, if at arm's length. A quite different way is that of Lasky and Knight; they followed the story firsthand wherever it led. Their pictures are taken on the spot, the people you meet have speaking parts in the drama. Theirs is a longer, harder and costlier way, but it is rewarding, and the books it gives us are special, like this one and *Whales,* with its luminous images of the Pacific humpback whale.

IN THE VILLAGE OF THE ELEPHANTS, by Jeremy Schmidt. Photographs by Ted Wood. Walker and Company, 1994 ($15.95). **LITTLE ELEPHANT,** by Miela Ford. Photographs by Tana Hoban. Greenwillow Books, 1994 ($14).

It is of course a village of people, not of elephants, but just as a car is parked in front of nearly every house in an American town, so here the family elephant spends the night tied to a tree next to almost every house. Sometimes it is asleep, standing up like a horse, sometimes it is quietly munching bamboo shoots from the big feed pile.

In this forest village of 15 simple, airy houses in the Nilgiri Hills of southern India, the people have been employed for a century by the government as elephant drivers and trainers, called mahouts. We meet Bomman, in his teens, his parents, and their handsome tusker Mudumalai, 27 years old and growing. Mudumalai is the lifetime responsibility of Bomman's father, but Bomman is an eager apprentice mahout, able to wash, feed and lead Mudumalai under his father's keen eye, until one day the skilled young man may merit so valuable an elephant on his own.

An elephant is no family car; even more than a pickup truck or a bulldozer, he is a hard-working partner in the family livelihood. Once the five-ton elephants (some weigh eight tons), able to push or pull six tons of logs easily at command, were used to log the big forest trees. Today the overcut forests are a sanctuary; the mahouts and the best

of their working elephants serve the wide sanctuary by moderating the thousands of elephants who still roam wild, keeping them out of the fields of the forest's farming neighbors.

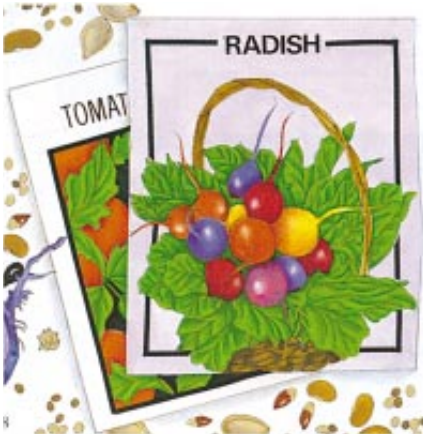
An elephant in the forest spends most of the day seeking food; the working elephants have no time for that. They are fed at government expense on a kind of rich porridge made of rice and whole-wheat flour, "served up steaming hot" at the village cookhouse. Bomman lifts one portion, about as big as a soccer ball, and places it far inside Mudumalai's waiting mouth. The elephant licks the boy's hand in affection, "his tongue as big as a watermelon." One day a holiday procession marches by, 50 elephants bright with big red-and-gold head ornaments, costumed riders bearing tall red umbrellas, a mahout walking at one knee of every elephant. Such a day celebrates long centuries of mutual respect and friendship between these partners, gentle giants and thoughtful people. This true report is as modern as the radio tracking of the wild tuskers, but all the same it is a tale of wonder, at once distant and intimate.

In the small book 20 big, clear photographs show a little zoo elephant who leaves Mother to play in a watery pool, much as human children will. "First one toe, then two. A big splash…Under I go…Time to get out…This is hard. Can I make it? Yes, I can!" Of course, Mother is solidly there, waiting. The photographer Tana Hoban has as usual made the entire scene vividly real. Her own grown-up daughter has supplied an artfully minimal text, three words or so to a page, splendid both for those who are read to and for those who have begun happily to read on their own.

Food

GROWING COLORS, by Bruce McMillan. Mulberry Paperback Books, William Morrow and Company, 1994 (paperbound, $4.95). **BLUE POTATOES, ORANGE TOMATOES,** by Rosalind Creasy. Illustrations by Ruth Heller. Sierra Club Books for Children, 1994 ($15.95). **APPLES,** written and illustrated by Roger Yepsen. W. W. Norton and Company, 1994 ($17.95).

Red, red raspberries five times life size, white onion bulbs on their rich black soil and string beans of deep purple, all are shown in spectacular full-page photographs, all glistening with the spray that enhances their gorgeous colors. A smaller photograph shows the whole plant as it grows. On each spread no more text appears



than a single word, say, "red," printed in red. It's all a prize for the eyes, good for small gardeners, and a consoling surrogate for the utterly landless at any age.

The Creasy-Heller book is a serious guide to simple gardening, meant for young readers with some access to land. It gives good value to beginners of any literate age. The book centers on a little pleasantry, the "rainbow garden," freed of color stereotype. The blue potato of Cuzco is well known in U.S. markets today, the yellow-orange tomato was always around, and multicolored radishes and yellow watermelons are here among half a dozen more novelties. The pages lead a beginner wisely from mail-order seed packet to soil preparation to planting, with options for starting both indoors and out, then on to feeding, watering, weeding and "critter control," all necessities of tender loving care.

The rainbow garden is surveyed by variety, specific hints for each of its crops. There is a recipe or two for each; the red, white and blue potato and bell pepper salad for the Fourth of July is a winner. The strongly colored illustrations, done in fond and helpful detail, are an asset and a pleasure. Northerners, though, will be lucky if yellow watermelon is ready to cut open much before Labor Day. The diversity of our big country is possibly a little problem for these expert Californians, who seem just a little evasive about garden timing.

Apples is a thick, square little book about the size of your hand. Its 90 colorful spreads each describe and paint, at about life size, one variety of American apple. The artist and author is a Pennsylvanian with an orchard and a sharp eye for our culture. The book celebrates apples, not only the bright red sphere of the alphabet books but real apples, distinct in taste, fragrance, shape, texture, season and use. Once variety was the pride of apple lovers; now most best-seller supermarket apples come from three or four varieties that appeal mainly by visual show, freedom from blemish, and uniformity; they are all good keepers and seem "closer to a logo" than to a fruit with a history of human interaction that is as old as Eden.

SODA POP: HOW IT'S MADE, by Arlene Erlbach. Lerner Publications Company, 1994 ($18.95). **VANILLA, CHOCOLATE, & STRAWBERRY: THE STORY OF YOUR FAVORITE FLAVORS,** by Bonnie Busenberg. Lerner Publications Company, 1994 ($22.95).

Pop and *Vanilla*. Each of these well-made books for readers in the middle grades offers nourishing portions of modern technology, small, indulgently sweetened by nature, but of surprising clarity and breadth. Soda pop is served a billion times a day worldwide, so Coke and Pepsi and their kin are more than TV catchwords—they engage substantial domains of technology. Useful water does not fall as rain: filtration, settling, chemical treatment and the final "polishing" step that wins visual purity by filtration through microscopic pores must follow. Sweetness is no longer the gift of either cane or beet sugar, at least in our corn-rich U.S., but comes from the liquid cornstarch yielded by the wet-milling of field corn kernels, made sweet by specific enzymatic processing. Carbonation supplies the pop!—by dissolving carbon dioxide. A kid's experiment with sugar and yeast is enough to inflate a balloon with the gas. A good look at the ingenuities of the mass assembly and filling of cans and bottles ends the story—except for recipes for home-brewed soda pops.

In somewhat more detail, for readers with a little more experience, the tale of the three great flavors tilts more toward history, economic botany, good maps and bright pods growing in dark tropical forests than to the chemical engineering that produces filled cans and bottles. "Great names in chocolate" are here with a gloss: Nestlé, Baker, Hershey, van Houten…and the decisive processing given modern cacao beans is well outlined.

But the best story among the three flavors, one not well known even to grown-ups, is that of the wise 18-century French gardeners who first found the rather subtle properties of the strawberry plant. They grasped how to cross large Virginia and Chilean berries with their tiny but flavorful European relatives, at last reaching the modern hybrid berries, at once fragrant and large. Again advice on how to grow the delicious fruit is given along with a few recipes, in a book whose graphics are fully up to imaging the crimson delights of the berry patch.

INCREDIBLE EDIBLE SCIENCE, by Tina L. Seelig. Illustrations in color by Lynn Brunelle. Scientific American Books for Young Readers, W. H. Freeman and Company, 1994 ($19.95; paperbound, $13.95).

We all have experience with the homely events in our kitchens. Those changes are chemical, and this book uses what we know as the place to begin some understanding of these events. Such firm grounding is especially useful because chemistry is abstract in itself: we never see the atoms in the materials we handle.

This quite entertaining account aims at practitioners in the middle grades. Their motivation and interest are inherent in the topics considered here: ice cream, lollipops, popcorn, pizza. The wonderful properties of matter are put on display, from the visibly stubborn refusal of oil and water to mix without the emulsifying honey and mustard, to the little explosions that puff and whiten popcorn and to the tears that all cut onions bring. This is experience well worthwhile in itself; here it is also tied to the microcosm, including cells, by simple, catchy arguments and diagrams,

though not in the tough domain of experiment.

The join is bound to be imperfect, for inferences are less compelling than they are plausible. "All matter is made up of…elements…. Sometimes atoms join together…. Matter can be found in three different states." Such aphorisms support but hardly demonstrate themselves or much else. It is fun to read, quite correctly, that a watched pot, hot enough, "*always* boils" and that corn kernels burst open like balloons, even though they don't much look like it.

Kids who will try these agreeable tasks will master a good deal, and even the arguments from enzymes and microtexture borrow some credibility, perhaps to be redeemed later in a culture where proteins and fats are standard TV jargon. It is hard to do better today than this lively essay, aimed at the practical level of the kitchen counter.

People

THE TOMBS OF THE PHARAOHS: A THREE-DIMENSIONAL DISCOVERY, illustrated by Sue Clarke. Hyperion Books for Children, 1994 ($16.95). **PYRAMID,** by James Putnam. Photography by Geoff Brightling and Peter Hayman. Alfred A. Knopf, 1994 ($17.99). **THE ICEMAN,** by Don Lessem. Crown Publishers, 1994 ($14).

Each big page of this 10-page book is a triangle—triangular books are rare—to remind you of pyramids, all in golds, reds and blues. The artist-author Sue Clarke had the three-dimensional help of paper engineer David Hawcock. He arranged for a pop-up pyramid and a shrine, many lift-up flaps that open to reveal hidden pockets and maps, and a set of foldouts within foldouts within foldouts to hold nested paper coffins, the innermost, solid gold.

Much of this tantalizing mystification is based on real finds in the pyramids and in the Valley of Kings, with its hidden tombs beside the Nile. The glowing colors of many small images are in the style of the old papyrus Book of the Dead, and the rich furnishings are drawn after the real unspoiled tomb of young Pharaoh Tutankhamen. They bring a willing young reader to share the feeling of unwrapping the ancient golden past. Not literal but not fictional either, this original book creates an imaginative entry to the wonders of ancient Egypt.

Facts, real artifacts, big buildings—these are all imaged, quite literally, in *Pyramid,* one among a long series of books that addresses a topic in sharp photographs as though you were walking by real cases in a fine museum. Tools, models, carvings in natural color, many on each white page, evoke old Egypt. Architecture is not neglected. The choice is wide; the wise author has included pages of Mesoamerican pyramids and temples along with those of Egypt and Nubia.

The third book describes the Iceman, whose frozen body was found in an Alpine glacier on the border between Austria and Italy during the fall of 1991. He was no missing tourist, just a man of the Alps who had been overtaken by the cold about 53 centuries ago.

It was what the Iceman wore and carried that helped most in understanding who he was. An artist, Bryn Barnard, has painted him very convincingly: a short, stocky man with brown, curly hair, maybe 40 years old. He carried a backpack, a very long and strong bow and a quiver of wooden arrows. An ax was slung at his side, its blade copper, a flint knife tucked in his belt. He wore a huge, warm cape of braided grass, a deerskin suit, hay-stuffed leather shoes and no cotton or wool about him. (They were not in use yet.) His people were village farmers of the Alpine foothill lakes who made such goods, although he was probably a hunter, a shepherd or a trader.

The account is clearly written. Lessem is best known for his admirable work on dinosaurs, events a million centuries past. Any good reader can grasp this vivid story of an old accident. Note: the photographs of the hunter's head and body so long held in the ice could be scary for the young.

MCHESHI GOES ON A JOURNEY/MCHESHI AENDA SAFARI, illustrated by Judy Wanjiku Mathenga and Robin Miranda. Jacaranda Designs, Nairobi, 1993 (in the U.S.: P.O. Box 7936, Boulder, CO 80306) (paperbound, $7.95).

Mcheshi is a sunny kid in the early grades with a fine taste in traveling clothes and a good eye for novelty. Good-bye, Mummy and Daddy, and off she goes with her aunt on a visit to the shore. The bus looks

pretty familiar to us, although it does have a colorful stripe, and downtown Nairobi buzzes with trucks, motorcycles and the odd nifty Land Rover, too. The Nairobi station has a colorful lot of ticket buyers, ready to board the long train of matched cars drawn by the big diesel. After a night in an upper berth, Mcheshi enjoys breakfast in the dining car. The landscapes sweep by; we pass baobab trees and come to a seaside minaret.

It is always hotter on the shore than in high-altitude Nairobi, and Mcheshi enthusiastically points out a boy with an ice cream cone as soon as they arrive. Just as every speaker of English knows the kiSwahili word "safari," so Mcheshi used the useful term "aiskrima." Soon she has her own cone and takes a cab to the airport. Up the coast they fly in a light airplane—Mcheshi of course wants to use the noisy helicopter, but it isn't going where they are.

Once at the island resort, Mcheshi gets a ride—"This is the best ride ever"—in a little man-drawn baggage cart and admires the fisherman's dhows—an old bilingual word—with their white sails. The people are less citified than Nairobians and have more varied clothing. A final brief donkey ride to her friend's shore house is the end of her adventure, as cheerily readable in Nebraska as in Nairobi, by careful design of the publishers, who intend these inexpensive and attractive bilingual books for children both in Kenya and in the U.S. There is a clear little map and word list for kids who might want to retell this story of a safari. Many more such books are coming from Jacaranda and their youthful artists, a growing series about Mcheshi and books on wider topics for more experienced readers.

Physics

BRIDGES GO FROM HERE TO THERE, written and illustrated by Forrest Wilson. Preservation Press, 1993 (1785 Massachusetts Avenue, N.W., Washington, DC 20036) ($16.95).

The big pages are striking with strong black silhouettes and nets of clear line. Once in a while we recognize a famous bridge, like the old bridge at Florence or the big structure that cantilevers the railroad across the Firth of Forth at Edinburgh; they are not even named, for Wilson has a lot to tell in very few words.

Most of the drawings show imagined teams of elephants, dogs, pigs and stocky heavyweight acrobats. All these figures have work to do. They teach by their efforts how bridges work, in the unmatched graphic style of this veteran architect and builder. Gravity, both enemy and designer, takes some explanation, so we see Planet Earth with a set of center-seeking arrows and again with every little piece of solid ground pushing up against gravity.

A single, friendly dog could be a small bridge, or a large team of trained dogs standing on one another's backs might even bridge a narrow fall. An arch "is all push," and we see—even better, we feel—strongman teams as one arch pushing hard, shoulder to shoulder, against two heavy elephant towers.

Cable pull is the best of all for a long bridge. A dozen dogs, jaws to tail, can build a growly bridge, held up at each end by one elephant trunk. All together such understanding can be used to make the longest cable suspension bridge in the world—it is drawn here very tall and long indeed—"because bridges are designed by gravity."

The author explains his book for young readers: "It is about bridges great and small and how gravity holds them together and pulls them apart. The reward of explaining bridges to young people is that if you listen carefully to their questions, you may understand the explanation yourself." The book does help wonderfully (although one remark about the cantilever leaves this reader looking still for someone to explain it to!).

BENDING LIGHT: DOZENS OF ACTIVITIES FOR HANDS-ON LEARNING, by Pat Murphy and the Exploratorium staff. Hand lens included. Little, Brown and Company, 1993 ($15.95).

The laboratory experience among kids in the early grades is not hard to simulate, but it is much rarer as the real thing. This thin book by a batch of knowing enthusiasts is a genuine specimen, as much for its tone overall as for its breadth of concrete, accessible variations.

Look around, notice what's up, and then you can play the changes while you watch: that's real experiment. Try the hand lens with the TV on in a darkened room, to make a neat upside-down image. Cover half the lens and cover half the screen; try them both. Make your own slide projector and draw some slides; all you need is your lens, a good flashlight and the right markers. Store-bought lenses are of plastic or glass, but try water in a plastic bag, Jell-O, even ice; all can make light-bending lenses, too. "Melt your way to a new view of the world." Don't forget your time in the bathtub with its underwater possibilities.

Air bubbles? Water droplets? Hot air dancing over the highway? The book is an open guide to help with details. Light is bending all around you, so watch and figure; you are just getting started.

Parents, this style of putting questions to the world and seeking a response is fortunately habit-forming.

Mathematics

SYMMETRY: A UNIFYING CONCEPT, by István Hargittai and Magdolna Hargittai. Illustrated with 800 photographs and diagrams. Shelter Publications, 1994 (P.O. Box 279, Bolinas, CA 94924) (paperbound, $21, including shipping).

A globe-trotting couple, structural chemists from Budapest, has assembled this fine display for general readers from ages 12 to 120. It shows that world of symmetries the authors first entered through the austere portals of electron diffraction.

First of all, it is a book of pictures in black-and-white. Half the book considers and displays in plenty chiral pairs of gloves and artfully dissected apples, pinwheels and flowers, sixfold snowflakes and the Eiffel Tower (a fourfold blossom as seen from straight above), balloon clusters and molecules. The latter half goes beyond mirrors and rotations, all those moves that leave one point fixed, to look at grander repeats, in fences and friezes, in spiral and helix, in honeycombs and tiled walls, finally in diamonds and Eschers.

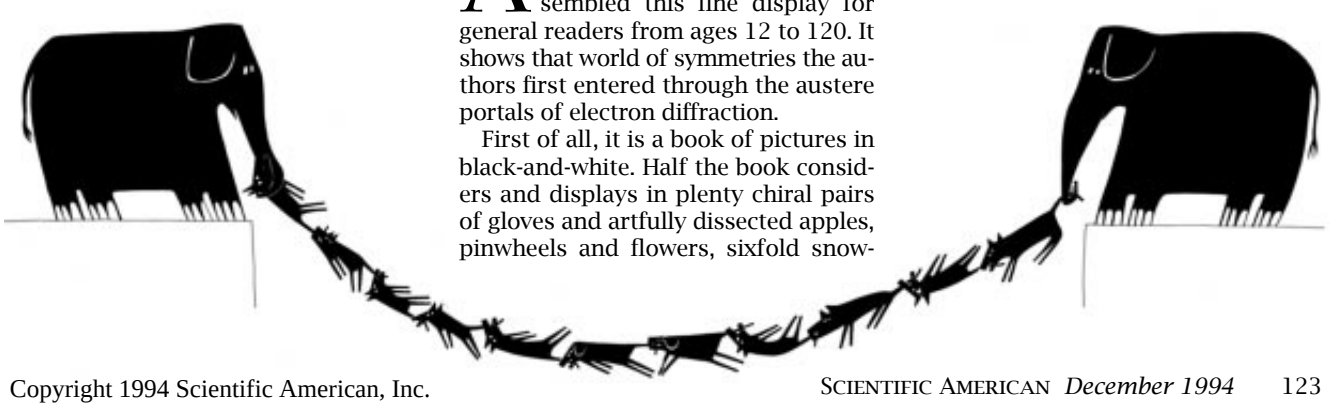
Art and nature draw similar attention here, mostly at the scale that meets the eye. The authors' own special interest in the microsymmetries inside matter is background, more strongly seen in their half a dozen technical books on the topic. As a field guide to easily grasped and beautiful exemplars of this powerful idea, the book is a storehouse hard to beat.

NUMBERS: FACTS, FIGURES AND FICTION, by Richard Phillips. Cambridge University Press, 1994 ($17.95).

Beautifully and devotedly made, this large, thin book is a cheerful and eccentric guide to the first 156 integers and a concise summary of the next ones up to 1,000. And it notes in passing a few landmarks on the long, long road past googol and googolplex to that infinity that is "countable but goes on forever."

Take 7, a popular member. It is a prime, a Lucas number, a Mersenne prime, the count of the deadly sins (all listed), part of the name *7-Up* that Mr. C. L. Griggs invented when his soft drink *Bib-label Lithiate Lemon-Lime Soda* wasn't selling, and the number of ways four paper hexagons fit together. It also is mentioned a lot in a verse about the way to St. Ives.

The book is an instructive amusement for the clubs and classes and libraries of arithmetic students who are coming to know the subtle art of counting. The extraordinary Ramanujan once remarked that even a random choice, 1,729, was interesting, as the smallest number expressible in more than one way as the sum of two cubes. Very few minds like his are met, but every young student ought to have the chance to build friendliness with some integer.



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AUTHORS

ARTICLES, BY KEY WORDS

THE AMATEUR SCIENTIST

MATHEMATICAL RECREATIONS

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ESSAY by Eric J. Chaisson

Clementine, Keyhole and Cosmic Rats

The cold war is over. It is time to lower the classification barriers concerning many of our nation's secret operations in space. The National Aeronautics and Space Administration, in particular, could roundly benefit from an infusion of expertise still guarded closely by the military-intelligence community. In fact, NASA could learn a number of very big lessons by studying how the "dark siders" develop and manage space missions of all kinds.

That our nation has two space programs is only shadily known. The obvious one is NASA—out in the open and frankly not doing too well these days. The other—larger in scope and budget—is the one run by the military and intelligence organizations. Although part of this space program is acknowledged to exist and its funding is in the public domain, its missions are largely secret. An even larger part is classified "black," meaning that it does not officially exist and that its budget is all but invisible.

America's clandestine space program began in the late 1950s and grew dramatically during the 1980s. In recent years two outstanding examples of the technologies this program has fostered have entered the public domain: the Global Positioning System (GPS) and the *Clementine* spacecraft. The GPS, developed and operated by the U.S. Air Force, is a big-technology program deploying 24 spacecraft in intermediate orbit. Although encrypted signals provide highly accurate targeting for Department of Defense (DOD) customers, the GPS also emits coarser signals that have revolutionized navigation for civilians. This magnificent practical application of space is comparable to the use of geosynchronous satellites for worldwide communications. Turning over this network to NASA, as Congress has proposed, would be a major mistake: the civil space agency has demonstrated repeatedly its inability to wield the vital tool of systems management.

In contrast with the scope of the GPS, *Clementine* is just one of the armada of small Star Wars vehicles lofted by the military and intelligence gatherers. Built by the U.S. Navy, it has carried to the moon miniature smart sensors that have returned a wealth of exciting information. With a budget of less than $80 million, *Clementine* is a superb example of how the DOD has acquired vast quantities of data for the dollar. Under the threat of budgetary cutbacks, the DOD was able quickly to reprogram its management structure to embrace the "small is beautiful" concept—something that inertia-ridden NASA seems unable to do. For the cost of a big-science *Cassini* spacecraft, now being defended by NASA, we could launch several dozen such *Clementine* probes to each of the planets and all of their major moons.

Foremost among the areas in which NASA might have learned a great deal from the intelligencers is the case of the *Hubble Space Telescope*. *Hubble* originally went into orbit in 1990 as a badly built vehicle—despite large cost overruns. A misshapen mirror, unstable solar arrays, poorly shielded electronics and, not least, inept systems management on the ground crippled the undertaking. Yet virtually every problem encountered by *Hubble* had previously plagued *Hubble*-class spy satellites.

That *Hubble* derives its technological heritage from Project Keyhole is well known. Keyhole is a cryptonym for an entire fleet of downward-looking "black" satellites, all controlled by a joint Air Force–Central Intelligence Agency directorate called the National Reconnaissance Office. By my estimate, since the mid-1970s nearly 20 *Hubble*-class Keyhole satellites have been launched, including several vehicles working impressively in orbit during the Persian Gulf War.

I now believe that at least the first Keyhole mirror that went into orbit was misshapen, in essentially the same way as was *Hubble*'s. The early Keyhole solar arrays wobbled—perhaps giving Keyhole its nickname, Big Bird—again, similar to problems *Hubble* suffered early in its mission. Likewise, only with experience did the dark siders come to realize the dangers to electronic equipment of traveling through the South Atlantic Anomaly of the Van Allen belt.

During *Hubble*'s commissioning in 1990–91, I served as unofficial liaison with some principal Keyhole handlers. During the course of these briefings, I learned the hard way that they knew all about the problem of solar-array oscillation, among other technical difficulties then plaguing *Hubble*. The implication I took from these awkward meetings was that because of the defense work ethic known as compartmentalization, the DOD had failed to warn NASA about faulty arrays, unshielded gadgets and the need to test its optics as a system. But since speaking out publicly about these issues—without revealing any numerical secrets, of course—I have received message after message from the intelligence community that they did, in fact, try to warn NASA about its misguided ways. Our civilian space agency simply failed to listen.

The military-intelligence fraternity has championed a host of unsurpassed, defense-triggered hardware and software. Certainly, it has also witnessed technical failures and management shortcomings, such as when a huge mirror shattered on the floor of a military observatory or when a *Hubble*-class spy satellite tumbled hopelessly in orbit. Yet the "other" space program is well out in front of NASA. Perhaps even more important, however, the reconnoiterers know well the art of systems engineering. They highly prize the concept of integrated design, analysis and testing. They practice holistic management, ever mindful of the complete product, the entire mission. With the cold war over, shouldn't we begin to break down some of the classification barriers, allowing knowledge and expertise to flow more easily between the two camps? The *Hubble* project especially could have benefited, then as now, from much greater technical input from those who years ago built its predecessors.

Oh, yes, cosmic rats. A slang term used by electronic intelligence agents (and a few *Hubble* astronomers), it describes high-energy particles zooming straight onto an array of light detectors. Without leaving a trail (as is normally the case), these corruptive little rascals—mostly residents of the South Atlantic Anomaly—tend to create "hot pixels," thereby increasing unwanted noise on an image. NASA would do well to know how the intelligencers handle such digital garbage. The space spooks, after all, have a lot more experience dealing with rats—cosmic and otherwise.

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