TELE-IMMERSION: LIKE BEING THERE ▪ HOW SAFE ARE GM FOODS?

SCIENTIFIC AMERICAN

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Whose Blood Is It, Anyway?

CORD STEM CELLS SAVE LIVES BUT RAISE QUESTIONS

PLUS:

Space Storms

The Roots of Violence

Life's Rocky Start

april 2001

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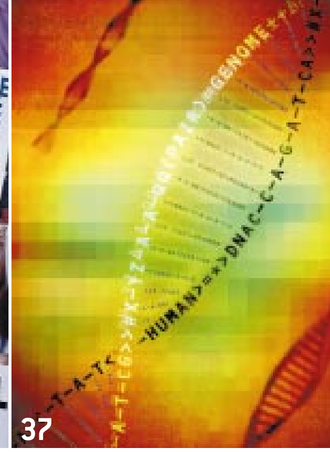


columns

Cover photograph by Robert Lewis;
preceding page: Pete McArthur;
this page (*clockwise from top left*):
Maurice Lima *AFP;* Brian Stauffer;
Timothy Archibald

SA Perspectives

The 21st-Century Handbook

Science has become the ultimate source of the most influential ideas transforming the world. Consider the evidence. Computers are the engines of the global economy. Three of the biggest international controversies are over the use of genetically modified crops, the prevention of global warming, and the feasibility of antimissile defenses. Some people even look to physics and cosmology for clues to the nature of God.

For readers of *Scientific American,* this is not news. This magazine has always been a must-read for the inexhaustibly curious, the ones who passionately want to understand what makes the world tick and who recognize that—especially in a technology-driven society—the only way to that enlightenment is through scientific discovery. For 155 years *SA* has been where they could turn for answers.

So why tamper with success? Why rethink the look and content of a magazine that is the best at what it does? Precisely because the magazine's mission hasn't changed but the readers' world has. The pace of discovery and innovation has quickened. Time for reading has become more precious. This magazine's methods and coverage therefore need to shift just so that it can continue to provide the same service.

Don't worry. This magazine will always be a forum where great minds (authors and readers alike) can gather to share insights and inspiration. Longtime fans of *SA* will continue to find the in-depth, authoritative feature articles by leading researchers and other experts that have been its hallmark. Top journalists and commentators will also continue to complement those articles with perspectives on new developments and their significance. The finest artists and photographers will elegantly illustrate the articles in these pages, as they have in the past. As editors, we remain committed to informing you of the facts clearly and fairly, to opening doors for further exploration—and maybe every once in a while to offering a provocative viewpoint as a challenge to your own thinking.

New departments will further enrich the *SA* experience. "News Scan" provides brief reports and observations to keep readers up-to-date. "Innovations" takes an informative look at how industries have managed new technologies. "Staking Claims" considers the intellectual-property controversies that now exert such a powerful influence on the shape of research, development and commerce in the digital/DNA era. "Technicalities" muses on the experience of test-driving new inventions, some fresh to the market, others still on the lab bench. It will alternate with "Voyages," debuting in the May issue, which will describe science-oriented destinations for travelers.

Science historian Michael Shermer will use his "Skeptic" column to weigh in on ideas that hover on the edge between breakthroughs and bunk. Dennis E. Shasha, of "Dr. Ecco" fame, carries on our tradition of mathematical recreations with "Puzzling Adventures."

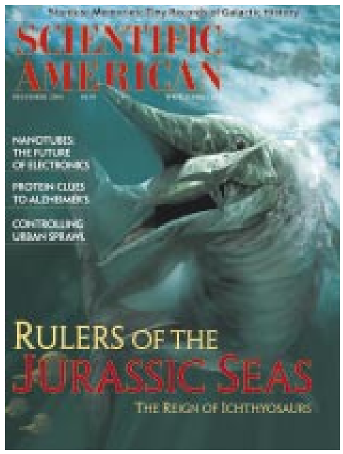
These days *SA* is literally more than can fit between magazine covers. Visit www.sciam.com, our Web site, for a roster of original articles (updated daily), supplements to the printed articles, and opportunities to communicate with the editors and authors.

I extend my thanks to Amy Rosenfeld and her colleagues, who developed our new layout and design. And to you, the reader, I extend an open-ended invitation to let us know what you think.

JOHN RENNIE editor in chief

A TALE OF ONE CITY

In "The Science of Smart Growth," Donald D. T. Chen equates low-density development with congestion. In fact, congestion results from higher densities and inadequate highways—exactly what smart growth prescribes. A comparison of Texas Transportation Institute traffic data with Census Bureau densities shows a strong correlation between high density and congestion. U.S. Department of Transportation data over time show no correlation between reductions in density and increases in driving. Low densities are the solution to congestion, and people prefer to live in such areas.



Planners in Portland, Ore., admit that their smart-growth policies will reduce per capita auto driving by less than 5 percent while quintupling the time people waste in traffic. Despite huge subsidies, transit-oriented developments in Portland suffer some of the highest vacancies in the region.

RANDAL O'TOOLE
Utah State University

CHEN REPLIES: Comparisons among these data sets actually show weak correlations, some supporting the opposite of what O'Toole claims. His argument is further weakened by its reliance on averaged densities across metropolitan areas, which lump sprawl with compact communities. Smart growth's traffic benefits are more a function of neighborhood-scale improvements, including design amenities, a diversification of uses (homes, shops, offices) and modest increases in density. A recent analysis of 50 empirical studies found that integrating these improvements in regions that have viable alternatives to driving can reduce vehicle-miles traveled by half.

The contention that Americans prefer to live in low-density areas has been disputed by the industry's leading annual analysis, Emerging Trends in Real Estate. *Since 1994 this report has predicted and demonstrated the declining appeal of sprawl and the booming demand for vibrant urban neighborhoods and "subcities" with good public transportation. These trends are evident in Portland, where land development officials note that transit-oriented projects they have overseen have average vacancy rates below 1 percent, outperforming conventional developments, which have vacancies of around 5 percent. Homes at Orenco Station, Portland's largest transit-oriented de-*

THE MAIL

"I HAVE DRIVEN IN EVERY DEVELOPED COUNTRY that drives on the left side of the road," writes Laurence W. Fredrick of the University of Virginia, "but I've never seen an intersection like the one depicted on page 84 ['The Science of Smart Growth,' by Donald D. T. Chen] of your December 2000 issue." Indeed, although smart growth attempts to reverse the harmful effects of sprawl, we inadvertently took that too literally: that photograph (of the 1986 inception of Virginia Beach Boulevard in Virginia Beach, Va.) was reversed, placing drivers on the wrong side of the road. Here it's shown in its correct orientation.

From flopped photographs to traffic congestion to space elevators to a gas that acts like a wave—have a look, won't you, at this column's discussion of December articles.

PHOTOGRAPH COURTESY OF DUANY PLATER-ZYBERK & CO.

velopment, sell for 20 percent more than similar homes elsewhere. Its only subsidies were federal grants for wider sidewalks and ornamental streetlights, which amounted to less than one half of 1 percent of the project's total cost.

Livability indicators tell a more comprehensive story. One recent Georgia Institute of Technology study found that, despite a decade of rapid population growth (26 percent), Portland has kept vehicle-miles traveled from rising and has reduced commute times, air pollution and per capita energy consumption while substantially boosting residents' perception of neighborhood quality. And in 2000, Money *magazine voted Portland the most livable city in America, citing its growth management efforts and transit system as major successes.*

ELEVATOR TO SPACE—GOING UP?

I'm surprised that "Nanotubes for Electronics," by Philip G. Collins and Phaedon Avouris, did not mention what may be by far nanotubes' most important application: the space elevator. Recently NASA's Institute for Advanced Concepts sponsored a six-month investigation that resulted in a fascinating report by Bradley C. Edwards concluding that the space elevator can be built using carbon nanotubes. His paper contains a section on their manufacture and possible cost, although these are, of course, extremely speculative.

When (not if!) the space elevator is built, the cost of reaching stationary orbit will be virtually zero, as most of the energy will be recovered in the return journey. I've often said that the real cost of escaping the earth one day will be catering and in-flight movies—although some kind of propulsion will also be needed to get away and to return.

ARTHUR C. CLARKE
Sri Lanka

AVOURIS AND COLLINS REPLY: *We have not read Edwards's report on the subject, but one may anticipate great difficulties in the implementation of the project. Although it is true that individual nanotubes have very high tensile strength, the record length achieved for a single nanotube is a mere two millimeters, and this applies only to multiwalled nanotubes, which have lower strength than single-walled tubes. One could make ropes from shorter tubes, but tube-tube adhesion is not particularly strong. That said, the carbon nanotube field is advancing at an incredible rate, and difficulties that appear insurmountable today may find simple solutions tomorrow.*

THE INDISTINGUISHABILITY OF ATOMS

In his description of the phenomenon of the Bose-Einstein condensate as the end of an elaborate and remarkable cooling process ["The Coolest Gas in the Universe"], Graham P. Collins concludes that "although the atoms still exist within it, composing it, they have lost their individuality." What does that mean for atoms? Later he states that they can expand to 100,000 times their normal size when sufficiently cooled. How do the atoms expand?

In the second section of the article, Collins refers to work by a JILA research group using "a double condensate." What does it entail to have "two overlapping condensates made of the same element (rubidium) but in different quantum states"?

JOSEPH E. QUITTNER
via e-mail

COLLINS REPLIES: The atoms in a condensate are utterly indistinguishable from one another, not just in practice but in principle. The measured physical properties of condensates experimentally confirm their indistinguishability—distinguishable atoms would not behave as condensates do. In many ways, a condensate containing a million atoms is not like a collection of a million particles but rather like a wave made a million times stronger.

What expands during cooling is each atom's wave function, meaning that the atom is effectively smeared out over a region of space. The nucleus and electrons of each atom still form a structure of the usual size, but the location of that structure, the atom, is made large and fuzzy, or uncertain.

The quantum states of the overlapping rubidium condensates relate to the arrangement of the electrons in each atom. Imagine that each marble in the article's opening analogy is covered with paint and that half are red and half are blue. Each group of atoms would form its own condensate, and, being very dilute gases, they can coexist in the same region, somewhat like the oxygen and nitrogen in the air around us. With lasers, the experimenters can change any number of atoms back and forth from "red" to "blue," altering the number of atoms in each condensate. Which particular atoms change from red to blue at any time? Impossible to say, and meaningless to try to say.

ERRATUM A paper cited in "Muscling DNA," by Diane Martindale [News Briefs, News and Analysis], appeared in the October 13 issue of *Science*, not *Nature*, as was stated.

50, 100 & 150 Years Ago

Baby Boom Noted ▪ Rabid Denial ▪ The Most Perfect Machine

APRIL 1951

1950 CENSUS—"Between 1940 and 1950 the U.S. experienced the largest numerical population increase in its history. According to the first detailed returns of the official 1950 Census count, our population rose by over 19 million during the decade. This large increase was not anticipated: the 1950 total of 150,697,361 was about seven million above the highest prediction made by population experts a decade ago. Wartime prosperity lifted the birth rate and produced the largest crop of babies ever. Concurrently the death rate has fallen to a new low. Immigration, although a relatively negligible factor, also added about one million, including refugees and displaced persons."

DDT SHORTAGE—"The World Health Organization last month reported a developing shortage of DDT so serious that it threatens the breakdown of the campaign against insect-borne disease, which since the end of the war has wiped out malaria in many parts of the world. The shortage is due to increasing use of the insecticide by farmers and by the armed forces for the defense program, and shortages of the ingredients. Roberto Caceres Bustamente, Under Secretary of Public Health in El Salvador, declared: 'DDT is for us a problem of living or dying. In a population of 2,500,000 there are more than 200,000 cases of malaria.'"

APRIL 1901

RABIES FEAR—"The committee reporting to the American Public Health Association says that rabies in the United States is becoming more common. Fatal as the disease is in man, the committee finds its greatest cause for alarm not in the dreadful nature of the disease, nor yet in the difficulties attending its control by sanitary measure, but in the existence in the United States of numerous societies with large membership which are deliberate and active in the circulation of literature calculated to deceive the people as to the existence of this disease, and to develop obstacles to the health officers in their efforts to eradicate it. It has been frequently asserted that there has not been a single well-established case of either rabies or hydrophobia in the great City of New York for the past thirty years, and yet the records of the American Veterinary College show an average of seven cases a year for twenty-five years."

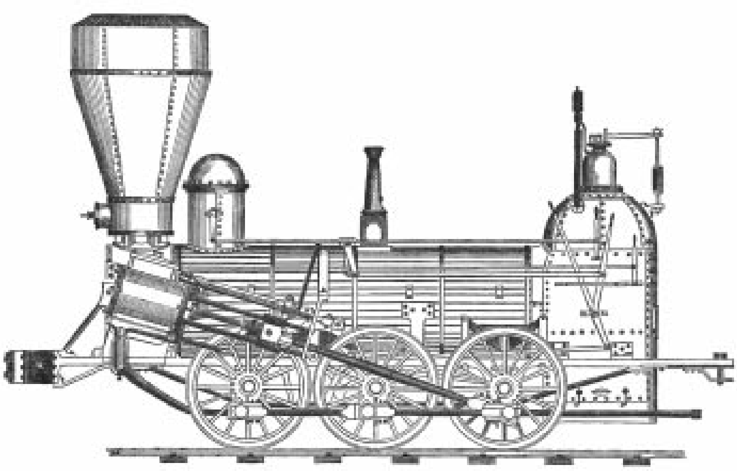
X-RAYS—"Five years have elapsed since Prof. Roentgen startled the world by the announcement of his discovery of the rays which are now quite commonly called by his name. We must admit that no more is known today as to the essence of the rays than was contained in Prof. Roentgen's original paper. They do not behave like any other radiation known to science; yet scientific men are generally of the opinion that they belong in the ultraviolet region of the spectrum, perhaps having the shortest wave length of any known radiation—so short that it is not possible to deviate them from their course by any known form of reflecting or refracting substance."

APRIL 1851

FOSSIL EGG—"Recently arrived in France, from the island of Madagascar, are three enormous fossil eggs, with some bones of a gigantic bird, which is not doubted to have hatched them, or been hatched from one of them. M. Isidor Geoffroy St. Hilaire pronounces these extraordinary remains to be those of a bird which he has named Epiornis. It is classed along with the gigantic fossil birds of New Zealand."

THE RAILWAY ENGINE—"The locomotive is the most perfect of machines. It approaches nearer to the spiritual and physical combination of the human machine than any other. In it we behold the steam engine 'unchained to the rock, and unfettered to the soil.' The accompanying engraving is a side elevation of an American wood-burning locomotive, the kind which is in general use in our country. The engine is of 162 horse power, and is capable of drawing 225 tons at the rate of about thirty miles per hour."

SCIENTIFIC AMERICAN



THE LOCOMOTIVE, "the most perfect of machines," 1851

FROM SCIENTIFIC AMERICAN

news SCAN

HEALTH

Aborted Thinking

REENACTING THE GLOBAL GAG RULE THREATENS PUBLIC HEALTH **BY MARGUERITE HOLLOWAY**

HURT MOST by withdrawn U.S. funds could be Russia's abortion-providing centers.

PHOTOGRAPH BY SOVFOTO/EASTFOTO

With the very first act of his presidency, George W. Bush managed in one fell swoop to alienate myriad family-planning groups, women's health organizations, physicians and European allies. A memo to the U.S. Agency for International Development revived what is officially known as the Mexico City Policy—or, less formally, the Global Gag Rule. The order states that U.S. AID cannot dispense family-planning money to an organization unless it agrees to neither perform nor promote abortion. Rather than barring funds for abortion itself—the 1973 Helms Amendment already does that—the policy instead curbs health care providers' ability to talk about medical options at organizations that continue to accept aid. For those that do not comply, the policy means a loss of funds for counseling and contraception.

Many public health experts say the effects of this order today may be more devastating than they were in 1984, when the policy was first introduced. The world is a different place with regard to the AIDS epidemic, the desire for contraception and family-planning services, women's rights and attitudes toward abortion. President Bush's initiative will cut money where it is most needed, says Anibal Faúndes, an obstetrician in Brazil and a member of the International Federation of Gynecology and Obstetrics. "Consequently, he will certainly be responsible for increasing the number of abortions instead of reducing them."

Some of the places hardest hit may be those where abortion is legal, such as Russia, India and Zambia. For instance, the International Planned Parenthood Federation has been actively promoting contraception in Russia. As a result, Russian women have shifted away from abortion—formerly considered the only method of family planning—to birth control. In recent years, the percent-

SETTING UP GAG RULES

The Mexico City Policy originated at an international conference on population in Mexico City 17 years ago. The rule, issued by former president Ronald Reagan, did not include a great deal of detail about implementation, and it was not until the administration of the elder George Bush that the policy was clarified in 10 pages of U.S. AID rules. President Bill Clinton lifted the policy by executive decree immediately after he took office in 1993. The Republican-led Congress reinstated the gag rule last year—linking it to appropriations for U.N. funding—but President Clinton waived it.

age of women using contraception rose from 19 to 24 percent, and the abortion rate dropped from 109 per 1,000 women to 76 per 1,000 women, according to Susan A. Cohen of the Alan Guttmacher Institute. The federation, however, now stands to lose $5 million in U.S. AID money as a result of President Bush's rule. "The construction of a firewall between abortion services and family planning means that when a woman gets an abortion, family planning is not there," contends Steven Biel, spokesperson for Population Action International. "We know that the time when women are most motivated to get contraception is following an abortion, when they have just gone through the horrible experience of terminating a pregnancy."

PROTESTERS in Brazil rally against the Bush family-planning decision.

PHOTOGRAPH BY MAURICIO LIMA *AFP*

In places where abortion is illegal, the policy may not reverse trends away from abortion but instead may impair physicians' ability to take care of patients. Although the rule stipulates that organizations can treat women suffering from postabortion complications, many providers may become too scared to do even this, Biel says. "The result we have seen most is that groups tend to overrespond and distance themselves from anything that has to do with abortion," he observes. Therefore, clinics may not keep manual vacuum aspiration (MVA) equipment on the premises, even though it is needed to treat postabortion distress (often caused by back-alley operations). More than 78,000 women die every year from botched abortions. "If you have ever seen a woman hemorrhage to death, you never want to see it again," says Adrienne Germain, president of the International Women's Health Coalition. "It is one of the worst possible deaths."

Women's groups that advocate safe abortion and receive U.S. funding will have to forfeit their right to speak. If they decide to forgo aid, they will lose money for contraceptives. That, in turn, may lead to more abortions—one of the policy's greatest ironies. Women who do not use contraception are nearly six times more likely to have an abortion than women who do, according to Cohen. Even absent the Mexico City Policy—which applies only to the $425-million family-planning budget of U.S. AID—the United Nations reports that there is a worldwide shortfall of $3.6 billion in meeting demands for family-planning services. This unmet need is reflected in 80 million unwanted pregnancies every year. "We have more and more women who are interested in delaying or avoiding pregnancy," says John Bongaarts of the Population Council. "All these women need contraception."

They also need condoms to prevent the transmission of HIV. At least 34 million people worldwide have AIDS or are infected with HIV. And there are some 5.4 million additional HIV infections every year, out of a total of 333 million new cases of sexually transmitted disease, according to U.N. reports. U.S. AID estimates that the paperwork involved in enforcing the Mexico City Policy—which requires certification by each organization and each group that subcontracts from it—will cost more than $500,000. That is equivalent to more than 19,379,000 condoms wholesale.

THE LEGAL DIFFERENCE

Where Abortion Is Legal	Abortions per 1,000 women	Maternal deaths*
U.S.	26	12
Australia	17	9
England/Wales	15	9
Japan	14	18
Finland	10	11
Netherlands	6	12
Where Illegal		
Peru	52	280
Chile	45	65
Dominican Republic	44	110
Brazil	38	220
Colombia	34	100
Mexico	23	110

*Rate per 100,000 live births; refers to any deaths associated with delivery

SOURCES: Alan Guttmacher Institute (abortion rate data); *Population Action International*

PHYSICS

Ultimate Stop Motion

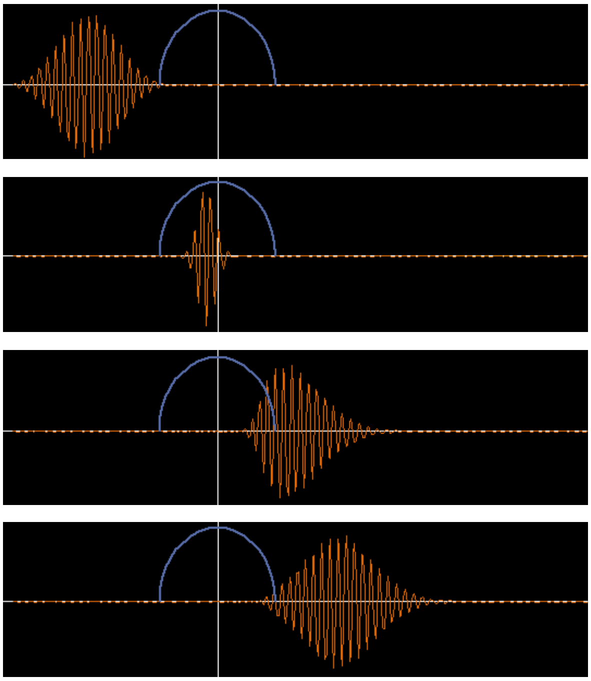
AN EXPERIMENTAL TOUR DE FORCE PUTS PULSES OF LIGHT ON ICE BY GRAHAM P. COLLINS

Light is the fleetest of phenomena. Indeed, "the speed of light" is synonymous with the universe's ultimate speed limit. Yet even light slows down when it has to slog its way through matter—glass or optical fiber, for example, cuts light back to about 70 percent of its top speed, which is still fast enough to circumnavigate the earth five times in a second. Two and a half years ago physicists demonstrated how a specially prepared gas could slow light by a factor of 20 million, to the pace of a speeding bicycle. Now two groups have used such a system to bring light, in effect, to a complete halt and then controllably release it back on its way. The process could have applications ranging from extremely precise measurements of properties of atoms to quantum computing.

Lene V. Hau's group at the Rowland Institute for Science in Cambridge, Mass., and at Harvard University carries out these tricks in a tiny cloud of sodium atoms chilled to less than a microkelvin above absolute zero. The other group, led by Ronald L. Walsworth and Mikhail D. Lukin of the Harvard-Smithsonian Center for Astrophysics, also in Cambridge, achieves much the same results in a four-centimeter-long cell of rubidium vapor almost as hot as boiling water. Both use the same two-step process to freeze the light.

First a laser sends a carefully tuned pulse of light into the gas. Usually the gas would be as opaque as a brick wall to this "signal" light and would completely absorb it. In these slow-light experiments, however, a second "control" laser beam is irradiating the gas, making it transparent to the signal pulse. This effect, called electromagnetically induced transparency, was pioneered in the early 1990s by Stephen E. Harris of Stanford University and others. The control light interacts with the atoms and by a process of quantum interference eliminates their ability to absorb photons of the signal pulse. The changes to the gas's optical properties also greatly slow down the speed of the signal pulse. Such slow light was demonstrated a couple of years ago by Hau and Harris and their colleagues.

Traveling through the gas in unison with the slow pulse is a pattern in the alignment of the atoms' tiny magnetic fields, which exactly mimics the form of the light pulse. The combination of atomic polarizations and light is called a polariton. Stopping this polariton—the second step of the process—is achieved by turning off the control beam while the polariton is still traversing the gas. As the control beam's intensity ebbs, the remaining signal light is absorbed, and the increasingly atomic polariton slows even more. At zero intensity, the last glimmer of the light vanishes into the atoms, and the polariton comes to a dead stop.



A PULSE OF LIGHT, a brief burst of electromagnetic oscillations (*orange*), is compressed and slowed in the artificially transparent atomic gas (*blue*). The pulse can be frozen in place as a magnetic pattern in the atoms and then regenerated.

IMAGES BY LENE V. HAU AND CHIEN LIU *Rowland Institute for Science*

All the properties of the light pulse remain encoded in this motionless entity. The experimenters demonstrated this by waiting for a while—only a fraction of a second but aeons on the timescale of the original light pulse—and then turning the control beam back on again. The polariton is converted back into a pulse that now crawls onward to the far end of the gas and then speeds away through the air.

Of course, the storage and regeneration of the light is not perfect; the longer the pause, the more degraded the output pulse becomes. The atoms that carry the polarizations are not, after all, frozen in place. Diffusion and collisions steadily disperse and destroy the polariton—more rapidly in the hot gas.

The process achieves a key function needed for large-scale quantum-information processing, as would occur in quantum computers: reliable interconversion of fast-moving quantum states (light pulses) and robust stationary ones (polaritons). Quantum-computing expert David P. DiVincenzo of IBM cautions, however, that other aspects of the slow-light system are not so well suited for quantum computation. "It doesn't produce a straight shot to a quantum computer," he says. Nevertheless, he calls it "beautiful research" that is "a very positive step forward in the manipulation of quantum systems."

FINGER ON THE PULSE

A 10-microsecond pulse of light is **three kilometers long** in air but is crammed into **0.3 millimeter** inside the cold gas used in the experiment.

The light pulse can be regenerated in **compressed or stretched form**—or in multiple copies—by varying how the "read-out" laser beam is applied.

The cold gas experiment stores and revives **entire pulses;** the hot gas stores only **parts of pulses.**

Longer storage times are achieved in the cold gas. Slightly colder gas—**a Bose-Einstein condensate**—should preserve pulses for even longer times.

OPTICS

Sight Unseen

ADAPTIVE OPTICS COULD IMPROVE LASIK AND IMPART SUPERHUMAN VISION **BY NEAL SINGER**

It's a heady prospect for those burdened by eyeglasses—reshaping the cornea itself so that the eye no longer needs help to see distant objects. Some 1.3 million Americans will undergo laser surgery this year, making the operation one of the most popular in the U.S. For about 2 percent of patients, however, laser in situ keratomileusis (better known as LASIK) has left them with vision that's worse or with annoying side effects such as starbursts when their pupils open wide. Now a more precise technique may lower the risks, correct problem results and even help eyeballs achieve the legendary vision of a hawk.

FOR ALL TO SEE: LASIK surgery at the Fair Oaks Mall in Fairfax, Va.

Currently in most LASIK procedures, a laser beam trims the cornea on a relatively broad scale. By correcting what is termed spherocylindrical error, the method usually results in light focused more accurately on the retina. But smaller-scale bumps and depressions that vary for each person go undetected and unimproved. That may soon change, thanks to adaptive optics—a system that measures light distortion and corrects it with deformable mirrors. It was adopted by earthbound astronomers to correct for atmospheric distortions and later borrowed by researchers—notably David R. Williams of the University of Rochester—who examined the eye's tiny rods and cones through its shifting vitreous liquid.

Further exploration demonstrated that adaptive optics could detect and compensate for imperfect cornea-lens combinations. Laboratory subjects achieved astonishing, above-average acuity, particularly in low light. "When you're using the adaptive optics system, you just say, 'Wow,' " Williams remarks.

Researchers are testing half a dozen or so instruments that rely on adaptive optics for laser eye surgery, known as customized corneal ablations. The first step is to map the corneal defects. Such a map can be generated in several ways: from individual points of light on the retina; from superimposition of a grid projected onto the retina (squiggly lines show corneal imperfections); or even from patients using joysticks to shift perceived points of light onto markers. The data guide lasers in ablating tiny amounts of tissue.

For the moment, the technique is restricted to research status in the U.S. "Everyone is racing" to get government approval, says Marguerite B. McDonald of the Southern Vision Institute in New Orleans. Firms involved include Bausch & Lomb, Nidek, VISX and Summit Autonomous.

Considering the potential complications of surgery, the rush to substitute possible hazards for the minor inconvenience of wearing lenses may be hard to understand. Indeed, unless one is a baseball player, say, or has suffered previous eye damage, customized corneal ablation "is essentially cosmetic surgery," comments Stephen Burns of the Schepens Eye Research Institute in Boston. "Most people work in offices and have no reason to see to infinity."

Burns raises philosophical questions as well. Could the slight differences in focal distance created by corneal irregularities actually aid the eye in seeing a variety of light frequencies? If so, is that more desirable than excellence of vision at a single frequency? The rapid pace of innovation, however, would seem to leave little time to ponder such questions. "There's so much happening, with so much equipment and so much money," Burns sighs. "It's hard to keep up with it all."

Neal Singer, based in Albuquerque, writes about science for Sandia National Laboratories. He is quite fond of his glasses.

PHOTOGRAPH BY STEPHEN JAFFE *AFP*

NEED TO KNOW: SIGHT LINES

A hawk's vision is estimated to be **20/5:** it sees from 20 feet what most people see from five.

Adaptive optics mirrors descended from "Star Wars" missile defense technology—they were **developed secretly by the U.S. military** to sharpen images taken of Soviet satellites in orbit.

There are several caveats to customized corneal ablations. Dilation agents added to the eye **distort the cornea** slightly, thereby affecting the data taken to program the laser. **The eye changes shape over time,** a natural process nearly guaranteed to throw any adjustment out of camber eventually. And **corneal thinness may make difficult the resectionings needed** to correct problems of earlier operations, such as starbursts.

CONSERVATION

Full of Croc?

A ZEALOUS CROCODILE WRESTLER GOES TO THE MAT FOR ANIMALS **BY SARAH SIMPSON**

Many people think of Steve Irwin as that crazy Aussie who wrestles crocodiles on TV. He has produced dozens of wildlife documentaries for cable's *Animal Planet*. His wild-man persona even dominates a Federal Express commercial and the trailers for Eddie Murphy's upcoming *Dr. Dolittle* film sequel. So is this guy just an entertainer with a brazen attitude around wild animals, or is he a committed wildlife conservationist? I went to Queensland, Australia, to ask the Crocodile Hunter himself.

Q: Why do you think you're so popular?
A: You know what I reckon it is? My belief is that what comes across on the television is my enthusiasm and my passion for wildlife. My mum and dad were very passionate about that, and I was lucky enough to go along. The first crocodile I ever caught was at nine years of age, and it was a rescue. So now what happens is the cameras follow me around and capture exactly what I've been doing since I was a boy. When I'm talking to the camera, I'm talking to *you,* in your living room.

Q: Is that zany approach an advantage for you or for your viewers?
A: It excites them, which helps me to educate. That's the main aim in our lives, to promote education about wildlife and wilderness areas, save habitats, save endangered species. So if we can get people excited about animals, then by crikey, it makes it a heck of a lot easier to save them. Take the crocodile, for example—my favorite animal. My tactic with conservation of predators is to take people to where they live. But I sincerely and vehemently oppose "sustainable use," where people think they can *farm* crocodiles and kill them and turn them into boots, bags and belts. Killing any wild animal will never save it.

Q: What do you see as Australia's biggest environmental issue?
A: I believe our biggest issue is the same biggest issue that the whole world is facing, and that's habitat destruction.

Q: How would you balance development and conservation, then?
A: We've got a koala conservation area—2,000 acres. We've got koalas and cows in the same paddy, and I'll demonstrate how it can be done. The problem that a lot of Third World nations have [with wildlife conservation] is currently incurable. I'm not sure what we do there, but I'm trying my darndest to get our show into every single country in the world—because *it works*.

CLOSE ENCOUNTER: Steve Irwin's uncanny sense for a crocodile's reach leads to some hair-raising feeding sessions.

PHOTOGRAPH BY TIM LYONS

MORE TO EXPLORE

Ever wonder how many times Steve Irwin's been bitten or what his wife, Terri, thinks of her husband's antics? Read the complete interview, which includes those topics and more about the Irwins' conservation efforts, at www.sciam.com

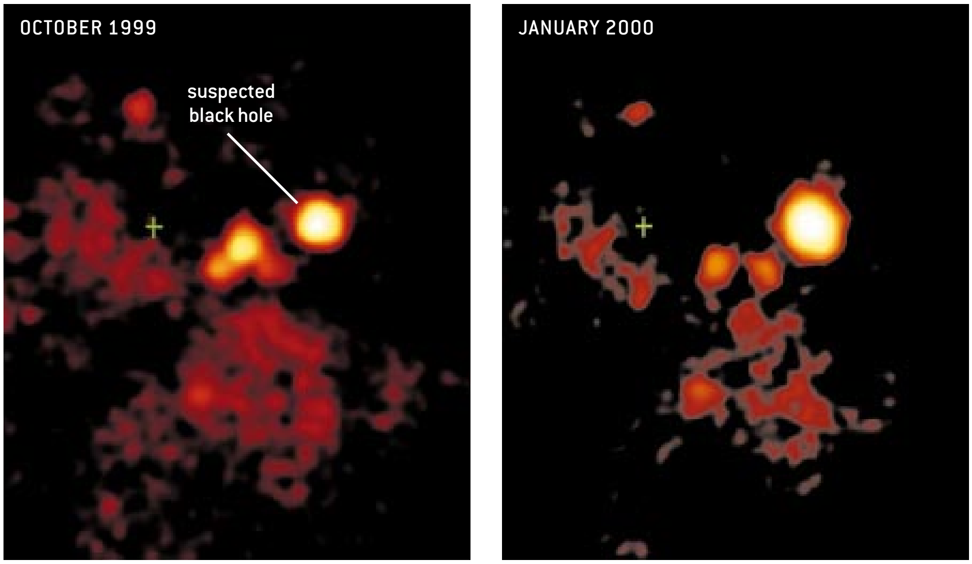
ASTRONOMY

Hole in the Middle

NOT TOO BIG, NOT TOO SMALL, A NEW CLASS OF BLACK HOLE EMERGES **BY GEORGE MUSSER**

Astronomy is the science of extremes—the biggest, farthest, oldest, hottest, coldest, densest, emptiest things known to man. But lately it seems that the strangest celestial bodies come in a medium size. Presenting: the midsize black hole.

The textbooks say that black holes fall into two categories: ones with the mass of a star, formed when a dying star implodes, and ones with the mass of a billion or so stars, formed no one knows quite how. Over the past several years, however, astronomers have built up a case for holes with a mass of 100 to 10,000 suns. "They might be a bridge between the ones we know about—the stellar-mass objects—and the ones we think we know about,



POSSIBLE MIDSIZE BLACK HOLE, 600 light-years from galaxy M82's center (*green cross*), got brighter over a three-month period. To its left are three splotches that got dimmer; they are thought to be smallish holes.

the supermassive black holes," says Martin J. Ward of the University of Leicester in England.

In the mid-1980s orbiting observatories began noticing mysterious dots gleaming in x-rays. These dots were brighter than known stellar-mass holes and dimmer than active supermassive holes. Taken at face value, their luminosity implied a mass of 100 or so suns. Any less and gravity would be unable to hold back the outward pressure of light; the objects, whatever they were, would blow themselves apart. Today astronomers know of more than 200 of these intermediate-luminosity x-ray objects (IXOs), according to Edward J. M. Colbert of Johns Hopkins University. Half the spiral galaxies examined have at least one.

Last fall three groups—led by Richard E. Griffiths of Carnegie Mellon University, by Philip Kaaret of the Harvard-Smithsonian Center for Astrophysics and by Hironori Matsumoto of the Massachusetts Institute of Technology—announced Chandra observations of the brightest IXO, located in the galaxy M82. If anyone thought that higher resolution would make the problem go away, that the IXO would prove to be a tight clump of ordinary bodies, they were wrong. Although Chandra did make out a clump, at least one member of the clump still qualifies as an IXO. It is clearly offset from the center of the galaxy—ruling out a dormant supermassive hole (which would quickly sink to the middle)—and from radio and infrared sources, arguing against supernova debris (which would glow at multiple wavelengths).

Kaaret's team also thought it had found 10-minute flickering, which, by implying a size of less than 10 light-minutes, would have been proof of a mesohole. NASA called a triumphal press conference. Two weeks later the flickering proved to be an instrumental artifact. NASA did not call a second press conference.

Other groups have taken x-ray spectra of various IXOs and caught them flip-flopping between two modes: bright and cool, dim and hot. Known holes do just that. Until recently, however, there was a problem with the hole hypothesis. A bigger hole has a wider maw, so the disk of material around it should stay farther away and hence be cooler. Yet IXOs are actually hotter than stellar-mass holes. Ken-ya Watarai of the University of Kyoto in Japan and his colleagues have proposed a solution: material falls into the hole at such a high rate that the disk, in effect, pushes inward. A fluctuating rate neatly explains changes in the luminosity and temperature of three IXOs.

For theorists, intermediate masses are a no-hole's-land. Dying stars might leave behind a hole of 15 solar-masses, tops; heavier stars don't necessarily make heavier holes, because they tend to shed weight during their flamboyant lives. On the other end, gas clouds in the early universe collapse to holes of a million solar-masses and up. Perhaps the midsize holes involve the merger of stars or stellar-mass holes in a star cluster, for which there is some evidence in M82. Or maybe they resulted from the collapse of the first generation of stars, which, having formed in simpler times, were a race of Titans. But none of these and other explanations is problem-free. "I apologize for the confusion," says theorist Roeland van der Marel of the Space Telescope Science Institute. "This is not a field where a paradigm has formed. That's what makes it interesting."

MOTHER OF ALL STARS

If middleweight black holes are the corpses of the very first generation of stars, the Milky Way may originally have contained 5,000 of them. Some merged into the supermassive hole at the center of our galaxy, and the rest may still be careening invisibly through interstellar space.

Once every 10 million years or so, one of these black holes enjoys a tasty platter of braised star. The plummeting morsels heat up and glow brightly, causing a spectacle that may be what x-ray satellites, such as the Chandra X-ray Observatory, have been seeing. This scenario, recently outlined by Piero Madau of the University of California at Santa Cruz and Martin J. Rees of the University of Cambridge, could be the key to understanding how galaxies took shape.

PHOTOGRAPHS COURTESY OF NASA/SAD/CXC

ROBOTICS

I, Robonaut

NASA'S SPACE-WALKING AUTOMATON SLOWLY COMES TO LIFE **BY PHIL SCOTT**

Space walks are dramatic, as the installation of the Destiny module on the International Space Station in February demonstrated. A micrometeorite impact, a snag, a wayward tool or even a misstep can spell doom for an astronaut. As the station takes shape, however, construction and repair will demand more of these extravehicular activities (EVAs). One remedy: let the android do it. At least that's the plan of the National Aeronautics and Space Administration scientists working on Robonaut.

The idea of maintenance robots originated after a 1990 study concluded that an orbital station would require 75 percent more space-walking time than originally planned. Keeping the station operational "would take more time than we had astronauts," explains Chris Culbert, chief of the robotic systems technology branch at the NASA Johnson Space Center. "That sent us on a path of finding robotic ways to do the maintenance."

The first stop for NASA's roboheads was DART, or Dexterous Anthropomorphic Robotic Testbed. "It had two arms and two hands," Culbert says, "but it was built using commercial, off-the-shelf products." The engineers controlled DART through "telepresence": an operator would don virtual-reality helmet and gloves, and the robot would mimic the operator's motions.

But it was too bulky ever to fly into space. So three years ago the robotics crew began to build Robonaut, designed to be the size of a suited astronaut and to be just as dexterous. "The biggest problem is that the operator has no sense of touch," comments Chris Lovchik, a NASA senior engineer working on the hands. "To some degree, it's like operating on Novocain, but at the same time the tools fit into your hand as you would expect them to. Visual feedback helps quite a bit."

"It can pick up an object and manipulate something on that object," adds Robert Ambrose, Robonaut project leader at the Johnson center. "It can use a pistol-grip drill designed for a human, and it can articulate the trigger. That's very unusual for a robot." Engineers plan to have Robonaut function beyond telepresence, operating on voice command.

Then, too, some Robonaut technology might come in handy down here on Earth. In Somerset, England, scientists have developed a robot that incorporates the brain of the primitive sea lamprey *Petromyzon marinus*. When fed information through light sensors, the brain sends signals to the robot's motors, telling it how to respond. Such technology could allow prosthetics to be controlled directly from the brain. Developing prosthetics from Robonaut, however, is not in NASA's immediate future. "It is not impossible," Culbert explains. "But to interface it to the human nervous system—we don't have that capability."

In fact, only late last year did the NASA team install Robonaut's left hand and torso. The best prediction is that it will be two years before the robot is ready for launch. The slow pace stems in large part from the project's minimal funding. "A lot of the attitude will change as the station becomes more and more of a burden on the astronauts," Lovchik says. "Systems like this will look much, much better."

Phil Scott is a technology writer based in New York City.

DO AS I DO: Virtual reality for controlling Robonaut's motions.

PHOTOGRAPH COURTESY OF NASA

ROBONAUT'S VITAL STATISTICS

Has more than **47 degrees of freedom,** 14 in each hand alone; human hands have 22

Has half the grip strength of a human, and **arm can lift only 21 pounds**—still strong enough for space work

Incorporates various sensors, including **thermal, positional, tactile, force and torque instrumentation**; each arm has more than 150 sensors

Relies on software written in **C and C++**

Why Robonaut resembles bounty hunter **Boba Fett from *Star Wars:*** "The face had to meet a couple of characteristics: it had to **support the cameras—the eyes**—and have room for additional cameras, small ones pointing down through the chin. It just happened to look like a character out of *Star Wars.*" —Chris Culbert, NASA

DATA POINTS: DRUGS FOR BUGS

Amount of antibiotics given annually to hogs, poultry and cattle in the U.S.:
In 1985: 18 million pounds
In late 1990s: 25 million pounds

Percent of all antibiotics given to livestock that is used to treat disease: 7

Amount of antibiotics used by Americans annually: 4.5 million pounds

Amount in topical creams, soaps and disinfectants: 1.5 million pounds

Percent of liquid soaps that contain antibacterial ingredients: 76

Percent of people who say they wash their hands after using a public restroom: 95

Percent observed doing so: 67

Number of Americans infected (after eating chicken) with *Campylobacter* resistant to antibiotic fluoroquinolone:
In 1998: 8,782
In 1999: 11,477

Percent of *Streptococcus pneumoniae* infections in the U.S. that were penicillin-resistant:
In 1987: 0.2
In 1994: 6.6

SOURCES: Union of Concerned Scientists, "Hogging It: Estimates of Antimicrobial Use in Livestock," January 2001; Beth Israel Deaconess Medical Center; American Society for Microbiology; U.S. FDA

AMAZON RIVER (*blue*) meets the Rio Negro (*black*); the colors differ because of the sediment they carry. Whether organic sediment from rivers makes it to the ocean had been unclear.

BIOLOGY

Disposing of Misfolded Proteins

A basic task of cells is to make proteins, which must fold properly in order to function. But sometimes cells botch the job, leading to misfolded proteins that are useless or even dangerous. How exactly most cells repair or destroy flawed proteins has remained somewhat elusive—until now. As reported in the January *Nature Cell Biology*, experiments revealed a component of the repair process that may participate in a cell's decision to fix or destroy a particular protein. Researchers found that a molecule called CHIP first prevented chaperones, which repair proteins, from trying to refold an unsalvageable protein, then subsequently transferred the hopeless case to a proteasome, which destroyed it. These findings may help researchers develop new treatments for Alzheimer's disease and other kinds of neurogenerative disorders associated with an accumulation of misfolded proteins in cells. *—Alison McCook*

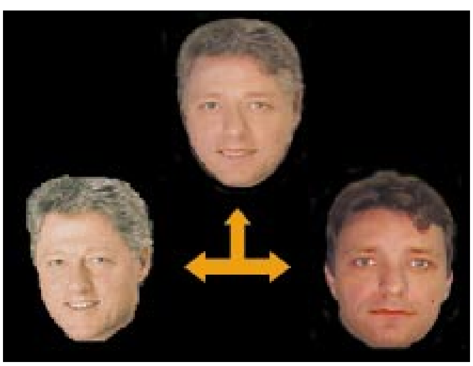
EARTH SCIENCE

Take Me to the Ocean

Rivers should dump plenty of organic matter into the sea, replacing all the ocean's carbon in 4,000 to 6,000 years. But geochemical studies have suggested that little of the riverine carbon, derived from plants, actually makes it out. In the January 25 *Nature*, researchers report a possible solution. Using radiocarbon techniques on sediments collected from four rivers, they determined that bacteria may alter riverine carbon, making it indistinguishable from ocean carbon. Although it fills in details about the carbon cycle, the study deals with timescales too long to affect carbon dioxide–influenced global warming by humans. In fact, in February the Intergovernmental Panel on Climate Change raised the estimate of the world's temperature rise between 1990 and 2100 from 1.0 to 3.5 degrees Celsius to 1.4 to 5.8 degrees C. *—Philip Yam*

NEUROSCIENCE

You Look Awfully Familiar



DO YOU KNOW ME? Subjects had their faces blended with a celebrity's to determine which hemisphere is involved in self-recognition, an ability shared with some apes and considered to be a hallmark of self-awareness.

Your sense of self may lie in the right side of your brain. In the January 18 *Nature*, Julian Keenan and his Harvard Medical School colleagues numbed the right or left hemispheres of five epilepsy patients and then showed each a computer image of his or her own face blended with the face of Bill Clinton or Albert Einstein (for men) and Marilyn Monroe or Princess Diana (for women). Once the anesthesia wore off, patients had to choose which face they had seen. All five selected their own face when only their right hemispheres were active, but four out of the five said they had seen the famous face when only their left hemispheres were awake. *—Alison McCook*

PHOTOGRAPHS BY EARTH SATELLITE CORP. *SPL/Photo Researchers, Inc.* (*top*); JULIAN KEENAN *Harvard Medical School* (*bottom*); ILLUSTRATION BY EDWIN FOTHERINGHAM

PHYSICS

Unexplained Moments

Since the 1970s the Standard Model has successfully explained and described quarks, electrons and the zooful of other subatomic particles. On February 8, though, physicists announced that one critter, called the muon, violates the model in a tiny but significant way. Since 1997 a team of 68 physicists has been racing muons—heavy relatives of the electron—around a magnetically bathed ring at Brookhaven National Laboratory. The Standard Model predicts that the muon's magnetic moment will precess at a certain rate, called $g-2$ ("*g* minus two"). (The value *g* isn't exactly 2 because, thanks to the uncertainty principle, particles and forces briefly pop into existence and affect the muons.) But using measurements 5.6 times more precise than ever before, researchers calculated that $g-2$ exceeds the value predicted by the Standard Model by about four parts per million. A 1 percent chance remains that the finding is merely a statistical fluke, but many researchers think it is evidence of long-sought new physics beyond the Standard Model, such as supersymmetry. See **http://phyppro1.phy.bnl.gov/g2muon/index.shtml** for additional details. —*Philip Yam*

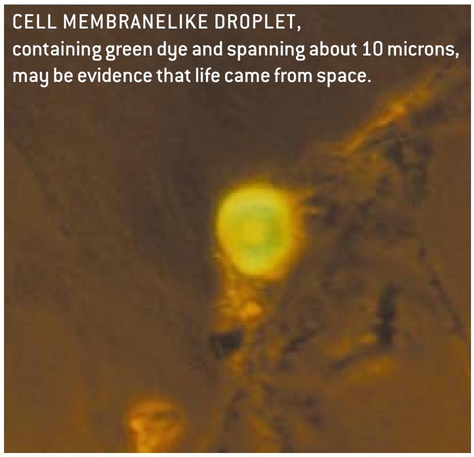
EVOLUTION

Species-Making Bacteria

Recent evidence adds credibility to a theory that parasites could foster the development of new species. In a study published in the February 8 *Nature,* Seth Bordenstein and his colleagues at the University of Rochester wrote that a parasitic bacterium, *Wolbachia pipientis,* prevented two closely related species of wasps (genus *Nasonia*) from producing hybrid offspring—it rendered the sperm of one species incompatible with the eggs of the other. Wasps treated with bacteria-killing antibiotics could interbreed freely, and none of the offspring exhibited the genetic defects that indirectly cause speciation, such as those that produce sterility or death. Infection with *Wolbachia* therefore probably preceded other barriers to reproduction between these closely related wasp species. —*Alison McCook*

THWARTED by bacteria

PHOTOGRAPHS COURTESY OF NASA (*top*); ©1980 JOHN H. WERREN (*bottom*)



CELL MEMBRANELIKE DROPLET, containing green dye and spanning about 10 microns, may be evidence that life came from space.

ASTROCHEMISTRY

Heavenly Seeds

Did life on the earth originate from molecules deposited by meteorites or comets? In the January 30 *Proceedings of the National Academy of Sciences,* researchers report experimenting with a mixture of simple compounds known to exist in interstellar space: water, methanol, ammonia and carbon monoxide. The scientists mimicked a space environment by freezing the mixture to temperatures close to absolute zero, then exposing it to harsh ultraviolet radiation. The procedure produced an oily residue composed of hundreds of complex organic molecules. Even more striking, when immersed in water the organic molecules in the residue formed tiny hollow droplets that resembled cell membranes. Although the droplets themselves are far from being alive, similar structures could have been precursors of the first primitive life-forms. —*Mark Alpert*

WWW.SCIAM.COM/NEWS

BRIEF BITS

The first analysis of the human genome was published in February. It seems humans have only about 30,000 genes—far fewer than the anticipated 100,000. www.sciam.com/explorations/2001/021201humangenome/

Space probe NEAR Shoemaker survived its controlled crash landing on asteroid Eros on February 12. It continued transmitting for a while and delivered some spectacular close-ups. www.sciam.com/explorations/2001/022001near

In Madagascar, paleontologists discovered fossils of a new dinosaur that has unusual, curved teeth from its curled lower jaw. They named it *Masiakasaurus knopfleri,* in part after Mark Knopfler, lead singer of Dire Straits, whose music seemed to bring them luck in finding fossils. sciam.com/news/012501/1.html

Engineers at Sandia National Laboratories created the smallest robot ever—able to sit on a nickel and propel itself about 20 inches per minute. sciam.com/news/020501/1.html

BY THE NUMBERS

Lifestyle Blues

WHEN IT COMES TO COMBATING HEALTH PROBLEMS BROUGHT ON BY HIGH LIVING, THE RECENT IMPROVEMENTS MAY BE OVER BY RODGER DOYLE

The six leading killers of Americans—coronary heart disease, stroke, lung cancer, colon cancer, diabetes and chronic obstructive pulmonary disease—were responsible for 43 percent of all deaths in 1998. These six are also the major "lifestyle" diseases—that is, diseases that trace mainly to imprudent living, such as poor diet, obesity, lack of exercise, and cigarette smoking. Indeed, shifts in lifestyle account for much of the change in mortality rates over recent decades. Coronary heart disease (CHD), stroke and colon cancer rates declined among both sexes. Rates of lung cancer and chronic obstructive pulmonary disease (COPD), both of which result overwhelmingly from cigarette smoking, declined among men but have been rising among women, a pattern that reflects the later adoption and subsequent abandonment of cigarettes by women as compared to use by men in the years after World War II. Lung cancer and COPD rates among women, however, are expected to turn down eventually because of women's declining use of cigarettes since the 1970s. Diabetes registered a big increase in mortality rates, apparently resulting from the growing trend to obesity.

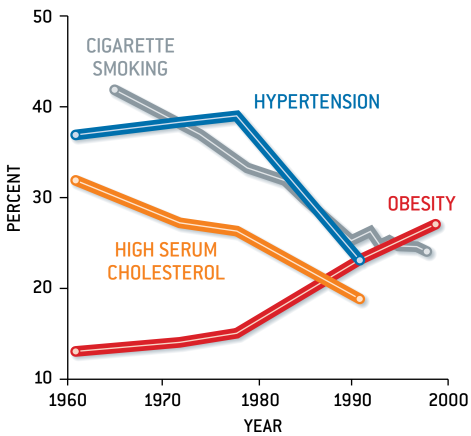
The prospect for future declines in the leading chronic diseases depends in part on trends in risk factors. Prevalence of cigarette smoking, which sends more than 400,000 Americans a year to a premature death, appears to be stabilizing at about 25 percent of the population. More disappointing is the rise in obesity. The substantial declines in prevalence of high serum cholesterol and high blood pressure of recent decades may be difficult to maintain, as those most concerned about their health have already mended their destructive ways, whereas those practicing a less prudent lifestyle will be less inclined to change. That suggests that mortality rates of the major chronic diseases will not decline as fast in the coming years as in the past, but it is likely that the *number* of deaths from lifestyle diseases will climb dramatically after 2010, when the baby boomers enter old age.

With few exceptions, such as the discovery of insulin, "magic bullets" have played a minor role in the prevention, cure and palliation of lifestyle diseases. This could change because of new work now under way, including genetic research and promising cancer treatments. Such research, if successful, will probably have its greatest impact beginning in the next decade.

NEED TO KNOW: BODILY HARM

High cholesterol is defined as amounts greater than 240 milligrams per deciliter of blood. **Hypertension** is defined as having a medically untreated systolic blood pressure (the first number in a reading) of at least 140 millimeters of mercury or a diastolic pressure (the second number) of at least 90. **Obesity** is defined as a body mass index of 30 or greater (calculated by dividing the weight in kilograms by the square of the height in meters). **Pulmonary disease** mortality includes deaths from emphysema, chronic bronchitis, asthma and other obstructive diseases of the lungs.

RISK-FACTOR PREVALENCE IN U.S.



SOURCE: Centers for Disease Control and Prevention

THE SIX LEADING LIFESTYLE DISEASES

	DEATHS IN 1998 (THOUSANDS)	PERCENT CHANGE IN MORTALITY RATE, 1980–1998	LEADING RISK FACTORS
CORONARY HEART DISEASE	460	–47	C,H,S,O,P
STROKE	158	–38	C,H,S,O
LUNG CANCER	155	+6	S
CHRONIC OBSTRUCTIVE PULMONARY DISEASE	113	+34	S
DIABETES	65	+35	O
COLON CANCER	57	–24	D,P
ALL CAUSES	2,337	–19	

Risk-factor abbreviations: C = high serum cholesterol; H = hypertension; S = smoking cigarettes; O = obesity; P = physically inactive; D = diet inadequate (for example, insufficient fruits or vegetables)

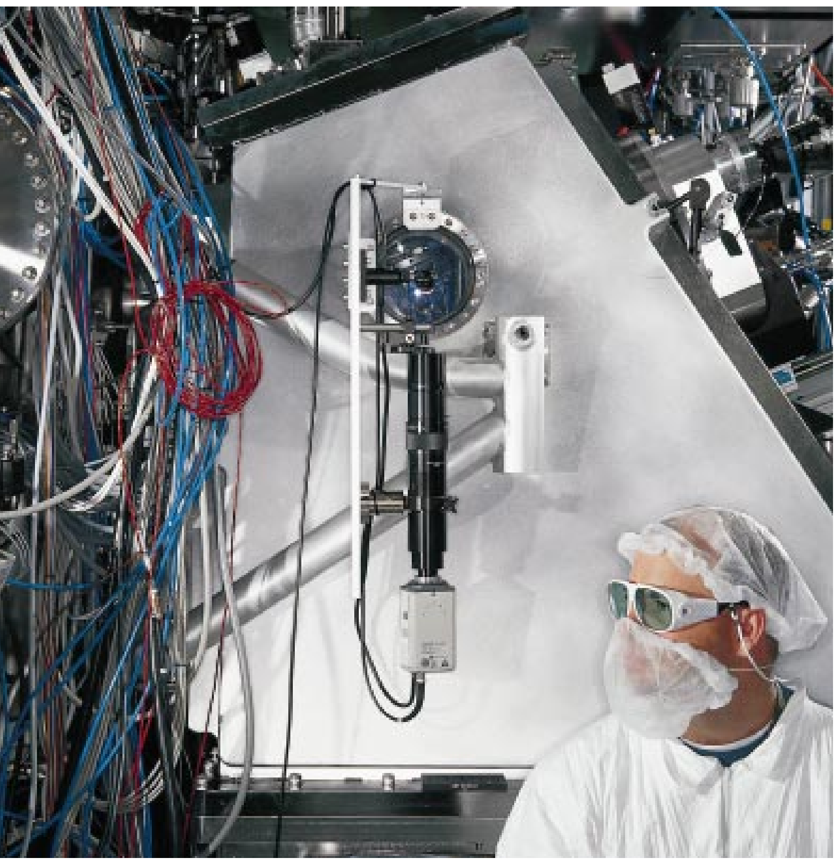
SOURCE: American Public Health Association. Changes in mortality rates are based on age-adjusted data.

Getting More from Moore's

Marshaling financial clout and technical astuteness, Intel has pushed its choice for the key technology that will extend silicon chips to their limits By GARY STIX

When Gordon Moore, one of the founders of Intel, plotted a growth curve in 1965 that showed the number of transistors on a microchip doubling every 18 months, no one had any idea that his speculations would not just prove prescient but would become a dictate—the law by which the industry lives or dies.

Like a drug addict in search of a fix, the semiconductor industry can keep on the curve of Moore's law only by constantly adopting new technology that requires ever greater infusions of capital and technical sophistication. Intel, the company that has served as the standard bearer for Moore's law, has waged a five-year crusade to develop a method of printing circuit patterns on chips that could take the reigning CMOS chip technology until circuits can be made no smaller, the last data point on the Moore curve.



NANOPRINTER: A worker at Sandia National Laboratories inspects the machine that will make chips with features under 100 nanometers.

PHOTOGRAPHS BY TIMOTHY ARCHIBALD

These new lithographic machines for making billion-transistor microprocessors will mark one of the most spectacular forays into the realm of nanotechnology, the precise manipulation of matter at the scale of a few billionths of a meter. The Intel-nurtured technology—extreme ultraviolet lithography (EUV)—has recently created one of its first images of a whole chip at a Department of Energy laboratory set up to engineer nuclear weapons. At a wavelength of 13 nanometers, EUV will eventually have the ability to print a transistor element just 40 atoms in width.

Progress toward what the industry calls its next-generation lithography lends credence to Intel's strategy of relying on collaborations with universities or national laboratories to tap a wellspring of basic research and development resources. The Intel approach stands in marked contrast to the large centralized laboratories built by AT&T, IBM and Xerox, which have often invented technologies that they never succeeded in commercializing. "The classic research model never worked," says G. Dan Hutcheson of VLSI Research, a market research firm that has tracked these technologies for 25 years. "Intel looked at research in a new way and showed how to get a return on investment from it." Even before the founding of Intel in 1968, Gordon Moore had developed a bias against the traditional approach after he witnessed Fairchild Semiconductor squandering capital on research that never turned into products during his tenure there in the 1960s.

Recent experience bolsters Intel's case. The demonstration at Sandia National Laboratories/California in Livermore comes a year or so after the demise of a lithography program, championed by IBM for decades, that used x-ray radiation. The program consumed hundreds of millions of dollars in expenditures by both IBM and the Defense Advanced Research Projects Agency—and some industry observers estimate that the sum exceeded $1 billion. Moreover, in recent months two major semiconductor equipment manufacturers—ASML and Applied Materials—dropped plans to develop electron projection lithography, which uses parallel beams of electrons to print circuit patterns, another contender for the next-generation lithography that had been under development for years inside AT&T Bell Laboratories.

Despite its role as lead sponsor for EUV, Intel cannot claim credit for inventing it. In the late 1980s AT&T Bell Laboratories (now part of Lucent Technologies) and NTT Communications published separate papers on soft x-ray projection lithography. Two national laboratories—Sandia and Lawrence Livermore—expanded on this work using technologies from the Strategic Defense Initiative. Sandia fashioned an early lithography prototype using radiation from a laser-generated plasma, which had been involved before in testing the response of different materials to the high-energy pulses that satellites might sustain in scenarios postulated by "Star Wars" planners.

It has been understood for decades that the billion-dollar expense and overwhelming difficulties of producing chips with nanoscale circuitry would require that chipmakers such as IBM, Intel or (at one time) AT&T fund the early research of their equipment manufacturers. Bell Labs, which oversaw parallel efforts in five separate lithography technologies during the early 1990s, was enticed by the idea of short-wavelength radiation that did not require a synchrotron, the giant x-ray generators found in high-energy physics laboratories. The technical difficulties that beset x-ray lithography at the time led the Bell Labs researchers to change the name from soft x-rays to extreme ultraviolet lithography. Intel had joined AT&T and others in a cooperative research program with the national laboratories. But the actual day-to-day research was concentrated at Lawrence Livermore, Sandia and Bell Laboratories.

When Congress eliminated the program in 1996, pegging it as a form of corporate welfare, AT&T decided to get out. Intel then stepped in to salvage and carry on the work. "Intel came to the realization [that] if they didn't put money into a couple of key technologies that would come into play in the 2000s, they were going to be in big trouble," says Richard R. Freeman, a professor of applied science at the University of California at Davis, who headed lithography development at AT&T Bell Labs and later the EUV program at the national laboratories during the mid-1990s.

On paper, EUV was attractive. With a wavelength of 13 nanometers—almost one twentieth the wavelength being readied for use in commercial chipmaking five years ago—EUV could be extended until the physical challenges of making atomic-scale chips rendered existing semiconductor technologies unworkable. And the technology used a machine tool that bears some resemblance to those deployed in existing fabrication facilities. Insiders at Intel were suspicious, though. "People start-

EXTREME ULTRAVIOLET LITHOGRAPHY

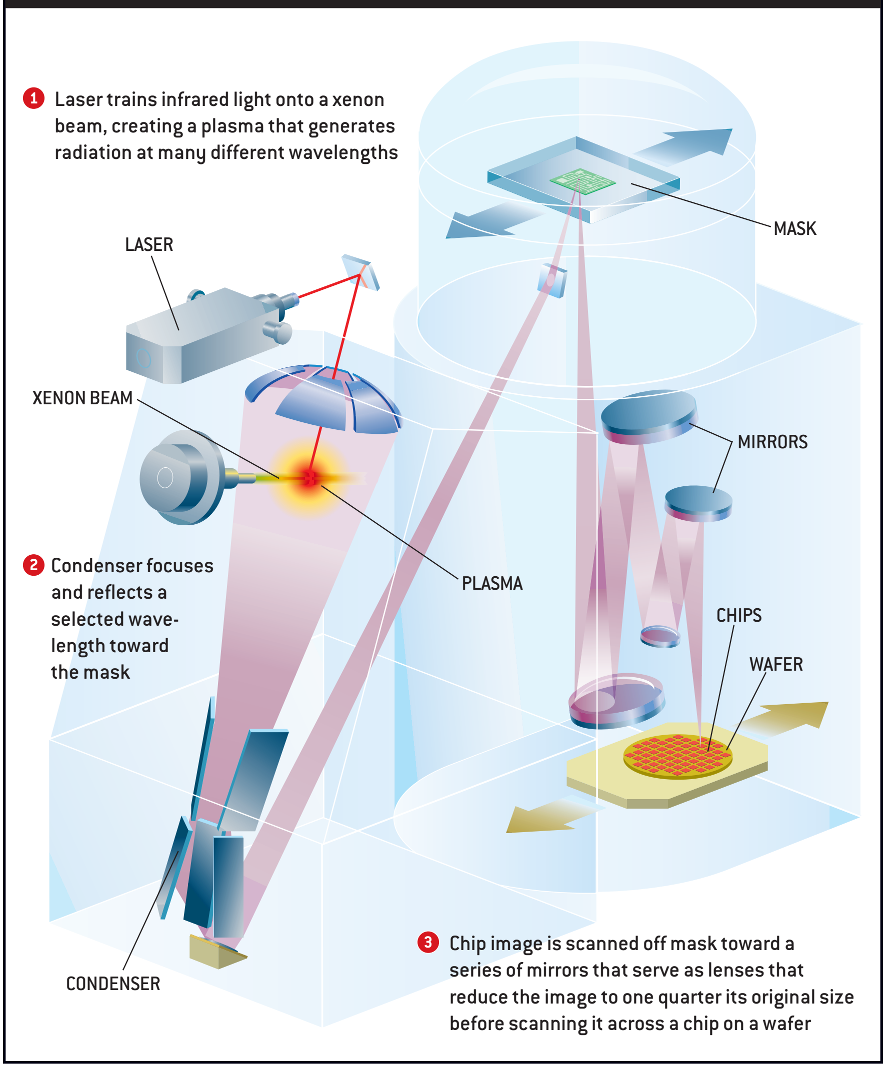


ILLUSTRATION BY SAMUEL VELASCO

ed asking, 'Can it do this, can it do that?,' and it was Gordon Moore who said we really don't have an alternative," recalls John Carruthers, who headed advanced technology research at Intel at the time.

Intel entered into a three-year contract (later extended to five) with an entity called the Virtual National Laboratory (VNL), which combined researchers and facilities from Lawrence Livermore, Sandia and Lawrence Berkeley national laboratories. Having one contract with three labs cut some of the red tape that usually discourages companies from seeking such collaborations. Later Intel brought in other chip manufacturers, including competitors AMD, Motorola, Micron and Infineon—and lithography equipment suppliers ASML and SVG.

In 1997, at the beginning of Intel's stepped-up involvement, looming technical difficulties caused EUV to be rated last out of four lithography technologies in a straw vote taken at an industry conference. Although it bears some similarities to existing methods, EUV is different enough to make the average fabrication-line manager quake. Conventional photolithography equipment projects ultraviolet light (usually at 248 or 193 nanometers) through a mask—a sheet of glass on which are traced a chip's circuit patterns. A series of lenses reduces the image to a quarter of its size. The image projected through the lenses is exposed in a chemical on the wafer. Another chemical treatment then etches away either the exposed or unexposed areas of the image, carving the circuit elements into the chip surface.

Things change at 13 nanometers, where extreme ultraviolet lithography earns its name. The mask and lenses, transparent at longer wavelengths, would absorb this radiation. So EUV uses mirrors for both the mask and the lenses. A laser trained on a jet of xenon gas creates a plasma that emits 13-nanometer radiation, which is focused onto a mask. The mask reflects the circuit pattern onto a series of curved mirrors that reduce the size of the image and focus it onto the wafer. The 80 alternating layers of silicon and molybdenum that make up the mirrors and the mask have to be smoothed to single-atom tolerances. The entire circuit-printing process, moreover, has to be done in a vacuum because air itself absorbs radiation at this wavelength. And the mask will distort the image if it contains more than a handful of defects measuring even 50 nanometers, about 2,000 times narrower than the width of a human hair. The development team sometimes muses on ways to describe to the outside world the relative size of a 50-nanometer defect, comparing it to a search for a golf ball in a state the size of Maryland, a basketball in the state of Texas or a hair on a football field.

Physicists and engineers who designed and engineered nuclear weapons technology had to solve these challenges. Unlike AT&T, which conducted early development work on EUV at Bell Labs with about 30 employees, Intel has only five full-time employees at VNL's main facility at the Sandia laboratory in Livermore (although more than 10 others labor on developing proprietary mask designs and other EUV-related technology at several Intel facilities). "They're using us as an advanced development and research lab," says Richard H. Stulen, the virtual laboratory's chief operating officer.

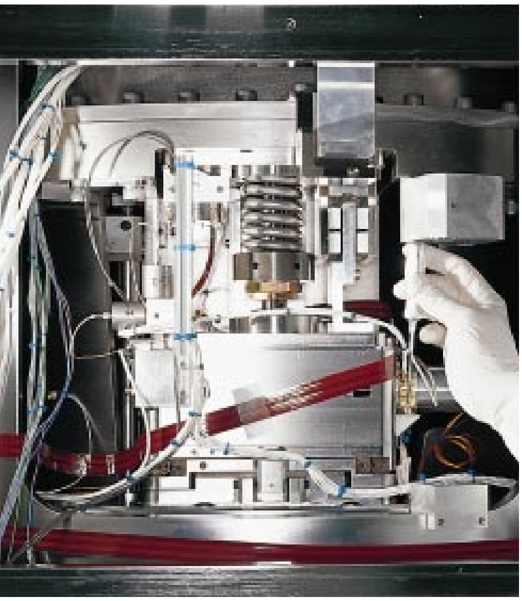
Although it bears some similarities to existing lithographic methods, EUV is different enough to make the average chip manufacturer quake.

The company kept a close eye on how decisions were made at the labs. If alternative methods were proposed for making lenses, Intel would press the research team to pick one, instead of testing the merits of both. "Nothing got spent that they didn't think would work," Freeman says. "They didn't do it Bell Labs style." Intel also implemented the same detailed risk-management system that the company uses internally—essentially a rating system of things that could go wrong. This flagged a list of about 200 problems, some of which the 150 national laboratories researchers who worked in the VNL might otherwise have downplayed. At one meeting, the VNL staff mentioned that it would need to increase the power of the laser by a factor of 40, which raised a red flag for suppliers. "The chip equipment manufacturers rated this at a much higher risk than we had," Stulen says.

VNL researchers identified what they called "seven deadly showstoppers," but by late 1998, at another industry session, solutions to many of these problems—such as how to make supersmooth mirrors—had been found, propelling EUV into first place when it came time to vote. "The group went from having an attitude of 'Sure, sure, tell us you can do that' to placing us up front," Freeman says.

Intel has also brought a get-the-job-done kind of urgency to laboratory employees unaccustomed to commercial deadlines. Peter J. Silverman, Intel's director of lithography capital equipment development, pushed forward by six to nine months the current circuit-printing demonstration and specified that the number of wafers produced by an EUV machine should be doubled. By moving the schedule, Intel has attempted to rally the industry around EUV and to eliminate electron projection lithography (EPL). "We fervently believe that there are not enough resources in the industry to develop both technologies," he says.

Silverman is also ready to blast ahead by placing an order with ASML for a $30-million EUV prototype machine, forcing the equipment manufacturer to commit to



a delivery schedule. It behooves Intel to push. Although AMD, Motorola, Infineon and Micron are partners, Intel negotiated contract terms that let it get the first machines produced and, because it is the largest investor in the $250-million program, the greatest number of tools.

Suppliers have to implement fully two crushingly difficult generations of technology before they finish making an investment of perhaps $750 million to start producing EUV machines. Getting them to buy into the breakneck schedule set by Intel may be a bigger challenge than creating angstrom-smooth mirrors. Even ASML, which dropped its involvement with EPL, is cautious, saying existing optical technologies may last longer than the industry expects. "It's too early to decide whether EUV will happen in the time frame Intel is pushing," says Jos Benschop, research manager at ASML.

Intel would also like to bring Nikon, its other main supplier, into the fold. But the industry's largest equipment manufacturer, which is researching EUV outside of the U.S. consortium, is not ready to commit to a single technology—and it continues work on EPL with IBM. Other chipmakers, such as Motorola and Texas Instruments, have voiced support for the EUV competitor. "It's still a horse race between EPL and EUV," says Gilbert L. Varnell, president and chief operating officer of Nikon Research Corporation of America. "Intel has taken the position that there's only one technology and they want to get rid of the competition. I'm not convinced that's the best approach for the industry. What if [EUV] fails? We're a toolmaker and they're a chipmaker, and there's a lot of other things we have to consider, such as manufacturability of the lithography equipment and profitability." Adds Lloyd R. Harriott, a former Bell Labs employee who headed the EPL program and worked on the early EUV program: "I think a lot of progress has been made with EUV. But they've got a really long way to go. There's a lot of marketing hype about how this is a done deal."

The collaborative structure of the EUV program may serve as a model for how the semiconductor industry conducts future research.

Varnell also believes that the current schedule—making commercial chips with EUV in 2005—is unrealistic, citing the nine years it took Nikon to develop the laser used in the current generation of lithography, a much less ambitious project. Says Varnell: "You're going from an image to full-up production system by 2005, and it is going to come from the national labs. I've been around the toolmaking business for a long time. I don't believe that's going to happen."

Along the way, another hurdle Intel and company have faced is convincing Washington to let a foreign company, the Dutch supplier ASML, enter the consortium. Four years ago the only major American tool supplier in the consortium was SVG. Ultratech Stepper, an early U.S. partner in EUV research, had to settle grudgingly for a minor role when it was viewed as lacking the necessary financial resources to develop an EUV product line. ASML, moreover, has subsequently bought SVG, which would leave ASML as the primary beneficiary of this technology transfer. Intel has "done everything in their power to give the technology on a silver platter to ASML," says David A. Markle, chief technology officer of Ultratech Stepper, adding that "Intel has approached this situation with the attitude that what's good for Intel is good for America."

Despite the trail of bruised egos, the EUV experience may serve as a case study for future research. It is one of the most successful collaborations between industry and national laboratories. More broadly, it constitutes a model for the creation of virtual laboratories that can undertake major projects on an as-needed basis without the huge overhead of a central research facility.

Whether Intel's buy-it-when-you-need-it strategy can work more generally remains to be seen. The real test may come in 15 years or so if EUV or EPL gives out and some wholly new substitute for silicon chips is needed. A paradigm shift—using molecules of DNA, nanotubes, quantum dots or other exotic materials to execute computations—may determine whether the virtual-research model can succeed. "Intel did a magnificent job of picking up the technology, recognizing its worthiness and driving it home," Freeman says. "But they're not putting the same effort into asking the questions about what to do when you get to 100 angstroms [10 nanometers]." Maybe one of Moore's successors will have to lay down the law for quantum computing. SA

Code of the Code

When you cross DNA nucleotides with the zeros and ones of digital bits, who owns what? By GARY STIX

In 1995 Craig Venter and his colleagues at the Institute for Genomic Research (TIGR) became the first to sequence all the A, G, C and T nucleotides in the genome of a free-living organism—the bacterium *Hemophilus influenzae,* which causes ear and respiratory infections. Human Genome Sciences (HGS), a major biotechnology firm with which TIGR was affiliated at the time, applied for a patent not just on the sequence of nucleotides in the DNA itself but on any "computer-readable medium having recorded thereon the nucleotide sequence."

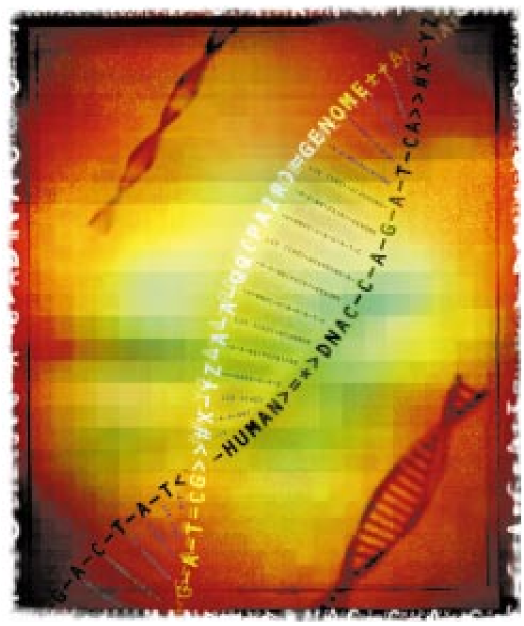


ILLUSTRATION BY BRIAN STAUFFER

In essence, the application asked for a patent on the exclusive use of the computer code representing the germ's genetic code. The patent, which is still pending in the U.S. and elsewhere, represents a "fundamental departure" from previous practice, wrote biotechnology law scholar Rebecca Eisenberg last year in the *Emory Law Journal:* "By claiming exclusionary rights in the sequence information itself, if stored in a computer-readable medium, HGS seeks patent rights that would be infringed by information storage, retrieval and analysis rather than simply by making, using or selling DNA molecules."

HGS and at least one other company have filed similar applications on other genomes, but it is highly uncertain that the U.S. Patent and Trademark Office will approve them, as it has repeatedly tightened rules to prevent patenting of genes for which there are no clear-cut uses. Even if these patents are denied, though, the blurring of distinctions between molecular and digital information is very likely to continue. Companies might seek protection for the code of a three-dimensional computerized representation of a receptor on a cell. And patents related to information gleaned from gene chips—which use segments of DNA as detectors to determine the presence of genes expressed in a given sample—pose similar dilemmas.

Such patents would have potentially far-reaching consequences. If accessing a patent on the Internet were to constitute an infringement, this would go against the fundamental quid pro quo on which patent law is based, Eisenberg contends.

The holder of a patent gets a 20-year monopoly on the right to make, use and sell an invention in exchange for revealing information about both its manufacture and usage. Access to this information promotes the free exchange of ideas essential to technological progress. "If the terms of the traditional patent bargain are altered to allow patent holders to capture the informational value of their discoveries," Eisenberg writes, "the bargain becomes less attractive to the public." Others cannot avail themselves of information needed to enhance the state of the art.

If DNA as information exceeds its value as a tangible molecule, it may be necessary to find some other intellectual-property protection for it. Patenting the zeros and ones representing As, Gs, Cs and Ts won't cut it. SA

Please let us know about interesting or unusual patents. Send suggestions to: patents@sciam.com

Colorful Pebbles and Darwin's Dictum

Science is an exquisite blend of data and theory   By MICHAEL SHERMER

Writing to a friend on September 18, 1861, Charles Darwin reflected on how far the science of geology had come since he first took it up seriously during his five-year voyage on the HMS *Beagle:*

> About thirty years ago there was much talk that geologists ought only to observe and not theorise; and I well remember some one saying that at this rate a man might as well go into a gravel-pit and count the pebbles and describe the colours. How odd it is that anyone should not see that all observation must be for or against some view if it is to be of any service!

For my money, this is one of the deepest single statements ever made on the nature of science itself, particularly in the understated denouement. If scientific observations are to be of any use, they must be tested against a theory, hypothesis or model. The facts never just speak for themselves. They must be interpreted through the colored lenses of ideas: percepts need concepts.

The facts never just speak for themselves. They must be interpreted through ideas.

When Louis and Mary Leakey went to Africa in search of our hominid ancestors, they did so not because of any existing data but because of Darwin's theory of human descent and his argument that we are obviously closely related to the great apes. Because the great apes live in Africa, it is there that the fossil remains of our forebears would most likely be found. In other words, the Leakeys went to Africa because of a concept, not a percept. The data followed and confirmed this theory, the very opposite of how we usually think science works. Science is an exquisite blend of data and theory, facts and hypotheses, observations and views. We can no more expunge ourselves of biases and preferences than we can find a truly objective, Archimedean perspective—a god's-eye view—of the human condition. We are, after all, humans, not gods.

In the first half of the 20th century, philosophers and historians of science (who were mostly scientists doing philosophy and history on the side) presented science as a progressive march toward a complete understanding of Reality—an asymptotic curve to Truth. It was only a matter of time before physics (and eventually even the social sciences) would round out their equations to the sixth decimal place. Later, professional philosophers and historians took over and, in a paroxysm of post-modern deconstruction, proffered a view of science as a relativistic game played by European white males who, in a reductionistic frenzy of hermeneutical hegemony, were hell-bent on suppressing the masses beneath the thumb of dialectical scientism and technocracy. (Yes, some of them actually talk like that, and one really did call Newton's *Principia* a "rape manual.")

Thankfully, intellectual trends, like social movements, have a tendency to push both ends to the middle, and these two extremist views of science are now largely passé. Physics is nowhere near explaining everything to six decimal places, and as for the social sciences, in the words of a friend from New Jersey, "fuhgeddaboudit." Yet science does progress, and some views really are superior to others, regardless of the color, gender or country of origin of the scientist holding that view. Although scientific data are "theory laden," as philosophers like to say, science is truly different from art, music, religion and other forms of human expression in that it has a self-correcting mechanism built into it. If you don't catch the flaws in your theory, the slant in your bias or the distortion in your preferences, someone else will. The history of science is littered with the debris of downed theories.

Future columns will explore these borderlands of science where theory and data intersect. Let us continue to bear in mind Darwin's dictum: all observation must be for or against some view to be of any service. SA

Michael Shermer, founding publisher of Skeptic *magazine, is author of* The Borderlands of Science.

PHOTOGRAPH BY BRAD HINES

Art as a Form of Life

Genetic artist Joe Davis has made more copies of his work than have all prior artists combined. But there's not much of a market for artworks embedded in bacterial genomes   **By W. WAYT GIBBS**

CAMBRIDGE, MASS.—Either Joe Davis is late or I am lost. For the third time, I check the address: Massachusetts Institute of Technology, building 68, room 604D. Here it is, locked and looking nothing like a studio for avant-garde art. "SEVERE EYE DAMAGE," cautions a sign on the door, referring to a laser inside. There are bins marked "RADIOACTIVE WASTE," refrigerated vaults containing cells in stasis, ultracentrifuges the size of washing machines, but no paints, no sculpting tools.

I wander downstairs to the office of Alexander Rich, the biophysicist who famously discovered "left-handed" DNA (the normal stuff twists to the right), who worked out the structure of transfer RNA and who invited Davis into his laboratory in 1992 as a "research affiliate," which grants the artist a space to work and access to the lab's expensive tools but no direct financial support. There is still no sign of Davis, until I press my nose against the window of a door to a small white room.

The room is warm: 98.6 degrees Fahrenheit. There, on shelves next to flasks in which swim strains of human gastrointestinal bacteria, sit five mason jars. Each jar is labeled "SELF-ASSEMBLING CLOCK" and holds the jumbled parts of a timepiece. I recognize this as an element of Davis's "experiment" to see whether, given the right conditions and enough time, the components of machines can self-assemble into working devices, just as life supposedly arose spontaneously from colliding precursory biochemicals billions of years ago. That theory suddenly seems less plausible and yet more profound.

Tick tick. I turn to see Davis walking down the hall, his self-made peg leg clacking, steel on tile. The test-tube stopper plugging its end has worn down. Ask him how he lost the limb, as someone does at his 50th birthday party the next day, and he smiles, inhales deeply and recites one of his poems, a frightening, erotic poem of slithering asps, black waters and an embrace with the long, luscious lips of an alligator.

Ask his friends, and they say he lost the leg in a motorcycle crash some 20 years ago, when he was still a sculptor and bike mechanic in Mississippi. That is where he was reared until problems at school got him sent up to the grandparents and to a psychiatric evaluation at age 13. In his report, Dr. J. F. Jastak urged that Davis should "apply his artistic abilities to his scientific ventures," maybe even as a scientific artist. A prescient forecast for 1964, although Jastak probably imagined Davis drawing pictures of atomic airplanes.

PHOTOGRAPHS BY KATHLEEN DOOHER

JOE DAVIS: GENESTHETICIST

- **Expelled from three high schools and two colleges for writing about atheism, refusing a haircut, making an ethanol still (which exploded) and being elected student body president on a "free marijuana" platform**
- **Walked into M.I.T. uninvited in 1982; secretary called the cops; 45 minutes later Davis walked out as a research fellow in visual studies**
- **Engineered bacterial genome to encode a symbol called *Microvenus:***

Davis himself had altogether different ideas about commingling science and art, ideas that have often made both professions uncomfortable. He championed a space shuttle experiment that would have pumped 100,000 watts from an electron gun into the upper atmosphere to create the first artificial aurora (the project was accepted, but the *Challenger* accident intervened). He led a quasicovert operation that translated vaginal contractions, the impetus of human conception, into text, music, phonetic speech and ultimately into radio signals beamed from M.I.T.'s Millstone radar to several nearby star systems (the air force shut down transmissions after 20 minutes). He drew up plans for channeling a lightning bolt into a laser powerful enough to create visible spots on the moon (an idea still awaiting a sponsor).

And then, about 15 years ago, Davis realized that genetic engineering offered a rich new medium for art—life itself. He convinced molecular biologists at Harvard University and the University of California at Berkeley to teach him how to synthesize DNA and insert it into the genomes of living microorganisms, then set about creating what he calls "an infogene, a gene to be translated by the machinery of human beings into meaning and not by the machinery of cells into protein." His idea was to create a message in a bottle for extraterrestrials: to encode a sign of human intelligence into the genome of bacteria, which could then be grown by the ton and flung out across the heavens.

For his bottle, Davis chose *E. coli,* a bacterium of the human gut that might well carry DNA intact for aeons in deep space. For his message, he designed *Microvenus,* a simple symbol—like a Y and an I superimposed—that represents both a Germanic rune for life and an outline of the external female genitalia, which was censored from the pictures of humans on the Pioneer and Voyager space probes.

Digitized and translated into a string of 28 DNA nucleotides, *Microvenus* first slipped between the genes of *E. coli* in 1987. The bacteria quickly multiplied in its beakers into trillions of cells. "I'm probably the most successful publisher in history," Davis says with a laugh.

Yet it was not until last September that the icon, explanations of the encoding, and cultures of the transgenic bacteria itself were finally put on public display in a biological containment facility erected at the Ars Electronica exhibition in Linz, Austria. There, also for the first time, Davis displayed some of his other biological artworks. There was synthetic DNA containing a coded text message—"I am the riddle of life; know me and you will know yourself"—and an audio microscope he built from borrowed and salvaged parts so that visitors could eavesdrop on the lives of single-celled animals.

And in a keynote lecture, he described his current artwork, the most ambitious yet: the genetic insertion of an image of the Milky Way into a mouse's ear, an idea inspired by a children's story written 30 years ago by a girlfriend. To encode such a large amount of binary information in DNA, he spent years figuring out a general method for archiving computer databases in biological form, a "supercode" that guarantees the infogene will be biochemically stable and yet prevents the host from translating it into protein.

SIGNALS and "self-assembling clocks" merge science and art.

Despite his professional recognition, Davis remains utterly dependent on donations of equipment and expertise from scientists. "Fortunately, Joe's always been a good Tom Sawyer of people," observes David Gessel, an engineer with Nebucon who has aided Davis on several projects. "It helps that he is consistently rigorous in his intellectual approach" and that he isn't in it for money. Indeed, because he sells his conventional sculptures at cost and cannot sell his transgenic art at all, Davis skirts homelessness—many of his belongings are jammed into a decrepit Volvo he obtained for a self-assembling clock.

As I leave Davis, smoking in the cold, I walk past the M.I.T. Media Lab, where so many millions of dollars have chased so many questionable attempts to weave technology into a cultural fabric. How perverse, it seems, that the same society offers so little support for art that does not merely comment passively on the transformations and ethical dilemmas that science forces on society but that actively enacts and illustrates them, co-opting the tools and media of science itself. SA

See www.sciam.com for an enhanced version of this Profile, including samples and technical details of Davis's work.

WHOSE BLOOD IS IT, ANYWAY?

Blood collected from umbilical cords and placentas—which are usually thrown away following birth—contains stem cells that can rebuild the blood and immune systems of people with leukemia and other cancers

By Ronald M. Kline >> Photographs by Max Aguilera-Hellweg

Kristina Romero, four months pregnant, plans to use the cord blood for her son with leukemia, Chase.

Wrinkly-faced, slippery and

Doctors clamp the umbilical cord of a child being delivered by cesarean section.

squalling, the newborn makes her debut into the world. As the parents share their joy and begin to count 10 perfect little fingers and 10 adorable tiny toes, they scarcely pay attention to birth's Act Two: the delivery of the placenta, or afterbirth.

After the ordeal of labor, most new mothers are happy they need to push only once more for their physician to scoop up the roughly one-pound, pancakelike organ that nourished their baby through the umbilical cord for nine months. After cutting the cord and checking the afterbirth for gaps and tears that might indicate that a piece still remains inside the mother's uterus—where it could cause a potentially fatal infection—the doctor usually tosses it into a stainless-steel bucket with the rest of the medical waste bound for incineration.

But more and more physicians and parents are realizing the value of what they used to regard as merely birth's byproduct. Since 1988 hundreds of lives have been saved by the three ounces of blood contained in a typical placenta and umbilical cord. That blood is now known to be a rich source of so-called hematopoietic stem cells, the precursors of everything in the blood from infection-fighting white blood cells to the red blood cells that carry oxygen to the platelets that facilitate blood clotting after an injury.

The stem cells from a single placenta are sufficient to rebuild the blood and immune system of a child with leukemia, whose own white blood cells are abnormally dividing and must be killed by chemotherapy. In the past, physicians had to seek a living donor to provide such children with transplants of bone marrow, which also contains stem cells that produce blood and immune cells. Unfortunately, many people have died during the long search for a donor with a matching tissue type or from complications if the donated marrow did not match well. Cord blood, which can be stored, is more likely to provide a suitable match and less likely to cause complications, because its stem cells are immunologically different from and more tolerant than those in adult bone marrow.

The benefits of umbilical cord blood transplantation have been demonstrated most conclusively in leukemia, but the process has other uses. The stem cells in cord blood can help to restore normal red blood cells in people with sickle cell anemia and to reconstitute the immune system of infants born with severe combined immunodeficiency. Cord blood can also be used to treat fatal inherited enzyme deficiencies, such as Hurler's syndrome, which results in progressive neurological degeneration and death. In such cases, the stem cells in cord blood can give rise not only to normal red and white blood cells but also to supporting cells in the brain called microglia that can provide the crucial missing enzyme there.

Recognizing the apparent advantages of umbilical cord blood transplantation, a number of medical centers have established banks so that a mother can donate her baby's cord blood for use by a stranger in need. The New York Blood Center's Placental Blood Program, pioneered by Pablo Rubinstein, now has 13,000 banked donations and is the nation's largest public cord blood bank. The University of California at Los Angeles and Duke University also have umbilical cord blood storage programs, which are federally funded.

But like many new scientific discoveries, umbilical cord blood transplantation brings with it a set of ethical questions [*see box on next page*]. Who owns umbilical cord blood: both parents, the mother or the infant? What happens if a mother donates her baby's cord blood to a bank but the child later develops leukemia and needs it? The ethical questions are compounded by the advent of for-profit companies that collect and preserve a newborn's cord blood for possible use by the family later. Is it right for such companies to aggressively market their services—which can cost $1,500 for collection and $95 per year for storage—when the chance a child will ever need his or her cord blood ranges from 1 in 10,000 (according to the New York Blood Center) to 1 in 200,000 (according to the National Institutes of Health)?

Founts of Stem Cells

THE FIRST HINT that umbilical cord blood could be clinically useful came in 1972, when Norman Ende of the University of Medicine and Dentistry of New Jersey and his brother, Milton, a physician in Petersburg, Va., reported giving a 16-year-old leukemia patient an infusion of cord blood. Weeks later the scientists found that the patient's blood contained red cells that they could identify as hav-

PHOTOGRAPH BY MAX-AGUILERA-HELLWEG *TimePix*

But Is It Ethical?

Marketing tactics and privacy issues raise eyebrows

LAST SEPTEMBER a little girl from California named Molly received a lifesaving transplant of umbilical cord blood from her newborn brother, Adam. Molly, who was then eight years old, suffered from a potentially fatal genetic blood disorder known as Fanconi anemia. But what made the procedure particularly unusual was that Adam might not have been born had his sister not been sick. He was conceived through in vitro fertilization, and physicians specifically selected his embryo from a group of others for implantation into his mother's womb after tests showed that he would not have the disease and that he would be the best tissue match for Molly.

Was this ethically appropriate? A panel of bioethicists decided that it was, because donating cord blood would have no effect on Adam's health.

Selectively conceiving a potential donor is only one of the myriad ethical issues surrounding umbilical cord blood transplantation. One of the most significant has to do not with how the blood is used but with the marketing campaigns aimed at prospective parents by for-profit companies that offer to collect and store a baby's cord blood—for a hefty fee—in case he or she might need it later.

Such companies market cord blood collection as "biological insurance" to expectant parents. But "the odds are so extraordinarily against their child's ever needing it," says Paul Root Wolpe, a fellow at the University of Pennsylvania Health System Center for Bioethics. He fears that parents who can scarcely afford the service might feel impelled to buy it even though their families have no history of blood disorders.

Viacord, a cord blood–preserving company based in Boston, says that just five of their 6,500 clients have so far needed infusions of their stored cord blood. Moreover, only 20 percent have a family history of a blood disorder or are now in treatment.

The American Academy of Pediatrics issued a policy statement on umbilical cord blood banking in July 1999 cautioning that "it is difficult to recommend that parents store their children's cord blood for future use" unless a family member has had a blood disorder. Instead it encouraged parents to donate their baby's cord blood to public banks.

Questions have been raised in the past concerning the ownership of cord blood. But bioethicist Jeremy Sugarman of Duke University states that it is now fairly clear that although an infant owns his or her own cord blood, parents have legal guardianship over it—just as they do over the child—until he or she reaches age 18. Sugarman and Wolpe contributed to a 1997 consensus statement on the ethics of umbilical cord blood banking in the *Journal of the American Medical Association*.

Sugarman adds that it is perfectly appropriate for a parent to use one sibling's cord blood to treat another. If the first child develops a need for a transplantation later on, the fact that the parents already used his or her stored blood is unfortunate but not unethical.

Of more concern is how to ensure the safety of cord blood donated to cord banks. What happens if parents donate a newborn's cord blood to a public bank and the child develops leukemia years later? If the donated blood has no identifying information to link it to the donor, there would be no way to prevent it from being used in another child. Stem cells in the umbilical cord blood of a child who later gets leukemia could also cause leukemia in a recipient. But keeping permanent records of donors carries privacy risks: What if the blood is transplanted into a recipient but doesn't take, and the sick child's parents want to track down the donor child for bone marrow cells?

Most public cord blood banks label samples so they can be linked to a particular donor for several years, at which time they destroy the identifying information. Wolpe says that this is a good trade-off but that risks will always be associated with donor cord blood, just as they are with donor adult blood. "You try to keep it as safe as you can," he says, "but people take a chance."

— Carol Ezzell, staff writer

ing sprung from the donor's stem cells.

But it took years for other physicians to recognize the potential of umbilical cord blood transplantation. In 1989 Hal E. Broxmeyer of the Indiana University School of Medicine, Edward A. Boyse of Memorial Sloan-Kettering Cancer Center in New York City and their colleagues revived interest in the technique by showing that human cord blood contains as many stem cells as bone marrow does. That same year Broxmeyer, Eliane Gluckman of Saint-Louis Hospital in Paris and their co-workers reported curing Fanconi anemia—a potentially fatal genetic disorder—in a five-year-old boy using blood from his baby sister's umbilical cord. Since then, approximately 75 percent of umbilical cord blood transplants have used cord blood from a nonrelative obtained from cord blood storage programs.

What's Bred in the Bone

UMBILICAL CORD BLOOD transplantation aims to obtain a source of stem cells that is the best possible match for a particular patient's tissue type. Tissue type is determined by a set of genes that make proteins called human leukocyte antigens (HLAs), which are found on the surfaces of all body cells. The immune system recognizes cells bearing the HLA proteins it has encountered since birth as normal, or belonging to the "self." Any other HLA proteins are regarded as "nonself," or foreign; cells carrying them are quickly killed.

There are six major HLA genes. Every person has two copies, or alleles, of each—one from each parent. (Each allele can come in more than 30 different types.) For bone marrow transplants, physicians aim to match the six alleles (of the total 12) that are most clinically relevant in transplantation. But because cord blood cells are immunologically different from bone marrow cells, doctors can use donor cord blood samples that match five—or even three—HLA alleles.

The genetic blueprints for making HLA proteins are found on chromosome 6. The rules of genetics dictate that the probability that two siblings will inherit the same maternal and paternal chromosome 6—and will therefore be good tissue-type matches—is only 25 percent.

Receiving a bone marrow transplant from someone who is not a good tissue-type match is potentially fatal. On one hand, the graft can fail if even a tiny amount of the recipient's own immune cells survive to generate an immune response that deems the transplanted cells foreign and kills them. This graft failure essentially leaves the patient without a functioning immune system and extremely vulnerable to infection. Conversely, the transplanted cells can attack the recipient's body as foreign in a dire phenomenon called graft-versus-host disease. Graft-versus-host disease can manifest itself as a blistering and ulcerating skin rash, liver damage that progresses to liver failure or severe gastrointestinal bleeding; it can quickly lead to death.

To minimize such serious complications in people who cannot obtain a bone marrow transplant from a well-matched sibling, in 1987 a coalition of national blood bank organizations persuaded the U.S. federal government to establish the National Marrow Donor Program to find the best matches for patients among a pool of registered potential bone marrow donors. The program—together with other, similar, international registries—lists 6.5 million names. But because there is only a 1 in 400 chance that an individual will be a match for someone who is not a relative, those in need typically have just a 60 percent chance of finding a potentially lifesaving donor. The odds are even worse for patients who are members of a minority group, because matches are more likely to occur between people of the same race and the registries do not have enough minority volunteers.

Even those who do find a suitable donor from one of the registries still face an alarming 80 percent risk of moderate to severe (grade II to IV) graft-versus-host disease. Scientists think this is because the matching process does not consider the many unknown minor HLA proteins. Although these proteins are not actively matched in sibling transplants either, the close genetic relationship of siblings ensures that many of them will be matched simply by chance. A good sibling pairing, however, still carries a 20 percent risk of graft-versus-host disease.

One way to slash this incidence would be to attempt to match all known HLA proteins, but that would drastically reduce the chances of finding any potential donor for a recipient. Umbilical cord blood transplantation offers a better alternative. Because of differences in the newborn's immune system, immune cells in umbilical cord blood are much less likely than those in an older child's or an adult's bone mar-

For-profit companies will preserve a newborn's cord blood for possible use by the family later. Is that right when the chance a child will ever need his or her cord blood ranges from 1 in 10,000 to 1 in 200,000?

A placenta and umbilical cord ready for cord blood collection.

THE AUTHOR

RONALD M. KLINE directs the division of pediatric hematology/oncology and blood and bone marrow transplantation at Atlantic Children's Medical Center in New Jersey, where he has been since 1998. Previously he directed the umbilical cord blood transplantation program at the University of Louisville and the blood and marrow transplantation program at Kosair Children's Hospital in Louisville. He received both his undergraduate degree and his M.D. from the University of California, Los Angeles. Kline has been a vocal advocate of the use of animals in research. In 1989 he wrote an essay for *Newsweek* magazine entitled "I Am the Enemy," in which he took the animal-rights movement to task for having little compassion for human suffering.

row to attack a recipient's tissues as foreign and cause graft-versus-host disease.

In 1997 Gluckman and her colleagues found evidence that umbilical cord blood transplantation—even between an unrelated donor and recipient—is safer than bone marrow transplantation. Her group studied 143 patients who had received umbilical cord blood transplants either from relatives or from a donor program. Although the transplants ranged from fully matched to two-thirds mismatched, the incidence of life-threatening (grade III or IV) graft-versus-host disease was just 5 percent in the related group and 20 percent in the unrelated group. It caused the death of only 1 percent of the related group and 6 percent of the unrelated group. In comparison, large studies using fully matched, unrelated bone marrow donors have shown a 47 percent incidence of life-threatening graft-versus-host disease, with 70 percent of those patients (33 percent of the total) eventually dying from the disease.

Umbilical cord blood transplantation has many other potential advantages over standard bone marrow transplants. The size of the potential donor pool is much larger for cord blood than for bone marrow, for example. The National Marrow Donor Program has required more than a decade to accumulate a pool of four million individuals who have been typed for potential bone marrow donation (the other 2.5 million donors are registered in other countries). But there are four million births in the U.S. annually, each of which is a potential opportunity to collect cord blood. The New York Blood Center has been able to provide suitable donors for 85 percent of its requests using a pool of only 13,000 stored cord blood samples. The pool represents just over a single day's births in the U.S.

Cord blood also has advantages in speed. Identifying a suitable unrelated bone marrow donor is a time-consuming process that takes an average of four months. During this period, potential donors are asked to go to donor centers to have blood drawn for tissue typing and testing for viruses such as the ones that cause AIDS and hepatitis. After a donor is selected, that individual must return, pass a physical examination, give his or her informed consent and then schedule a time for the bone marrow to be harvested from the hipbone using a needle.

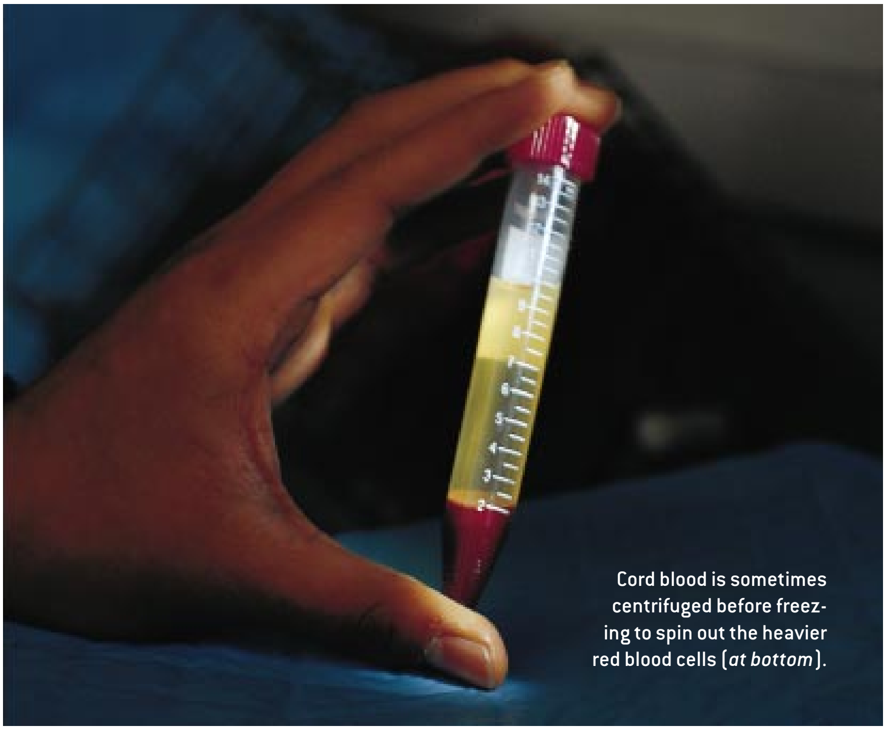
In contrast, cord blood is readily available from a bank's freezer and has already undergone viral testing and tissue typing. An umbilical cord blood match can be

One day an infant born with a **genetic defect** of the bone marrow or blood may be able to have his or her umbilical **cord blood** harvested at birth, repaired by genetic engineering and then reinfused.

A sample of frozen cord blood banked at the New York Blood Center.

made in as few as three or four days, which can spell life or death for someone who is already immunodeficient and at high risk for a fatal infection. The collection of umbilical cord blood from as many donors as possible would also increase the likelihood that people from minority groups would be able to find a match. According to the National Marrow Donor Program, African-Americans have only a 57 percent chance of finding a bone marrow donor. Pacific Islanders and Asians have a higher match rate of 74 percent; Hispanics have a 78 percent chance; and American Indians and Alaska Natives have an 84 percent likelihood of finding a donor. Caucasians have odds of 87 percent.

Cord blood will also be virtually free of a virus that in the past has been responsible for 10 percent of deaths following bone marrow transplants: cytomegalovirus (CMV). More than half of the adult U.S. population carries CMV, which continues to live in the white blood cells of the host after initial infection. Although CMV generally causes an innocuous viral syndrome in a healthy person, it can kill someone who is immunosuppressed after a bone marrow transplant. Bone marrow donors are tested for CMV, but patients often receive CMV-positive marrow if it is the best match. Because fewer than 1 percent of infants contract CMV in the womb, umbilical cord blood could be much safer than bone marrow.



Cord blood is sometimes centrifuged before freezing to spin out the heavier red blood cells (*at bottom*).

The Downside

CORD BLOOD TRANSPLANTATION is not without risks, however. One is the chance that the stem cells in a cord blood sample might harbor genetic mistakes that could cause disease in a recipient. Such disorders—which could include congenital anemias or immunodeficiencies—might not become apparent in the donor for months or years, by which time the cord blood might have already been transplanted into another recipient.

Umbilical cord blood banks could largely avoid this risk by quarantining the blood for six to 12 months and by contacting the family at that time to ensure that the donor is healthy. A long-term identification link between a donor and his or her unit of cord blood would be necessary, a prospect that has aroused privacy concerns among medical ethicists.

Currently the New York Blood Center asks potential donor parents to complete detailed questionnaires that emphasize their family histories of disease as well as their sexual histories. If responses to the questionnaire generate medical reservations, the center does not collect or store the cord blood. The center maintains only a short-term link with the donor until viral testing is complete, when the cord blood becomes anonymous.

Another limitation of umbilical cord blood is the relatively small number of stem cells contained within a single sample. Although cord blood can be used for transplantation in adults, studies by Pablo Rubinstein have demonstrated that because of the limited number of stem cells in cord blood, larger (that is, older) patients benefit less than smaller (younger) patients. Researchers are now working to devise ways to increase the number of stem cells in cord blood samples using nutrients and growth factors. They are also genetically engineering stem cells to correct genetic disorders such as severe combined immunodeficiency. In such a case, physicians would collect a patient's own cord blood, insert normal genes into the stem cells of the cord blood and reinfuse the cells into the child's body.

All of this portends even more exciting uses for cord blood. One day an infant born with a genetic defect of the bone marrow or blood may be able to have his umbilical cord blood harvested at birth, repaired by genetic engineering and then reinfused, so that he need never suffer the negative effects of his genetic inheritance. Alternatively, such a child could be cured by the infusion of stem cells from an unrelated—but perfectly matched—sample of umbilical cord blood from a donor bank. These scenarios will soon move from the realm of science fiction to science, as advances in biotechnology expand the potential of umbilical cord blood to cure diseases that once were fatal. SA

MORE TO EXPLORE

Ethical Issues in Umbilical Cord Blood Banking. J. Sugarman, V. Kaalund, E. Kodish, M. F. Marshall, E. G. Reisner, B. S. Wilfond and P. R. Wolpe in *Journal of the American Medical Association,* Vol. 278, No. 11, pages 938–943; September 17, 1997.

Umbilical Cord Blood Transplantation: Providing a Donor for Everyone Needing a Bone Marrow Transplant? Ronald M. Kline and Salvatore J. Bertolone in *Southern Medical Journal,* Vol. 91, No. 9, pages 821–828; September 1998.

For more details on the cord blood transplantation process, visit the University of California at Los Angeles site at **www.cordblood.med.ucla.edu**

Photographs by Pete McArthur

GENETICALLY MODIFIED FOODS:

Are They Safe?

The world seems increasingly divided into those who favor genetically modified (GM) foods and those who fear them. Advocates assert that growing genetically altered crops can be kinder to the environment and that eating foods from those plants is perfectly safe. And, they say, genetic engineering—which can induce plants to grow in poor soils or to produce more nutritious foods—will soon become an essential tool for helping to feed the world's burgeoning population. Skeptics contend that GM crops could pose unique risks to the environment and to health—risks too troubling to accept placidly. Taking that view, many European countries are restricting the planting and importation of GM agricultural products. Much of the debate hinges on perceptions of safety. But what exactly does recent scientific research say about the hazards? The answers, too often lost in reports on the controversy, are served up in the pages that follow. *—The Editors*

Seeds of Concern

Are genetically modified crops an environmental dream come true or a disaster in the making? Scientists are looking for answers

By Kathryn Brown

Two years ago in Edinburgh, Scotland, eco-vandals stormed a field, crushing canola plants. Last year in Maine, midnight raiders hacked down more than 3,000 experimental poplar trees. And in San Diego, protesters smashed sorghum and sprayed paint over greenhouse walls.

This far-flung outrage took aim at genetically modified crops. But the protests backfired: all the destroyed plants were conventionally bred. In each case, activists mistook ordinary plants for GM varieties.

It's easy to understand why. In a way, GM crops—now on some 109 million acres of farmland worldwide—are invisible. You can't see, taste or touch a gene inserted into a plant or sense its effects on the environment. You can't tell, just by looking, whether pollen containing a foreign gene can poison butterflies or fertilize plants miles away. That invisibility is precisely what worries people. How, exactly, will GM crops affect the environment—and when will we notice?

Advocates of GM, or transgenic, crops say the plants will benefit the environment by requiring fewer toxic pesticides than conventional crops. But critics fear the potential risks and wonder how big the benefits really are. "We have so many questions about these plants," remarks Guenther Stotzky, a soil microbiologist at New York University. "There's a lot we don't know and need to find out."

As GM crops multiply in the landscape, unprecedented numbers of researchers have started fanning into the fields to get the missing information. Some of their recent findings are reassuring; others suggest a need for vigilance.

Fewer Poisons in the Soil?

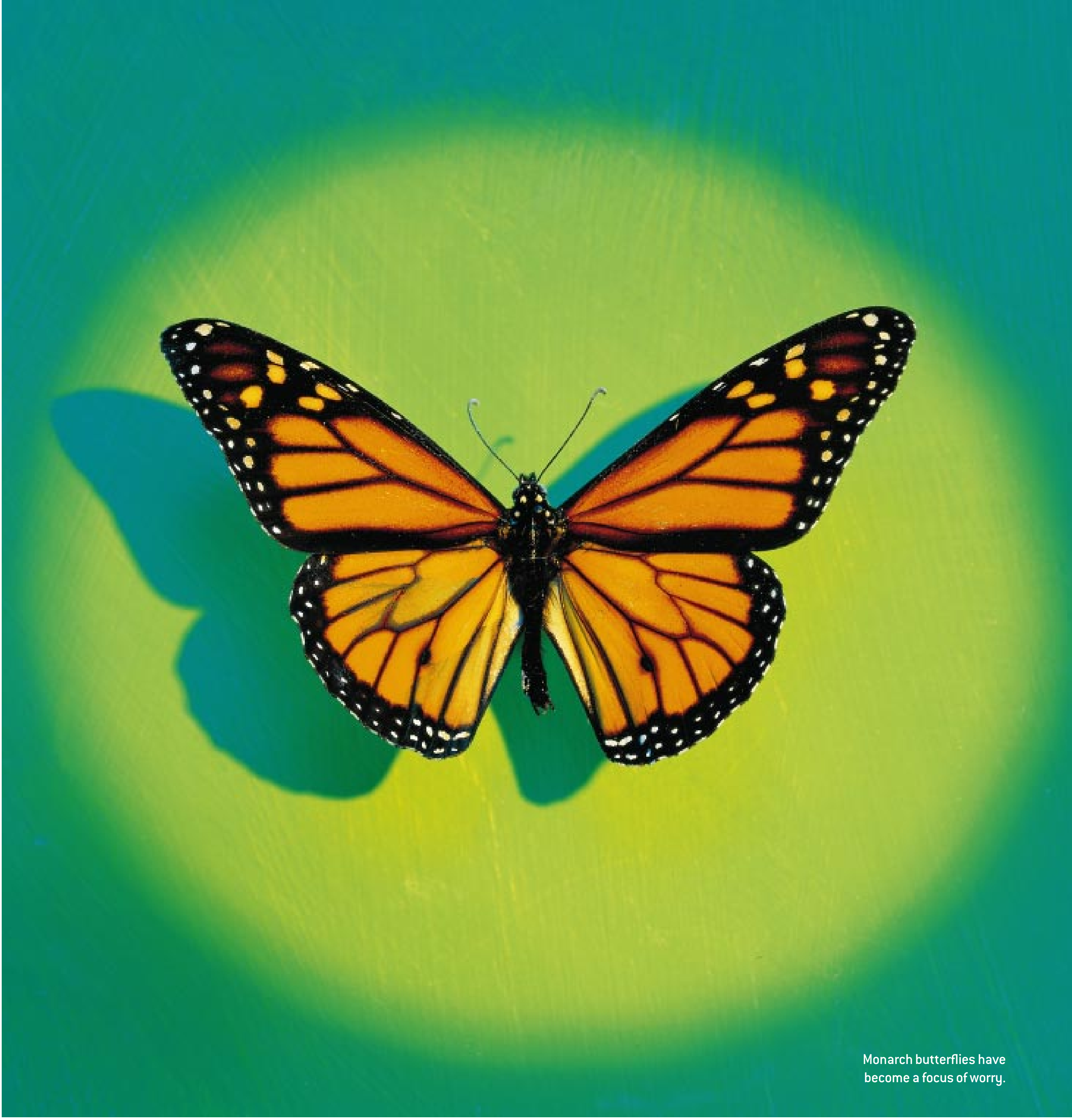
EVERY YEAR U.S. GROWERS shower crops with an estimated 971 million pounds of pesticides, mostly to kill insects, weeds and fungi. But pesticide residues linger on crops and the surrounding soil, leaching into groundwater, running into streams and getting gobbled up by wildlife. The constant chemical trickle is an old worry for environmentalists.

In the mid-1990s agribusinesses began advertising GM seeds that promised to reduce a farmer's use of toxic pesticides. Today most GM crops—mainly soybean, corn, cotton and canola—contain genes enabling them to either resist insect pests or tolerate weed-killing herbicides [*see box on page 56*]. The insect-resistant varieties make their own insecticide, a property meant to reduce the need for chemical sprays. The herbicide-tolerant types survive when exposed to broad-spectrum weed killers, potentially allowing farmers to forgo more poisonous chemicals that target specific weed species. Farmers like to limit the use of more hazardous pesticides when they can, but GM crops also hold appeal because they simplify operations (reducing the frequency and complexity of pesticide applications) and, in some cases, increase yields.

But confirming environmental benefit is tricky. Virtually no peer-reviewed papers have addressed such advantages, which would be expected to vary from plant to plant and place to place. Some information is available, however. According to the U.S. Department of Agriculture, farmers who plant herbicide-tolerant crops do not necessarily use fewer sprays, but they do apply a more benign mix of chemicals. For instance, those who grow herbicide-tolerant soybeans typically avoid the most noxious weed killer, turning instead to glyphosate herbicides, which are less toxic and degrade more quickly.

Insect-resistant crops also bring mixed benefits. To date, insect resistance has been provided by a gene from the soil bacterium *Bacillus thuringiensis* (Bt). This gene directs cells to manufacture a crystalline protein that is toxic to certain insects—especially caterpillars and beetles that gnaw on crops—but does not harm other organisms. The toxin gene in different strains of *B. thuringiensis* can affect different mixes of insects, so seed makers can select the version that seems best suited to a particular crop.

Of all the crops carrying Bt genes, cotton has brought the biggest drop in pesticide use. According to the Environmental Protection Agency, in 1999 growers in states using high amounts of Bt cotton sprayed 21 percent less insecticide than usual on the crop. That's a "dramatic and impressive" reduction, says Stephen Johnson, an administrator in the EPA's Office of Pesticide Programs. Typically, Johnson says, a farmer might spray



Monarch butterflies have become a focus of worry.

insecticides on a cotton field seven to 14 times during a single growing season. "If you choose a Bt cotton product, you may have little or no use for these pretty harsh chemicals," he notes. Growers of Bt corn and potatoes report less of a pesticide reduction, partly because those plants normally require fewer pesticides and face fluctuating numbers of pests.

Defining the environmental risks of GM crops seems even harder than calculating their benefits. At the moment, public attention is most trained on Bt crops, thanks to several negative studies. Regulators, too, are surveying the risks intensely. This spring or summer the EPA is expected to issue major new guidelines for Bt crops, ordering seed producers to show more thoroughly that the crops can be planted safely and monitored in farm fields.

In the face of mounting consumer concern, scientists are stepping up research into the consequences of Bt and other GM crops. Among their questions: How do Bt crops affect "non-target" organisms—the innocent bugs, birds, worms and other creatures that happen to pass by the modified plants? Will GM crops pollinate nearby plants, casting their genes into the wild to create superweeds that grow unchecked? What are the odds that the genetically engineered traits will lose their ability to protect against insects and invasive weeds, leaving GM plants suddenly vulnerable?

At What Cost to Wildlife?

IN 1998 A SWISS STUDY provoked widespread worry that Bt plants can inadvertently harm unlucky creatures. In this laboratory experiment, green lacewing caterpillars proved more likely to die after eating European corn-borer caterpillars that had fed on Bt corn instead of regular corn. The flames of fear erupted again a year later, when Cornell University entomologist John Losey and his colleagues reported that they had fed milkweed leaves dusted with Bt corn pollen to monarch butterfly larvae in the lab and that those larvae, too, had died.

"That was the straw that broke the camel's back," says David Pimentel, also an entomologist at Cornell. Suddenly, all eyes turned to the organisms munching GM plant leaves, nipping modified pollen or wriggling around in the soil below the plants—organisms that play vital roles in sustaining plant populations. Another alarming study relating to monarch butterflies appeared last August.

But the lab bench is not a farm field, and many scientists question the usefulness of these early experiments. The lab insects, they note, consumed far higher doses of Bt toxin than they would outside, in the real world. So researchers have headed into nature themselves, measuring the toxin in pollen from plots of GM corn, estimating how much of it drifts onto plants such as milkweed and, finally, determining the exposure of butterfly and moth larvae to the protein. Much of that work, done during the 2000 growing season, is slated to be reported to the EPA shortly.

According to the agency, however, preliminary studies evaluating the two most common Bt corn plants (from Novartis and Monsanto) already indicate that monarch larvae encounter Bt corn pollen on milkweed plants—but at levels too low to be toxic. What is toxic? The EPA estimates that the insects face no observable harm when consuming milkweed leaves laden with up to 150 corn pollen grains per square centimeter of leaf surface. Recent studies of milkweed plants in and around the cornfields of Maryland, Nebraska and Ontario report far lower levels of Bt pollen, ranging from just six to 78 grains of Bt corn pollen per square centimeter of milkweed leaf surface. "The weight of the evidence suggests Bt corn pollen in the field does not pose a hazard to monarch larvae," concludes EPA scientist Zigfridas Vaituzis, who heads the agency's team studying the ecological effects of Bt crops.

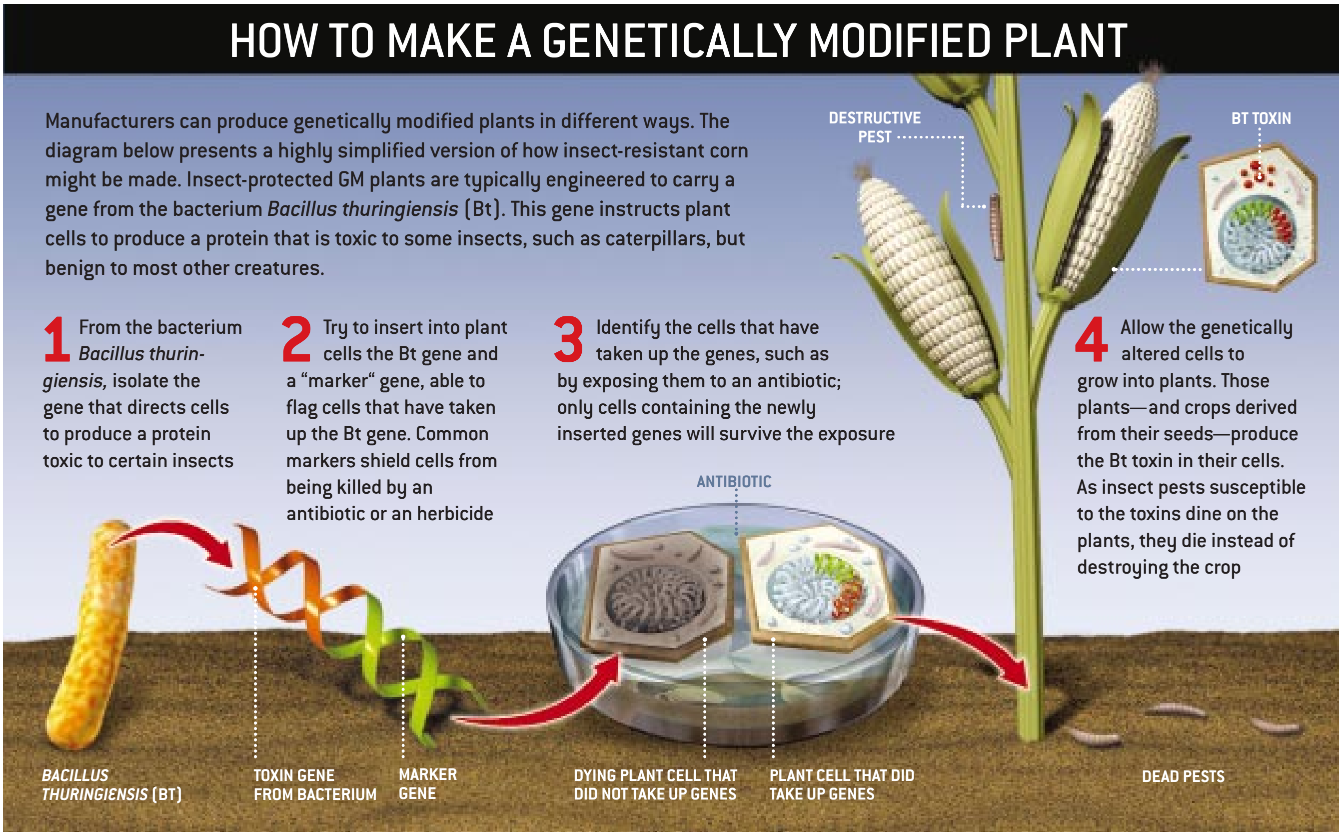
> The weight of evidence suggests that pollen from insect-resistant corn plants in the field does not pose a hazard to the larvae of monarch butterflies. But the jury is still out.

But the jury is still out. "There's not much evidence to weigh," notes Jane Rissler of the Union of Concerned Scientists. "This issue of nontarget effects is just a black hole, and EPA has very little good data at this point to conclude whether the monarch butterfly problem is real, particularly in the long term."

In an EPA meeting on GM crops last fall, Vaituzis acknowledged the lack of long-term data on Bt crops and insect populations. Such studies "require more time than has been available since the registration of Bt crops," Vaituzis remarked. The EPA,

THREE WORRIES

1 INNOCENT CREATURES WILL BE HURT by insecticides built into many GM crops.	2 SUPERWEEDS WILL ARISE as genes that give crops the ability to kill insect pests or to withstand herbicides find their way into weeds.	3 GM CROPS WILL SUDDENLY FAIL because insect pests will evolve tolerance to built-in insecticides and because weeds will evolve immunity to herbicides sprayed over fields of herbicide-tolerant GM plants.
What the research says: Laboratory studies indicate that nontarget insects, such as monarch butterflies, could be harmed, but field studies suggest that the risk is small.	*What the research says:* Studies have found no superweeds, but anecdotal reports have surfaced. Because pollen from GM plants can often fertilize weedy relatives of those plants, GM crops should not be grown near such relatives.	*What the research says:* No failures have been documented, but they are likely to occur. Critics and proponents of GM crops disagree over the adequacy of current preventive measures.



he added, continues to collect Bt crop data—but so far without evidence of "unreasonable adverse effects" on insects in the field.

Seeding Superweeds?

WORRIES ABOUT THE FLOW of genes from the original plant to others also surround GM crops. Unwitting insects or the right wind might carry GM crop pollen to weedy plant relatives, fertilizing them. And if that happens, the newly endowed plants could break ecological rank, becoming "superweeds" that are unusually resistant to eradication by natural predators or pesticides. Scientists have stopped asking if such gene flow is possible. "In many cases," says Cornell ecologist Allison Power, "we know gene flow will occur. The question now is, What will the consequences be?"

So far no scientific studies have found evidence of GM crops causing superweeds, and a 10-year study reported in *Nature* in February found no weedlike behavior by GM potatoes, beets, corn or canola planted in England. But worrisome anecdotes have appeared. Canadian farmers, in particular, have described GM canola escaping from farm fields and invading wheat crops like a weed. This canola also resisted pesticide sprays.

Power's studies of gene flow from virus-resistant GM plants give further reason for precaution. For now, virus-resistant crops stake a small share of the GM landscape, but they are likely to become more prevalent, particularly in the developing world. Power investigates gene flow in cultivated grain crops—wheat, barley and oats—engineered to contain genes that make the plants resistant to the barley yellow dwarf virus (which damages some 100 grass species). These GM grain crops could be on the market within the next decade.

Power's work, carried out in the laboratory, indicates that wild oats—a weedy relative of cultivated oats—can "catch" the genes conferring resistance to barley yellow dwarf virus. If that happened in the field, she says, wild oats might run amok in the western U.S., outcompeting native grasses with kudzu-like intensity. Every GM crop, Power cautions, brings its own environmental personality and its own risks.

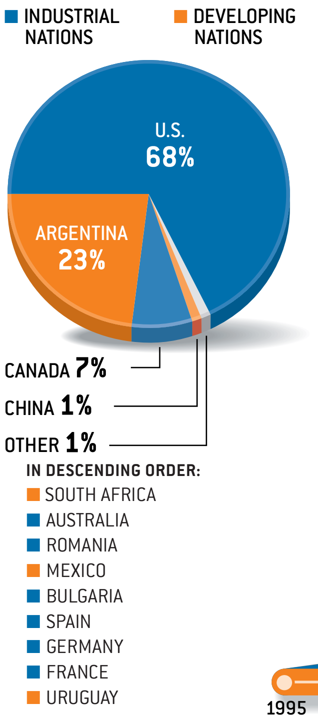
In the U.S., at least, landscape logistics make it rather unlikely that herbicide-tolerant or Bt crops will spread their biotech genes to weeds. That's because the GM crops sown in this country have no close relatives in the regions where they grow; most plants can pollinate others only if the recipients and the donors have certain features in common, such as the same chromosome number, life cycle or preferred habitat. A known exception to the "no relatives" rule in the U.S. is wild cotton growing in Hawaii and southern Florida, which, by virtue of its unusual similarity to GM cotton, can accept the GM pollen. To separate the wild and biotech plants from each other, the EPA has ordered companies not to sell GM cotton south of Florida's Interstate 60 or in Hawaii.

But it may prove harder to avoid creating superweeds outside North America, where weedy relatives of cultivated crops are common. Wild cotton, for instance, creeps past the Florida Keys, across the Gulf of Mexico and into Mexico. In South America, a weedy corn relative, teosinte, dresses the edges of domesticated cornfields. Either plant would readily

ILLUSTRATION BY JOE ZEFF

THE LATEST CROP OF NUMBERS

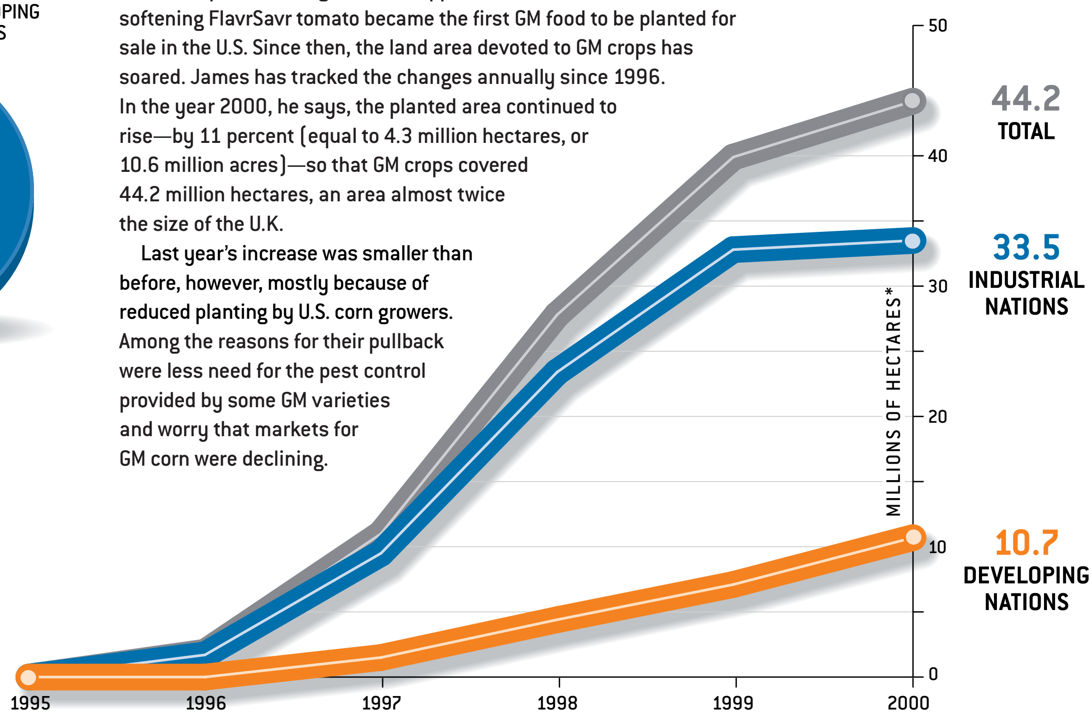
COUNTRIES PRODUCING GM CROPS IN 2000



Commercial planting of genetically modified crops began in China with tobacco in 1992, according to Clive James of the International Service for the Acquisition of Agri-biotech Applications. In 1994 the slow-softening FlavrSavr tomato became the first GM food to be planted for sale in the U.S. Since then, the land area devoted to GM crops has soared. James has tracked the changes annually since 1996. In the year 2000, he says, the planted area continued to rise—by 11 percent (equal to 4.3 million hectares, or 10.6 million acres)—so that GM crops covered 44.2 million hectares, an area almost twice the size of the U.K.

Last year's increase was smaller than before, however, mostly because of reduced planting by U.S. corn growers. Among the reasons for their pullback were less need for the pest control provided by some GM varieties and worry that markets for GM corn were declining.

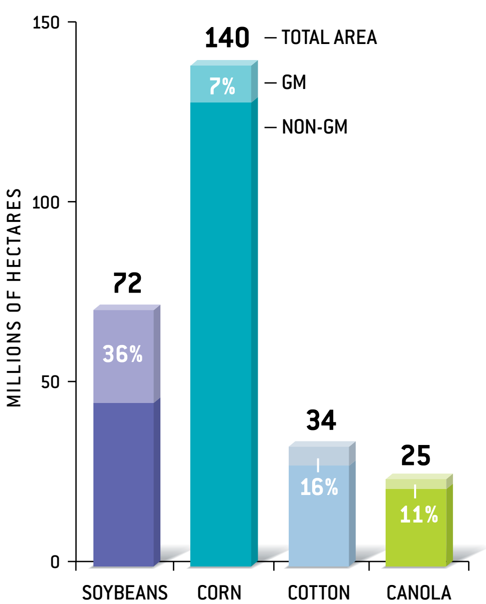
GLOBAL AREA OF GM CROPS



*Data were rounded to the nearest 100,000 hectares. 1 hectare = 2.471 acres

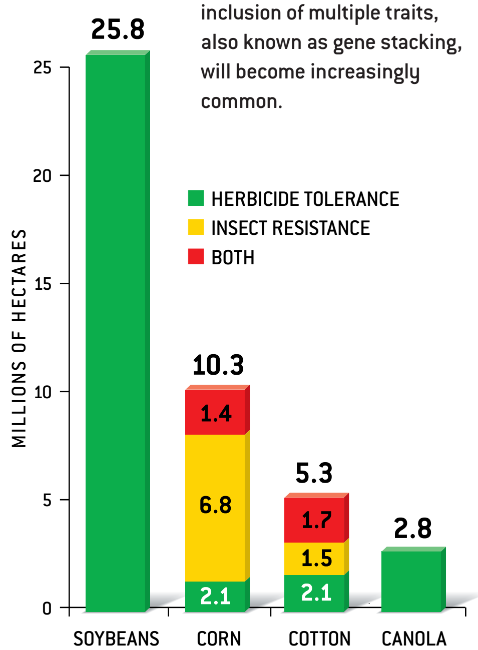
THE MOST COMMON GM CROPS . . .

Soybeans, corn, cotton and canola were the dominant GM crops in 2000, covering 16 percent of the 271 million hectares devoted to those four commodities.

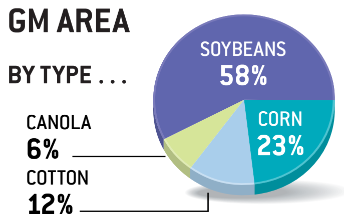


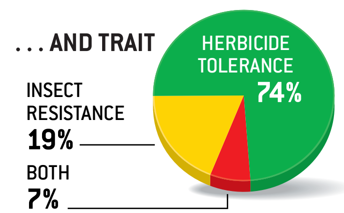
. . . AND HOW THEY'RE MODIFIED

Virtually all GM soybeans and canola planted in 2000 were herbicide-tolerant; corn and cotton were herbicide-tolerant or insect-resistant, or both. James predicts that inclusion of multiple traits, also known as gene stacking, will become increasingly common.



PERCENT OF TOTAL GM AREA





Figures may not add up to 100% because of rounding.

Farmers cultivated other GM crops as well, but these essentially dropped off the data screen when James rounded his figures to the nearest 100,000 hectares. Among them were potatoes, squash, papayas, melons, tomatoes and plants engineered for such traits as virus resistance, delayed spoilage and improved nutrition.

SOURCE: Clive James, ISAAA Briefs No. 21, *Global Status of Commercialized Transgenic Crops: 2000*; www.isaaa.org accept the pollen from a GM relative. Indeed, scientists say, GM crops in many countries could end up growing near their ancestral plants—and sharing more than the sunshine overhead. "Almost every crop has weedy relatives somewhere in the world," says Stephen Duke, a USDA plant physiologist in Oxford, Miss. "How do you keep GM crops out of places where they're not supposed to be?"

Taking Refuge

FINALLY, ONE RISK follows GM crops wherever they're planted: evolution. Over time, insect pests and weeds can become resistant to killing by routine chemical sprays. The same is bound to happen in the biotech age: eventually, impervious insects will munch away on GM insect-resistant plants, and the weeds surrounding herbicide-tolerant crops will shrug off the herbicide of choice. "Agriculture is an evolutionary arms race between plant protections and pests," comments botanist Jonathan Wendel of Iowa State University. "And GM crops are just one more way that we're trying to outsmart pests—temporarily."

After five years of commercial Bt crop use, no reports of insect resistance to the crops have emerged, according to Monsanto. The company contends that roughly 90 percent of Bt corn and cotton growers comply with refuge requirements.

But some environmentalists question that rosy scenario and also argue that non-Bt refuges are either too small or too poorly designed to keep insect resistance at bay for long. "At the EPA meeting last fall, scientists seemed to agree that bigger, better refuges were the way to go but that cotton farmers would never agree to big refuges," says Rebecca Goldburg, a senior scientist at Environmental Defense, a nonprofit organization based in New York City. More broadly, Goldburg questions how much GM crops really do for the environment. "In however many years," she says, "we'll lose Bt as an effective control against insects, and then we'll be on to another chemical control. Many of us view this current generation of biotech crops as a kind of diversion, rather than a substantive gain for agriculture." She favors sustainable agriculture alternatives, including careful crop rotation and organic farming methods, over pesticides sprayed on or engineered into plants.

U.S. landscape logistics make it unlikely that herbicide-tolerant or Bt crops will spread their biotech genes. It may be harder to avoid creating superweeds elsewhere.

To keep weeds vulnerable to herbicides, Monsanto and other companies urge growers to use the sprays responsibly, only when necessary. To slow insect resistance to the Bt toxin, the EPA requires Bt crop growers to set aside some part of their farmland for crops that have not been genetically modified. These "refuges" may be a corner of a field outside a Bt crop, for instance, or rows of standard plants that break up a Bt plot. Inside the refuges, insects that have acquired some Bt resistance breed with those that have not, diluting the resistance trait.

Virus-resistant GM crops have escaped widespread public concern, but they, too, pose some of the same risks as other GM crops. Some scientists worry that viruses will pick up resistance traits from virus-fighting GM crops and evolve into hard-to-beat strains that infect a newly expanded repertoire of plants. Some critics also question the ecological safety of emerging crops designed to resist drought, tolerate salt or deliver an extra nutritional punch. For example, Margaret Mellon of the Union of Concerned Scientists notes that salt-tolerant rice could potentially behave like a disruptive weed if it found its way into vulnerable wetlands.

"I don't think it's fair to say that every single GM crop is going to be a problem," Rissler remarks. "But we need to devote the research to risks now, rather than deal with repercussions later."

Still, some farmers are confident that GM technology can revolutionize agriculture for the better. For 30 years, Ryland Utlaut of Grand Pass, Mo., has been sowing and reaping 3,500 acres along the Missouri River. Last year, for the first time, he planted only herbicide-tolerant corn and soybeans across his entire, soil-friendly, no-till farm. As a result, he claims, he sprayed the crops half as often as he did before and got bigger yields. "If even the strongest environmentalist could see my farming practices now, I think they'd understand the benefits," Utlaut says. "I'm a fervent believer in this technology." Now he has to wait and see whether science confirms that belief. SA

Kathryn Brown is a science writer based in Alexandria, Va.

MORE TO EXPLORE

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The Ecological Risks and Benefits of Genetically Engineered Plants. L. L. Wolfenbarger and P. R. Phifer in *Science,* Vol. 290, pages 2088–2093; December 15, 2000.

Genetically Modified Pest-Protected Plants: Science and Regulation. National Research Council. National Academy Press, 2000.

Transgenic Crops in Natural Habitats. M. J. Crawley and R. S. Chails et al. in *Nature,* Vol. 409, pages 682–683; February 8, 2001.

Royal Society of Canada Expert Panel Report on the Future of Food Biotechnology. February 5, 2001. Available at **www.rsc.ca**

Information generally favorable to agricultural biotechnology, and extensive links, can be found at the Agbioworld Web site at **www.agbioworld.org/**

Information generally skeptical of agricultural biotechnology, and extensive links, can be found at the Union of Concerned Scientists Web site at **www.ucsusa.org/food/0biotechnology.html**

ILLUSTRATION BY JOE ZEFF

GM FOOD SAFETY

By Karen Hopkin

The Risks on the Table

More than half the foods in U.S. supermarkets contain genetically modified ingredients. Have they been proved safe for human consumption?

A farmworker crouches in the hot Texas sun, harvesting celery for market. That evening, painful red blisters erupt across his forearms. The celery—a newly developed variety prized for its resistance to disease—unexpectedly produces a chemical able to trigger severe skin reactions.

Traditional breeding methods generated this noxious vegetable. But opponents of genetically modified foods worry that splicing foreign genes (often from bacteria) into food plants through recombinant-DNA technology could lead to even nastier health surprises. The stakes are high: GM foods are sold in many countries. In the U.S., an estimated 60 percent of processed foods in supermarkets—from breakfast cereals to soft drinks—contain a GM ingredient, especially soy, corn or canola; some fresh vegetables are genetically altered as well.

Detractors cite several reasons for concern. Perhaps proteins made from the foreign genes will be directly toxic to humans. Maybe the genes will alter the functioning of a plant in ways that make its food component less nutritious or more prone to carrying elevated levels of the natural poisons that many plants contain in small amounts. Or perhaps the modified plant will synthesize proteins able to elicit allergic reactions.

Allergy was the big worry last year when StarLink corn—genetically modified to produce an insecticidal protein from the bacterium *Bacillus thuringiensis* (Bt)—turned up in taco shells, corn chips and other foods. Before the corn was ever planted commercially, U.S. regulators saw signs that its particular version of the Bt protein could be allergenic; they therefore approved StarLink for use only in animal feed, not in grocery products. They are examining claims of allergic reactions to foods harboring that corn, but a scientific advisory committee has determined that the amounts in consumer products were quite low and thus unlikely to provoke allergic reactions.

Proponents offer a number of defenses for genetically engineered foods. Inserting carefully selected genes into a plant is safer than introducing thousands of genes at once, as commonly occurs when plants are crossbred in the standard way. GM crops designed to limit the need for toxic pesticides can potentially benefit health indirectly, by reducing human exposure to those chemicals. More directly, foods under study are being designed to be more nutritious than their standard counterparts. Further, GM crops that produced extra nutrients or that grew well in poor conditions could provide critical help to people in developing nations who suffer from malnutrition.

Advocates note, too, that every genetically engineered food crop has been thoroughly tested for possible health effects. Relatively few independent studies have been published, but manufacturers have conducted extensive analyses, because they are legally required to ensure that the foods they sell meet federal safety standards. In the past, the companies have submitted test results to the U.S. Food and Drug Administration voluntarily in advance of sale. But an FDA rule proposed in January should make such review mandatory.

The manufacturers' studies typically begin by comparing the GM version under consideration with conventionally bred plants of the same variety, to see whether the addition of a foreign gene significantly alters the GM plant's chemical makeup and nutritional value. If the proteins made from the inserted genes are the only discernible differences, those proteins are checked for toxicity by feeding them to animals in quantities thousands of times higher than humans would ever consume. If the genetic modification leads to more extensive changes, toxicity testers may feed the complete GM food to lab animals.

To assess the allergy-inducing potential, scientists check the chemical makeup of each novel protein produced by the genetically altered plant against those of 500 or so known allergens; having a similar chemistry would raise a red flag. Proteins are also treated with acid to mimic the environment they will encounter in the stomach; most known allergens are quite stable and survive such treatment unscathed. Finally, investigators consider the original source of the protein. "There is no way that a peanut gene will ever be allowed into a strawberry," observes T. J. Higgins of the Commonwealth Scientific and Industrial Research Organization in Australia: too many people are allergic to proteins in peanuts.

Arguably, the testing system has worked well so far. It showed that the protein in StarLink corn might be allergenic (hence the animal-feed-only approval) and led other products—such as soybeans that contained a protein from Brazil nuts—to be abandoned before they had a chance to hit grocery shelves. "I don't know of any evidence that any product on the market is unsafe," says Peter Day, director of the Institute of Biomolecular Research at Rutgers University.

The safety tests are not necessarily foolproof, though. For example, GM plants often cannot make enough of the foreign protein for use in feeding studies. So researchers have bacteria churn out the proteins. But a protein made by plants, the form people would consume, might be slightly different from the one made by microbes—a difference that might theoretically affect the safety assessment of that protein. And studies using whole GM foods are limited by the amount of any food that can be introduced into an animal's diet without generating nutritional imbalances that can confound the test results. This effect is one reason that scientists have criticized a controversial 1999 study claiming that the foreign DNA in GM potatoes led to abnormalities in the intestinal lining in rats.

Beyond the acute safety considerations, some critics fear that GM foods will do harm more insidiously, by hastening the spread of antibiotic resistance in disease-causing bacteria. When food designers genetically alter a plant, they couple the selected genetic material with a "marker" gene that reveals which plants have taken up foreign genes. Often the marker genes render plant cells resistant to antibiotics that typically kill them. At issue is the possibility that resistance genes might somehow jump from GM foods to bacteria in a consumer's gut, thereby aggravating the already troubling rise of antibiotic resistance among disease-causing bacteria.

The chances of such transfer are reportedly remote—"less likely than winning a national lottery three times in a row," notes Hans Günter Gassen of the Institute of Biochemistry at the University of Technology in Darmstadt, Germany. Even so, to allay public concern, the use of antibiotic resistance genes will probably be phased out in the next five years.

Meanwhile many consumers remain disturbed that most safety tests are performed by the very corporations that produce GM foods. Steve L. Taylor, head of the department of food science and technology at the University of Nebraska, admits that some may view the practice as unseemly. But, he asks, who else should shoulder the burden—and the expense? "I'd rather see the companies spend the money than have the government use my tax dollars," he adds. "I don't care if we're talking about bicycles or GM corn, it's their obligation to prove that their products are safe." No doubt concerned scientists and citizens will continue watching to see that they do so. SA

Detractors cite several reasons for concern. Perhaps proteins made from the foreign genes will be directly toxic to humans. Perhaps GM plants will elicit allergic reactions.

Karen Hopkin is a science writer based in Somerville, Mass.

MORE TO EXPLORE

Adequacy of Methods for Testing the Safety of Genetically Modified Foods. H. A. Kuiper et al. in *Lancet*, Vol. 354, No. 9187, pages 1315–1316; Oct. 16, 1999.

Effect of Diets Containing Genetically Modified Potatoes Expressing Galanthus Nivalis Lectin on Rat Small Intestine. S.W.B. Ewan and A. Pusztai in *Lancet*, Vol. 354, No. 9187, pages 1353–1354; Oct. 16, 1999.

Safety Aspects of Genetically Modified Foods of Plant Origin. Report of a joint FAO/WHO expert consultation on foods derived from biotechnology. Geneva, June 2000. Available at **www.who.int/fsf/gmfood/fao-who_consultation_report_2000.pdf**

Possible Health Risks of GM Foods. H. G. Gassen. Available from the OECD Web site at **www.oecd.org/subject/biotech/Gassen.pdf**

Two leading figures in the debate over genetic engineering defend their stances

Interviews by Sasha Nemecek

YES

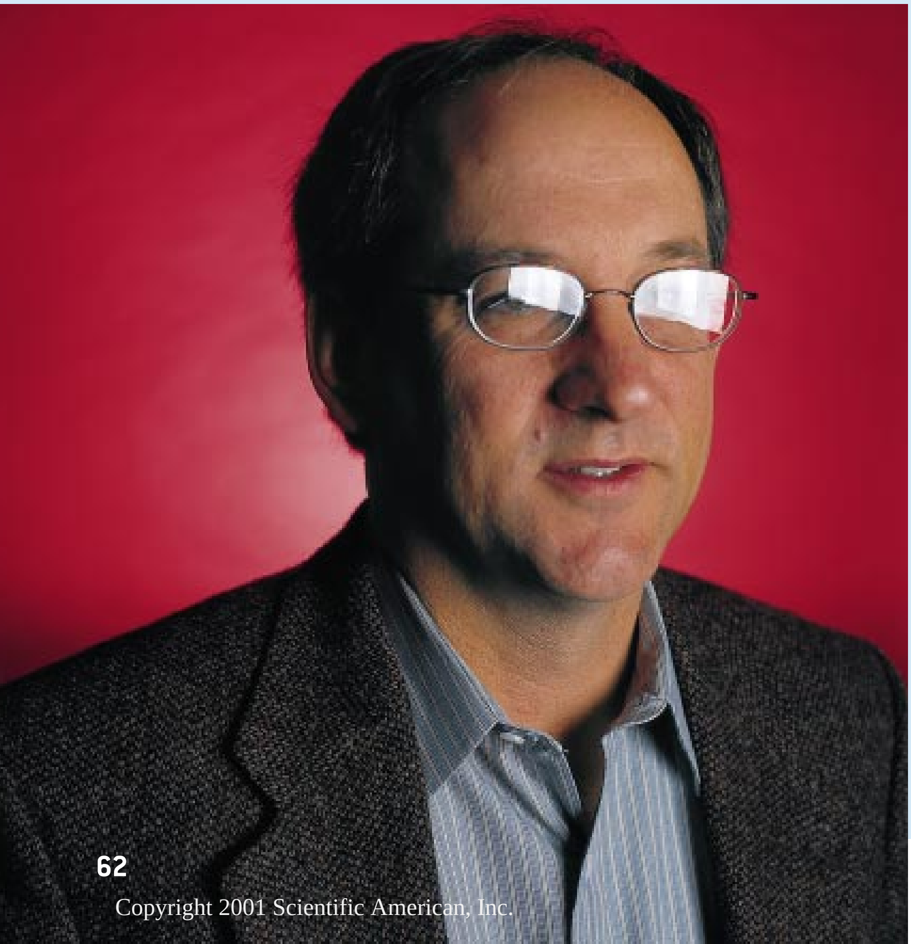
Does the World Need GM Foods?

ROBERT B. HORSCH, vice president of product and technology cooperation at Monsanto Company, received the 1998 National Medal of Technology for his pioneering experiments in the genetic modification of plant cells. He talks about the promise of GM crops.

How did you become interested in the genetic modification of plants?

I started in this field with a strong interest in plants but with what you might call an academic interest in agriculture. I had this vague, naive notion that if we could genetically improve plants with the new tools of molecular biology, we would find a way to make biotechnology relevant to agriculture.

That has now happened. Biotechnology is a great tool that will allow us to produce more food on less land and with less depletion or damage to water resources and biodiversity. I am convinced that biotechnology is not just relevant but imperative for helping us meet the rapidly growing demand for food and other agricultural products. The combination of more people and rising incomes will increase the demand for food by at least 50 percent in the next 25 years.



But critics of genetically modified foods point out that companies are not going to start giving products away. Can a corporation like Monsanto make biotechnology affordable for farmers in the developing world?

Cultivating commercial markets and applying technology to help the developing world are not mutually exclusive at all. One approach that works very well is to segment the market into three different areas. One is the pure commercial market. It makes economic sense, as a for-profit company, for us to invest in products and market developments in places where we can sell our products and where we think we can make a profit.

The other end of the spectrum is noncommercial technology transfer, which is largely focused on public-sector collaboration. Take, for example, our collaboration to put virus-resistance genes in the sweet potato. We will never have a commercial business in the sweet potato because it's just not a market economy crop. But by sharing our intellectual property and our technical knowledge with scientists from Kenya, we have helped them develop sweet potatoes that show resistance to the most serious sweet potato disease in Africa, which can cause the loss of 20 to 80 percent of the crop.

Then there's a third area, what I call a transitional market, where we have less experience related to biotechnology but that in the long run I think may be more powerful and beneficial for development efforts. We have used this approach with our older, nonbiotech products,

PHOTOGRAPHS BY TOM WOLFF

such as high-yielding corn hybrids, and I think we can use it in the future with biotech products. Small farmers can see results in a demonstration plot and, if they want, try it themselves on a portion of their farm. If it works for them, they can expand or repeat it the next year. We have programs like this in Mexico, India and parts of Africa. By the third or fourth year, if it's working, the farmers will have made enough money from the experimentation phase to be able to run essentially on their own.

And what about profits for Monsanto?

We sell the seeds and the herbicide at market prices, and we subsidize the learning, the testing and the development of distribution channels so that we don't actually make a profit in the first several years. Only if the project is successful enough to become self-sustaining will we start making a profit. At this point, we haven't gotten that far with any of these programs.

Let's turn to the environmental effects of GM crops. What do you consider the most important benefits of the technology?

Lower use of pesticides is the environmental benefit that people relate to immediately, and it's huge for a product like Bt cotton. [*Editors' note: Bt crops have been genetically modified to produce a bacterial protein that kills certain insect pests.*] According to a recent report, 2.7 million pounds of pesticides have not been used in the past four years, and many, many more won't be used in the future as biotech expands in acreage and in traits.

Beyond that there are also yield benefits. The Bt corn we have today doesn't displace a whole lot of insecticides, but what it does do is boost the yields by a noticeable margin. It depends on the year and on the region, but the increase in yield can range from 5 to 15 percent. If you think about it, that leverages land use, water use, fertilizer use and all the pesticides that go into growing corn. You get a 10 percent greater corn harvest with the same resources that you were going to use anyway. You're getting more out of your resources.

Getting more from really good farmland, then setting aside land that is of marginal quality and returning it to habitat for wildlife is very beneficial to the environment. We can't continue to indefinitely expand our old practices—of chemical use, of water diversion, of plowing wild lands and converting them to farms, of nonagricultural sprawl and of the production of industrial waste.

One of the benefits of biotech that we first heard about was nutritionally enhanced foods. But despite promises of healthier broccoli, we have Bt corn. The famous "golden rice" is not available to consumers yet and is still in very early stages of testing. Will we ever have nutritionally enhanced foods?

We're seeing progress across industry, academia and the nonprofit community. For example, we are collaborating with a nonprofit group, TERI [Tata Energy Research Institute] in India, on development of a product related to golden rice—golden mustard oil—that, like golden rice, is high in beta-carotene, a precursor of vitamin A. This may help alleviate vitamin A deficiencies in places where mustard oil is a staple in the local diet.

While making improvements to food for the industrial world is not a priority for Monsanto, other companies and university researchers are working hard in this area. For example, Du Pont has developed a modified oil with an increased amount of the fatty acid oleic acid. This product has reduced levels of polyunsaturated fatty acids and is more stable upon storage. Efforts are under way to modify other fatty acids to make oils more healthy for consumers. Also, there is research ongoing elsewhere to increase the amount of vitamin D in soybean oil.

Monsanto and other scientists have also been involved in research that may help reduce the likelihood of allergic responses to foods. We have been able to take a protein that is currently an allergen and modify specific amino acids in the protein to dramatically reduce the allergenic nature of the protein. Other scientists are using this and other methods to reduce the allergenic nature of some foods, such as peanuts and soybeans, which cause allergic reactions in a significant number of people.

Monsanto has been one of the most criticized, even despised, corporations because of its role in the development of genetically modified foods. Has it ever been hard to tell people you're an employee of Monsanto?

I've had a few people react negatively, but my experience is that when people meet you as a person, their reactions are very different than when they are commenting on the big nameless, faceless company.

I think the company is making an effort to address people's concerns about GM foods more openly. We've recognized that some genetic modifications are particularly bothersome. Among vegetarians, for instance, the idea of eating a vegetable that has an animal gene in it might raise questions. For certain cultures or religious groups, there could be similar concerns. So we decided it was better to avoid using animal genes in food crops.

I don't think it serves anybody's interest—including Monsanto's—to discount the potential risks of biotechnology. But for where we are today, and for what I see in the pipeline for the next few years, I really don't see a measurable risk from the GM products we are selling or developing. There have been numerous national and international scientific organizations that have reached this same conclusion, including the American Medical Association, the National Academy of Sciences, the World Health Organization and many others.

We at Monsanto have recently pledged to listen better to and engage in dialogue with concerned groups, to be more transparent in the methods we use and the data we have about safety, to respect the cultural and ethical concerns of others, to share our technology with developing countries, and to make sure we deliver real benefits to our customers and to the environment. I think this new attitude and new set of commitments will help improve both our company's image and the acceptance of this new technology.

NO

Does the World Need GM Foods?

MARGARET MELLON, director of the agricultural and biotechnology program of the Union of Concerned Scientists in Washington, D.C., holds a law degree and a Ph.D. in molecular biology. She explains her concerns about the effects of GM foods on human health and the environment.

How did you become interested in genetically modified foods?

I became aware of genetic engineering while running a program on toxic chemicals at the Environmental Law Institute in the 1980s. I was initially more positively disposed toward biotechnology than I came to be over the years. Like a lot of folks, I wasn't very critical. But the more I knew about the technology and the deeper the questions I asked about it, the less likely I was to accept at face value the extravagant promises made on its behalf.

I should also say, however, that my colleagues and I at the Union of Concerned Scientists are not opposed to biotechnology. We think its use in drug manufacture, for example, makes a lot of sense. The therapeutic benefits of the new drugs outweigh the risks, and often there aren't any alternatives. But in agriculture, it's different. So far, at least, there are only modest benefits associated with biotechnology products, and it has yet to be shown that the benefits outweigh the risks. And there are exciting alternatives to solving agricultural problems that we are simply ignoring.

Agriculture isn't like medicine. We in the U.S. produce far more food than we need. And we are so wealthy that whatever we can't produce we can buy from somebody else. As a result, there are about 300,000 food products on our grocery shelves and 10,000 new ones added every year. The notion that consumers in the U.S. fundamentally need new biotechnology foods isn't persuasive.

But, of course, many scientists and policy experts argue that we *do* need biotechnology to feed the world, especially the developing world.

That is an important question to ask because so many people—about 800 million—are undernourished or hungry. But is genetic engineering the best or only solution? We have sufficient food now, but it doesn't get to those who need it. Most hungry people simply can't afford to buy what's already out there even though commodity prices are at all-time lows. How does genetic engineering address the problems of income disparity?

The real tragedy is that the debate about biotechnology is diverting attention from solving the problem of world hunger. I'd like to see people seriously asking the question, "What can we do to help the world's hungry feed themselves?" and then make a list of answers. Better

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technology, including genetic engineering, would be somewhere on the list, but it would not be at the top. Trade policy, infrastructure and land reform are much more important, yet they are barely mentioned.

Genetic engineering has a place and should not be taken off the table, but I don't believe it is a panacea for world hunger. Treating it as if it is distorts this important debate. It is also amazing to me how quickly some have dismissed the virtues of traditional breeding—the technology that, after all, made us into an agricultural powerhouse.

Can we turn to another potential benefit that people claim for GM foods: agriculture that is more environmentally friendly?

Let's ask a question: What is a green agriculture? Is it one that doesn't depend on pesticides? I think it's a lot more than that, actually. But if we just consider avoiding pesticide use, we now have some data on the impacts of engineered crops. Surveys of American farmers by the Department of Agriculture show that the use of Bt [pest-resistant] corn aimed at the corn borer, for example, hasn't done much to reduce the application of pesticides to corn, because the vast majority of corn acreage isn't treated with pesticide to control that pest.

The introduction of Bt cotton, however, has resulted in a measurable drop in pesticide use. That's good for the environment and good for the farmers who cut their input costs. But this benefit will last only as long as the Bt trait keeps working. I think most scientists expect that the way Bt crops are being deployed will lead—sooner rather than later—to the evolution of resistance in the target pests, which means that the Bt cotton won't work anymore. We are likely to run through Bt cotton just like we ran through all the pesticides before it. So it isn't a durable path to a greener agriculture.

And there are environmental risks out there. Most scientists agree now that gene flow will occur—genes *will* go from engineered crops to nearby relatives. That means pollen will carry novel genes from the agricultural settings into neighbors' fields or into the wild. Gene flow from herbicide-resistant GM crops into the wild is already leading to the creation of herbicide-resistant weeds in Canada.

What about the health risks of GM foods? Do you see any looming problems?

I know of no reason to say the foods currently on the market are not safe to consume. But I don't have as much confidence as I should in that statement. There was a letter published in the journal *Science* last June from someone who had searched the literature for peer-reviewed studies comparing GM food to non-GM food. The researcher found something like five studies. That's not enough of a basis on which to claim, from a scientific standpoint, that we know enough to assure ourselves that these foods are going to be safe.

With the little we know about the food safety issue, I would say the biggest concern is allergenicity. Introducing new toxins into food is also a risk. Of course, breeders are going to try to avoid doing that, but plants have lots of toxins in them; as scientists manipulate systems that they don't completely understand, one of the unexpected effects could be turning on genes for toxins. There are rules that govern how genes come together and come apart in traditional breeding. We're not obeying those rules.

So you don't see genetic engineering of crops to be an extension of traditional breeding?

No, not at all. You just can't get an elephant to mate with a corn plant. Scientists are making combinations of genes that are not found in nature.

From a scientific standpoint, there is no dispute that this is fundamentally different from what has been done before. And that it is unnatural. Now, because it's new and unnatural doesn't *necessarily* mean that it will prove to be more risky. But it is certainly a big enough break with what we have done before to demand an extra measure of caution.

And caution is particularly appropriate where the technology involves our food supply. Lots and lots of people—virtually the whole population—could be exposed to genetically engineered foods, and yet we have only a handful of studies in the peer-reviewed literature addressing their safety. The question is, do we *assume* the technology is safe based on an argument that it's just a minor extension of traditional breeding, or do we *prove* it? The scientist in me wants to prove it's safe. Why rest on assumptions when you can go into the lab?

Science can never prove that any technology is 100 percent safe. Will you ever be satisfied that we've tested GM foods enough? And how much risk is acceptable?

Sure, I could be satisfied that GM foods have been adequately tested. But it's premature to address that question now. Nobody is saying, "Look, we've got this large body of peer-reviewed experimental data comparing GM with non-GM foods on a number of criteria that demonstrate the food is safe."

When we have generated such a body of evidence, *then* there will be an issue of whether what we have is enough. And eventually, if things go well, we'll get to a point where we say, we've been cautious, but now we're going to move ahead—we need to fish or cut bait. But we're nowhere near that point now.

Obviously, we take risks all the time. But why are we taking these risks? If we didn't have an abundant food supply, if we didn't have something like 300,000 food products on our shelves already, then we would have an argument for taking this society-wide risk. But we've got plenty of food. In fact, we've got too much. And although we have many problems associated with our food system, they are not going to be solved by biotechnology.

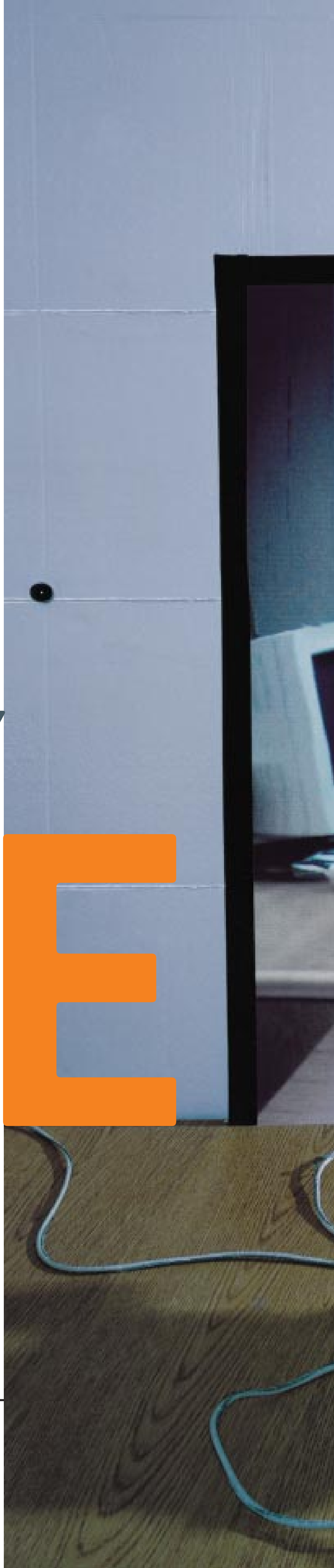
Sasha Nemecek, a former editor at Scientific American, *is a science writer based in New York City.*

VIRTUALLY THERE

Three-dimensional tele-immersion may eventually bring the world to your desk

BY JARON LANIER

PHOTOGRAPH BY DAN WINTERS



JARON LANIER, physically located in Armonk, N.Y., as he appears on a tele-immersion screen in Chapel Hill, N.C.

Like many researchers, I am a frequent but reluctant user of videoconferencing. **Human interaction** *has both verbal and nonverbal elements, and videoconferencing seems precisely configured to confound the nonverbal ones. It is impossible to make eye contact* properly, for instance, in today's videoconferencing systems, because the camera and the display screen cannot be in the same spot. This usually leads to a deadened and formal affect in interactions, eye contact being a nearly ubiquitous subconscious method of affirming trust. Furthermore, participants aren't able to establish a sense of position relative to one another and therefore have no clear way to direct attention, approval or disapproval.

Tele-immersion, a new medium for human interaction enabled by digital technologies, approximates the illusion that a user is in the same physical space as other people, even though the other participants might in fact be hundreds or thousands of miles away. It combines the display and interaction techniques of virtual reality with new vision technologies that transcend the traditional limitations of a camera. Rather than merely observing people and their immediate environment from one vantage point, tele-immersion stations convey them as "moving sculptures," without favoring a single point of view. The result is that all the participants, however distant, can share and explore a life-size space.

Beyond improving on videoconferencing, tele-immersion was conceived as an ideal application for driving network-engineering research, specifically for Internet2, the primary research consortium for advanced network studies in the U.S. If a computer network can support tele-immersion, it can probably support any other application. This is because tele-immersion demands as little delay as possible from flows of information (and as little inconsistency in delay), in addition to the more common demands for very large and reliable flows.

Virtual Reality and Networks

BECAUSE TELE-IMMERSION sits at the crossroads of research in virtual reality and networking, as well as computer vision and user-interface research, a little background in these various fields of research is in order.

In 1965 Ivan Sutherland, who is widely regarded as the father of computer graphics, proposed what he called the "Ultimate Display." This display would allow the user to experience an entirely computer-rendered space as if it were real. Sutherland termed such a space a "Virtual World," invoking a term from the philosophy of aesthetics, particularly the writings of Suzanne K. Langer. In 1968 Sutherland realized a virtual world for the first time by means of a device called a head-mounted display. This was a helmet with a pair of display screens positioned in front of the eyes to give the wearer a sense of immersion in a stereoscopic, three-dimensional space. When the user moved his or her head, a computer would quickly recompute the images in front of each eye to maintain the illusion that the computer-rendered world remained stationary as the user explored it.

In the course of the 1980s I unintentionally ended up at the helm of the first company to sell general-purpose tools for making and experiencing virtual worlds—in large part because of this magazine. *Scientific American* devoted its September 1984 issue to emerging digital technologies and chose to use one of my visual-programming experiments as an illustration for the cover.

At one point I received a somewhat panicked phone call from an editor who noticed that there was no affiliation listed for me. I explained that at the time I had no affiliation and neither did the work being described. "Sir," he informed me, "at *Scientific American* we have a strict rule that states that an affiliation must be indicated after a contributor's name." I blurted out "VPL Research" (for Visual Programming Language, or

Overview / *Tele-immersion*

- This new telecommunications medium, which combines aspects of virtual reality with videoconferencing, aims to allow people separated by great distances to interact naturally, as though they were in the same room.
- Tele-immersion is being developed as a prototype application for the new Internet2 research consortium. It involves monumental improvements in a host of computing and communications technologies, developments that could eventually lead to a variety of spin-off inventions.
- The author suggests that within 10 years, tele-immersion could substitute for many types of business travel.

TELE-COLLABORATORS hundreds of miles apart consider a computer-generated medical model, which both of them can manipulate as though it were a real object. The headpiece helps the computers locate the position and orientation of the user's head; such positioning is essential for presenting the right view of a scene. In the future, the headpiece should be unnecessary.

PHOTOGRAPH COURTESY OF THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL

Virtual Programming Language), and thus was born VPL. After the issue's publication, investors came calling, and a company came to exist in reality. In the mid-1980s VPL began selling virtual-world tools and was well known for its introduction of glove devices, which were featured on another *Scientific American* cover, in October 1987.

VPL performed the first experiments in what I decided to call "virtual reality" in the mid- to late 1980s. Virtual reality combines the idea of virtual worlds with networking, placing multiple participants in a virtual space using head-mounted displays. In 1989 VPL introduced a product called RB2, for "Reality Built for Two," that allowed two participants to share a virtual world. One intriguing implication of virtual reality is that participants must be able to see representations of one another, often known as avatars. Although the computer power of the day limited our early avatars to extremely simple, cartoonish computer graphics that only roughly approximated the faces of users, they nonetheless transmitted the motions of their hosts faithfully and thereby conveyed a sense of presence, emotion and locus of interest.

At first our virtual worlds were shared across only short physical distances, but we also performed some experiments with long-distance applications. We were able to set up virtual-reality sessions with participants in Japan and California and in Germany and California. These demonstrations did not strain the network, because only the participants' motions needed to be sent, not the entire surface of each person, as is the case with tele-immersion.

Computer-networking research started in the same era as research into virtual worlds. The original network, the Arpanet, was conceived in the late 1960s. Other networks were inspired by it, and in the 1980s all of them merged into the Internet. As the Internet grew, various "backbones" were built. A backbone is a network within a network that lets information travel over exceptionally powerful, widely shared connections to go long distances more quickly. Some notable backbones designed to support research were the NSFnet in the late 1980s and the vBNS in the mid-1990s. Each of these played a part in inspiring new applications for the Internet, such as the

THE AUTHOR

JARON LANIER is a computer scientist often described as "the father of virtual reality." In addition to that field, his primary areas of study have been visual programming, simulation, and high-performance networking applications. He is chief scientist of Advanced Network and Services, a nonprofit concern in Armonk, N.Y., that funds and houses the engineering office of Internet2. Music is another of Lanier's great interests: he writes for orchestra and other ensembles and plays an extensive, exotic assortment of musical instruments—most notably, wind and string instruments of Asia. He is also well known as an essayist on public affairs.

THREE USERS in different cities can share a virtual space thanks to this telecubicle.

World Wide Web. Another backbone-research project, called Abilene, began in 1998, and it was to serve a university consortium called Internet2.

Abilene now reaches more than 170 American research universities. If the only goal of Internet2 were to offer a high level of bandwidth (that is, a large number of bits per second), then the mere existence of Abilene and related resources would be sufficient. But Internet2 research targeted additional goals, among them the development of new protocols for handling applications that demand very high bandwidth and very low, controlled latencies (delays imposed by processing signals en route).

Internet2 had a peculiar problem: no existing applications required the anticipated level of performance. Computer science has traditionally been driven by an educated guess that there will always be good uses for faster and more capacious digital tools, even if we don't always know in advance what those uses will be. In the case of advanced networking research, however, this faith wasn't enough. The new ideas would have to be tested on something.

Allan H. Weis, who had played a central role in building the NSFnet, was in charge of a nonprofit research organization called Advanced Network and Services, which housed and administered the engineering office for Internet2. He used the term "tele-immersion" to conjure an ideal "driver" application and asked me to take the assignment as lead scientist for a National Tele-Immersion Initiative to create it. I was delighted, as this was the logical extension of my previous work in shared virtual worlds.

Although many components, such as the display system, awaited invention or refinement before we could enjoy a working tele-immersion system, the biggest challenge was creating an appropriate way of visually sensing people and places. It might not be immediately apparent why this problem is different from videoconferencing.

Seen through polarizing glasses, two walls of the cubicle dissolved into windows, revealing offices with people who **WERE LOOKING BACK AT ME.**

Beyond the Camera as We Know It

THE KEY IS THAT in tele-immersion, each participant must have a personal viewpoint of remote scenes—in fact, two of them, because each eye must see from its own perspective to preserve a sense of depth. Furthermore, participants should be free to move about, so each person's perspective will be in constant motion.

Tele-immersion demands that each scene be sensed in a manner that is not biased toward any particular viewpoint (a camera, in contrast, is locked into portraying a scene from its own position). Each place, and the people and things in it, has to be sensed from all directions at once and conveyed as if it were an animated three-dimensional sculpture. Each remote site receives information describing the whole moving sculpture and renders viewpoints as needed locally. The scanning process has to be accomplished fast enough to take place in real time—at most within a small fraction of a second. The sculpture representing a person can then be updated quickly enough to achieve the illusion of continuous motion. This illusion starts to appear at about 12.5 frames per second (fps) but becomes robust at about 25 fps and better still at faster rates.

Measuring the moving three-dimensional contours of the inhabitants of a room and its other contents can be accomplished in a variety of ways. As early as 1993, Henry Fuchs of the University of North Carolina at Chapel Hill had proposed one method, known as the "sea of cameras" approach, in which the viewpoints of many cameras are compared. In typical scenes in a human environment, there will tend to be visual features, such as a fold in a sweater, that are visible to more than one camera. By comparing the angle at which these features are seen by different cameras, algorithms can piece together a three-dimensional model of the scene.

This technique had been explored in non-real-time configurations, notably in Takeo Kanade's work, which later culminated in the "Virtualized Reality" demonstration at Carnegie Mellon University, reported in 1995. That setup consisted of 51 inward-looking cameras mounted on a geodesic dome. Because it

PHOTOGRAPH COURTESY OF THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL was not a real-time device, it could not be used for tele-immersion. Instead videotape recorders captured events in the dome for later processing.

Ruzena Bajcsy, head of the GRASP (General Robotics, Automation, Sensing and Perception) Laboratory at the University of Pennsylvania, was intrigued by the idea of real-time seas of cameras. Starting in 1994, she worked with colleagues at Chapel Hill and Carnegie Mellon on small-scale "puddles" of two or three cameras to gather real-world data for virtual-reality applications.

Bajcsy and her colleague Kostas Daniilidis took on the assignment of creating the first real-time sea of cameras—one that was, moreover, scalable and modular so that it could be adapted to a variety of rooms and uses. They worked closely with the Chapel Hill team, which was responsible for taking the "animated sculpture" data and using computer graphics techniques to turn it into a realistic scene for each user.

But a sea of cameras in itself isn't a complete solution. Suppose a sea of cameras is looking at a clean white wall. Because there are no surface features, the cameras have no information with which to build a sculptural model. A person can look at a white wall without being confused. Humans don't worry that a wall might actually be a passage to an infinitely deep white chasm, because we don't rely on geometric cues alone—we also have a model of a room in our minds that can rein in errant mental interpretations. Unfortunately, to today's digital cameras, a person's forehead or T-shirt can present the same challenge as a white wall, and today's software isn't smart enough to undo the confusion that results.

Researchers at Chapel Hill came up with a novel method that has shown promise for overcoming this obstacle, called "imperceptible structured light," or ISL. Conventional lightbulbs flicker 50 or 60 times a second, fast enough for the flickering to be generally invisible to the human eye. Similarly, ISL appears to the human eye as a continuous source of white light, like an ordinary lightbulb, but in fact it is filled with quickly changing patterns visible only to specialized, carefully synchronized cameras. These patterns fill in voids such as white walls with imposed features that allow a sea of cameras to complete the measurements.

The Eureka Moment

WE WERE ABLE TO demonstrate tele-immersion for the first time on May 9, 2000, virtually bringing together three locations. About a dozen dignitaries were physically at the telecubicle in Chapel Hill. There we and they took turns sitting down in the simulated office of tomorrow. As fascinating as the three years of research leading up to this demonstration had been for me, the delight of experiencing tele-immersion was unanticipated and incomparable. Seen through a pair of polarizing glasses, two walls of the cubicle dissolved into windows, revealing other offices with other people who were looking back at me. (The glasses helped to direct a slightly different view of the scenes to each eye, creating the stereo vision effect.) Through one wall I greeted Amela Sadagic, a researcher at my lab in Armonk, N.Y. Through the other wall was Jane Mulligan, a postdoctoral fellow at the University of Pennsylvania.

Unlike the cartoonish virtual worlds I had worked with for many years, the remote people and places I was seeing were clearly derived from reality. They were not perfect by any means. There was "noise" in the system that looked something like confetti being dropped in the other people's cubicles. The frame rate was low (2 to 3 fps), there was as much as one second of delay, and only one side of the conversation had access to a tele-immersive display. Nevertheless, here was a virtual world that was not a simplistic artistic representation of the real world but rather an authentic measurement-based rendition of it.

In a later demo (in October 2000) most of the confetti was gone and the overall quality and speed of the system had increased, but the most important improvement came from researchers at Brown University led by Andries van Dam. They arrived in a tele-immersive session bearing virtual objects not derived from the physical scene. I sat across the table from Robert C. Zeleznik of Brown, who was physically at my lab in Armonk. He presented a simulated miniature office interior (about two feet wide) resting on the desk between us, and we used simulated laser pointers and other devices to modify walls and furniture in it collaboratively while we talked. This was a remarkable blending of the experience of using simulations associated with virtual reality and simply being with another person.

When Can I Use It?

BEYOND THE SCENE-CAPTURE system, the principal components of a tele-immersion setup are the computers, the network services, and the display and interaction devices. Each of these components has been advanced in the cause of tele-immersion and must advance further. Tele-immersion is a voracious consumer of computer resources. We've chosen to work with "commodity" computer components (those that are also used in common home and office products) wherever

COMPARISON OF TWO VIEWS of a person taken by the tele-immersion cameras yields this image. The colors represent the first rough calculation of the depth of the person's features.

IMAGE COURTESY OF THE UNIVERSITY OF PENNSYLVANIA

HOW TELE-IMMERSION WORKS

In this highly simplified scheme for how a future tele-immersion scheme might work, two partners separated by 1,000 miles collaborate on a new engine design

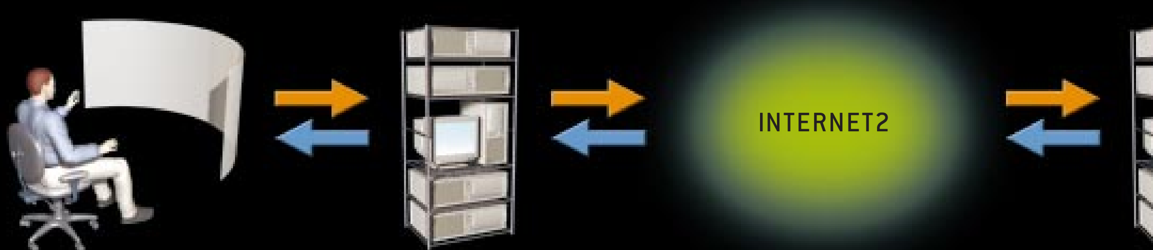
"SEA OF CAMERAS"
Hidden cameras provide many points of view that are compared to create a three-dimensional model of users and their surroundings. The cameras can be hidden behind tiny perforations in the screen, as shown here, or can be placed on the ceiling, in which case the display screen must also serve as a selectively reflective surface.

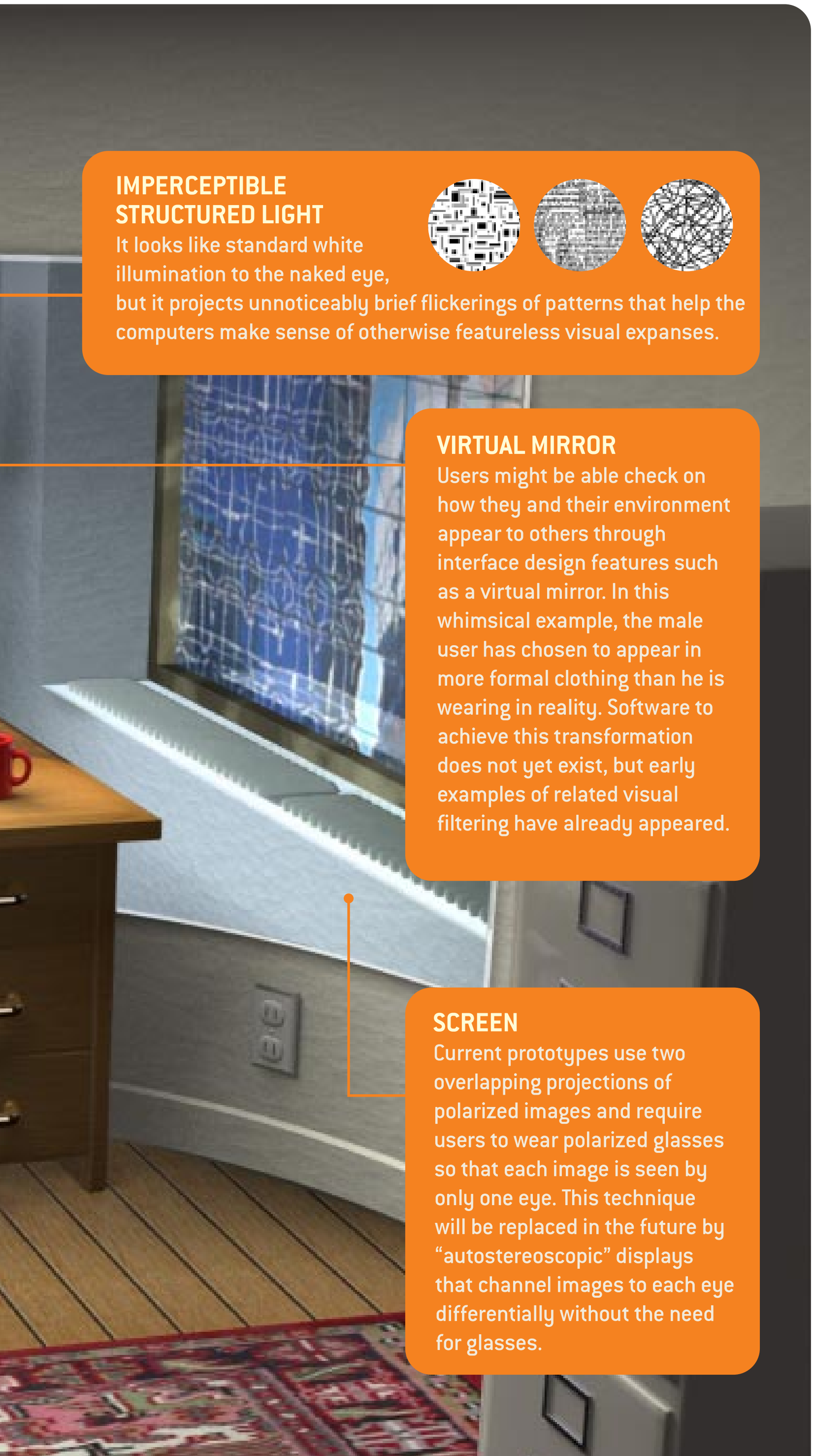
SHARED SIMULATION OBJECTS
Simulated objects appear in the space between users. These can be manipulated as if they were working models. One stream of research in the National Tele-immersion Initiative concerns finding better techniques to combine models developed by people on opposite ends of a dialogue using incompatible local software design tools.

FOLLOWING THE FLOW OF INFORMATION

Tele-immersion depends on intense data processing at each end of a connection, mediated by a high-performance network.

FROM THE SENDER . . .
Parallel processors accept visual input from the cameras and reinterpret the scene as a three-dimensional computer model.





IMPERCEPTIBLE STRUCTURED LIGHT

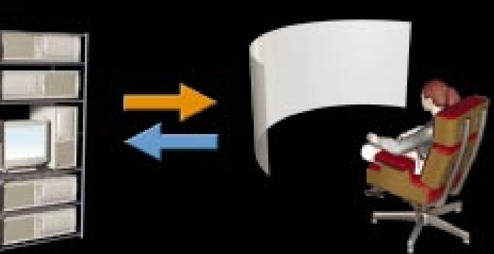
It looks like standard white illumination to the naked eye, but it projects unnoticeably brief flickerings of patterns that help the computers make sense of otherwise featureless visual expanses.

VIRTUAL MIRROR

Users might be able check on how they and their environment appear to others through interface design features such as a virtual mirror. In this whimsical example, the male user has chosen to appear in more formal clothing than he is wearing in reality. Software to achieve this transformation does not yet exist, but early examples of related visual filtering have already appeared.

SCREEN

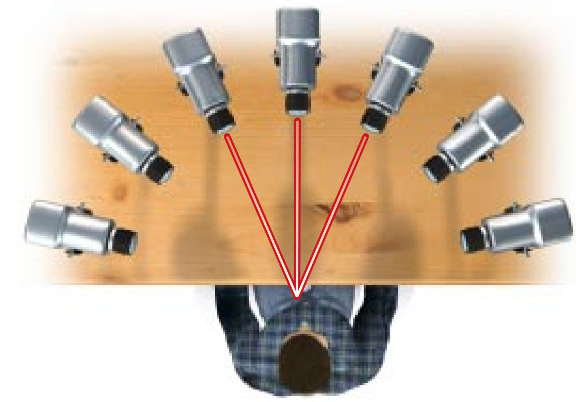
Current prototypes use two overlapping projections of polarized images and require users to wear polarized glasses so that each image is seen by only one eye. This technique will be replaced in the future by "autostereoscopic" displays that channel images to each eye differentially without the need for glasses.



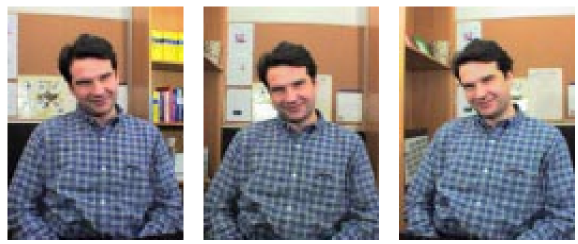
. . . TO THE RECEIVER

Specific renderings of remote people and places are synthesized from the model as it is received to match the points of view of each eye of a user. The whole process repeats many times a second to keep up with the user's head motion.

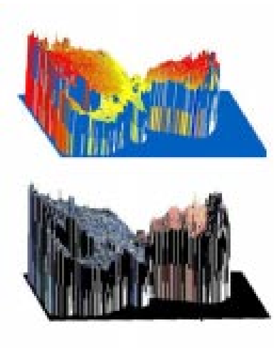
GENERATING THE 3-D IMAGE



1 An array of cameras views people and their surroundings from different angles. Each camera generates an image from its point of view many times in a second.



2 Each set of the images taken at a given instant is sorted into subsets of overlapping trios of images.



3 From each trio of images, a "disparity map" is calculated, reflecting the degree of variation among the images at all points in the visual field. The disparities are then analyzed to yield depths that would account for the differences between what each camera sees. These depth values are combined into a "bas relief" depth map of the scene.

4 All the depth maps are combined into a single viewpoint-independent sculptural model of the scene at a given moment. The process of combining the depth maps provides opportunities for removing spurious points and noise.

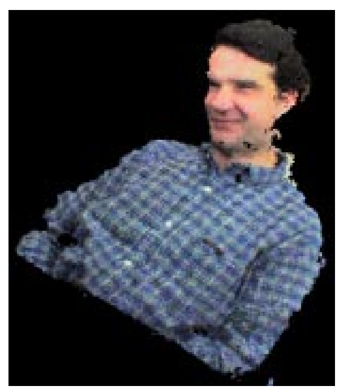


ILLUSTRATION BY JOE ZEFF

SEVEN CAMERAS scrutinize the user in the tele-immersion setup in Chapel Hill.

possible to hasten the day when tele-immersion will be reproducible outside the lab. Literally dozens of such processors are currently needed at each site to keep up with the demands of tele-immersion. These accumulate either as personal computers in plastic cases lined up on shelves or as circuit boards in refrigerator-size racks. I sometimes joke about the number of "refrigerators" required to achieve a given level of quality in tele-immersion.

Most of the processors are assigned to scene acquisition. A sea of cameras consists of overlapping trios of cameras. At the moment we typically use an array of seven cameras for one person seated at a desk, which in practice act as five trios. Roughly speaking, a cluster of eight two-gigahertz Pentium processors with shared memory should be able to process a trio within a sea of cameras in approximately real time. Such processor clusters should be available later this year. Although we expect computer prices to continue to fall as they have for the past few decades, it will still be a bit of a wait before tele-immersion becomes inexpensive enough for widespread use. The cost of an eight-processor cluster is anticipated to be in the $30,000 to $50,000 range at introduction, and a number of those would be required for each site (one for each trio of cameras)—and this does not even account for the processing needed for other tasks. We don't yet know how many cameras will be required for a given use of tele-immersion, but currently a good guess is that seven is the minimum adequate for casual conversation, whereas 60 cameras might be needed for the most demanding applications, such as long-distance surgical demonstration, consultation and training.

Our computational needs go beyond processing the image streams from the sea of cameras. Still more processors are required to resynthesize and render the scene from shifting perspectives as a participant's head moves during a session. Initially we used a large custom graphics computer, but more recently we have been able instead to draft commodity processors with low-cost graphics cards, using one processor per eye. Additional processors are required for other tasks, such as combining the results from each of the camera trios, running the imperceptible structured light, measuring the head motion of the user, maintaining the user interface, and running virtual-object simulations.

Furthermore, because minimizing apparent latency is at the heart of tele-immersion engineering, significant processing resources will eventually need to be applied to predictive algorithms. Information traveling through an optical fiber reaches a destination at about two thirds the speed of light in free space because it is traveling through the fiber medium instead of a vacuum and because it does not travel a straight path but rather bounces around in the fiber channel. It therefore takes anywhere from 25 to 50 milliseconds for fiber-bound bits of information to cross the continental U.S., without any allowances for other inescapable delays, such as the activities of various network signal routers.

By cruel coincidence, some critical aspects of a virtual world's responsiveness should not be subject to more than 30 to 50 milliseconds of delay. Longer delays result in user fatigue and disorientation, a degradation of the illusion and, in the worst case, nausea. Even if we had infinitely fast computers at each end, we'd still need to use prediction to compensate for lag when conducting conversations

MORE TO EXPLORE

National Tele-immersion Initiative Web site: **www.advanced.org/teleimmersion.html**

Tele-immersion at Brown University: **www.cs.brown.edu/~lsh/telei.html**

Tele-immersion at the University of North Carolina at Chapel Hill: **www.cs.unc.edu/Research/stc/teleimmersion/**

Tele-immersion at the University of Pennsylvania: **www.cis.upenn.edu/~sequence/teleim1.html**

Tele-immersion site at Internet2: **www.internet2.edu/html/tele-immersion.html**

Information about an autostereoscopic display: **www.mrl.nyu.edu/projects/autostereo** across the country. This is one reason the current set of test sites are all located on the East Coast.

One promising avenue of exploration in the next few years will be routing tele-immersion processing through remote supercomputer centers in real time to gain access to superior computing power. In this case, a supercomputer will have to be fast enough to compensate for the extra delay caused by the travel time to and from its location.

Bandwidth is a crucial concern. Our demand for bandwidth varies with the scene and application; a more complex scene requires more bandwidth. We can assume that much of the scene, particularly the background walls and such, is unchanging and does not need to be resent with each frame. Conveying a single person at a desk, without the surrounding room, at a slow frame rate of about two frames per second has proved to require around 20 megabits per second but with up to 80-megabit-per-second peaks. With time, however, that number will fall as better compression techniques become established. Each site must receive the streams from all the others, so in a three-way conversation the bandwidth requirement must be multiplied accordingly. The "last mile" of network connection that runs into computer science departments currently tends to be an OC3 line, which can carry 155 megabits per second—just about right for sustaining a three-way conversation at a slow frame rate. But an OC3 line is approximately 100 times more capacious than what is usually considered a broadband connection now, and it is correspondingly more expensive.

I am hopeful that in the coming years we will see a version of tele-immersion that does not require users to wear special glasses or any other devices. Ken Perlin of New York University has developed a prototype of an autostereoscopic display that might make this possible.

Roughly speaking, tele-immersion is about 100 times too expensive to compete with other communications technologies right now and needs more polishing besides. My best guess is that it will be good enough and cheap enough for limited introduction in approximately five years and for widespread use in around 10 years.

Prospects

WHEN TELE-IMMERSION becomes commonplace, it will probably enable a wide variety of important applications. Teams of engineers might collaborate at great distances on computerized designs for new machines that can be tinkered with as though they were real models on a shared workbench. Archaeologists from around the world might experience being present during a crucial dig. Rarefied experts in building inspection or engine repair might be able to visit locations without losing time to air travel.

In fact, tele-immersion might come to be seen as real competition for air travel—unlike videoconferencing. Although few would claim that tele-immersion will be absolutely as good as "being there" in the near term, it might be good enough for business meetings, professional consultations, training sessions, trade show exhibits and the like. Business travel might be replaced to a significant degree by tele-immersion in 10 years. This is not only because tele-immersion will become better and cheaper but because air travel will face limits to growth because of safety, land use and environmental concerns.

Tele-immersion might have surprising effects on human relationships and roles. For instance, those who worry about how artists, musicians and authors will make a living as copyrights become harder and harder to enforce (as a result of widespread file copying on the Internet) have often suggested that paid personal appearances are a solution, because personal interaction has more value in the moment than could be reproduced afterward from a file or recording. Tele-immersion could make aesthetic interactions practical and cheap enough to provide a different basis for commerce in the arts. It is worth remembering that before the 20th century, all the arts were interactive. Musicians interacted directly with audience members, as did actors on a stage and poets in a garden. Tele-immersive forms of all these arts that emphasize immediacy, intimacy and personal responsiveness might appear in answer to the crisis in copyright enforcement.

Undoubtedly tele-immersion will pose new challenges as well. Some early users have expressed a concern that tele-immersion exposes too much, that telephones and videoconferencing tools make it easier for participants to control their exposure—to put the phone down or move offscreen. I am hopeful that with experience we will discover both user-interface designs (such as the virtual mirror depicted in the illustration on pages 72 and 73) and conventions of behavior that address such potential problems.

I am often asked if it is frightening to work on new technologies that are likely to have a profound impact on society without being able to know what that impact will be. My answer is that because tele-immersion is fundamentally a tool to help people connect better, the question is really about how optimistic one should be about human nature. I believe that communications technologies increase the opportunities for empathy and thus for moral behavior. Consequently, I am optimistic that whatever role tele-immersion ultimately takes on, it will mostly be for the good. SA

Tele-immersion *Team Members*

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  www.cs.brown.edu/~lsh/telei.html
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  Jaron Lanier, Amela Sadagic
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LIFE'S ROCKY START

Air, water and rock were the only raw materials available on the early earth. The first living entities must have been fabricated from these primitive resources. New experiments suggest that minerals—the basic components of the rocks—could have played starring roles in that dramatic feat.

BY ROBERT M. HAZEN

PHOTOGRAPHS BY ROBERT LEWIS

No one knows how life arose on the desolate young earth, but one thing is certain: life's origin was a chemical event. Once the earth formed 4.5 billion years ago, asteroid impacts periodically shattered and sterilized the planet's surface for another half a billion years. And yet, within a few hundred million years of that hellish age, microscopic life appeared in abundance. Sometime in the interim, the first living entity must have been crafted from air, water and rock.

Of those three raw materials, the atmosphere and oceans have long enjoyed the starring roles in origins-of-life scenarios. But rocks, and the minerals of which they are made, have been called on only as bit players or simply as props. Scientists are now realizing that such limited casting is a mistake. Indeed, a recent flurry of fascinating experiments is revealing that minerals play a crucial part in the basic chemical reactions from which life must have arisen.

The first act of life's origin story must have introduced collections of carbon-based molecules that could make copies of themselves. Achieving even this nascent step in evolution entailed a sequence of chemical transformations, each of which added a level of structure and complexity to a group of organic molecules. The most abundant carbon-based compounds available on the ancient earth were gases with only one atom of carbon per molecule, namely, carbon dioxide, carbon monoxide and methane. But the essential building blocks of living organisms—energy-rich sugars, membrane-forming lipids and complex amino acids—may include more than a dozen carbon atoms per molecule. Many of these molecules, in turn, must bond together to form chainlike polymers and other molecular arrays in order to accomplish life's chemical tasks. Linking small molecules into these complex, extended structures must have been especially difficult in the harsh conditions of the early earth, where intense ultraviolet radiation tended to break down clusters of molecules as quickly as they could form.

Carbon-based molecules needed protection and assistance to enact this drama. It turns out that minerals could have served at least five significant functions, from passive props to active players, in life-inducing chemical reactions. Tiny compartments in mineral structures can shelter simple molecules, while mineral surfaces can provide the scaffolding on which those molecules assemble and grow. Beyond these sheltering and supportive functions, crystal faces of certain minerals can actively select particular molecules resembling those that were destined to become biologically important. The metallic ions in other minerals can jumpstart meaningful reactions like those that must have converted simple molecules into self-replicating entities. Most surprising, perhaps, are the recent indications that elements of dissolved minerals can be incorporated into biological molecules. In other words, minerals may not have merely helped biological molecules come together, they might have become part of life itself.

Protection from the Elements

FOR THE BETTER PART of a century, following the 1859 publication of Charles Darwin's *On the Origin of Species,* a parade of scientists speculated on life's chemical origins. Some even had the foresight to mention rocks and minerals in their inventive scenarios. But experimental evidence only sporadically buttressed these speculations.

One of the most famous experiments took place at the University of Chicago in 1953. That year chemist Harold C. Urey's precocious graduate student Stanley L. Miller at-

FELDSPAR SPECIMEN COURTESY OF THE AMERICAN MUSEUM OF NATURAL HISTORY, WITH PERMISSION OF THE DEPARTMENT OF EARTH AND PLANETARY SCIENCES tempted to mimic the earth's primitive oceans and atmosphere in a bottle. Miller enclosed methane, ammonia and other gases thought to be components of the early atmosphere in a glass flask partially filled with water. When he subjected the gas to electric sparks to imitate a prehistoric lightning storm, the clear water turned pink and then brown as it became enriched with amino acids and other essential organic molecules. With this simple yet elegant procedure, Miller transformed origins-of-life research from a speculative philosophical game to an exacting experimental science. The popular press sensationalized the findings by suggesting that synthetic bugs might soon be crawling out of test tubes. The scientific community was more restrained, but many workers sensed that the major obstacle to creating life in the laboratory had been solved.

FELDSPAR: SHELTERS GROWING CHAINS OF MOLECULES

It did not take long to disabuse researchers of that notion. Miller may have discovered a way to make many of life's building blocks out of the earth's early supply of water and gas, but he had not discovered how or where these simple units would have linked into the complex molecular structures—such as proteins and DNA—that are intrinsic to life.

To answer that riddle, Miller and other origins scientists began proposing rocks as props. They speculated that organic molecules, floating in seawater, might have splashed into tidal pools along rocky coastlines. These molecules would have become increasingly concentrated through repeated cycles of evaporation, like soup thickening in a heated pot.

In recent years, however, researchers have envisioned that life's ingredients might have accumulated in much smaller containers. Some rocks, like gray volcanic pumice, are laced with air pockets created when gases expanded inside the rock while it was still molten. Many common minerals, such as feldspar, develop microscopic pits during weathering. Each tiny chamber in each rock on the early earth could have housed a separate experiment in molecular self-organization. Given enough time and enough chambers, serendipity might have produced a combination of molecules that would eventually deserve to be called "living."

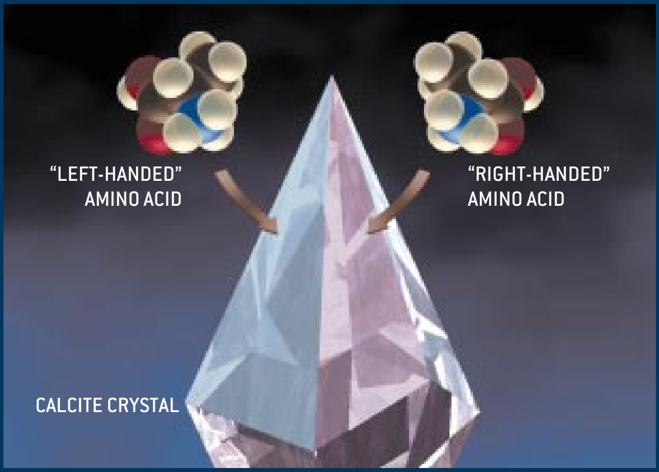
Underlying much of this speculation was the sense that life was so fragile that it depended on rocks for survival. But in 1977 a startling discovery challenged conventional wisdom about life's fragility and, perhaps, its origins. Until then, most scientists had assumed that life spawned at or near the benign ocean surface as a result of chemistry powered by sunlight. That view began to change when deep-ocean explorers first encountered diverse ecosystems thriving at the superheated mouths of volcanic vents on the seafloor. These extreme environments manage to support elaborate communities of living creatures in isolation from the sun. In these dark realms, much of the energy that organisms need comes not from light but from the earth's internal heat. With this knowledge in mind, a few investigators began to wonder whether organic reactions relevant to the origins of life might occur in the intense heat and pressure of these so-called hydrothermal vents.

CRYSTAL POWER

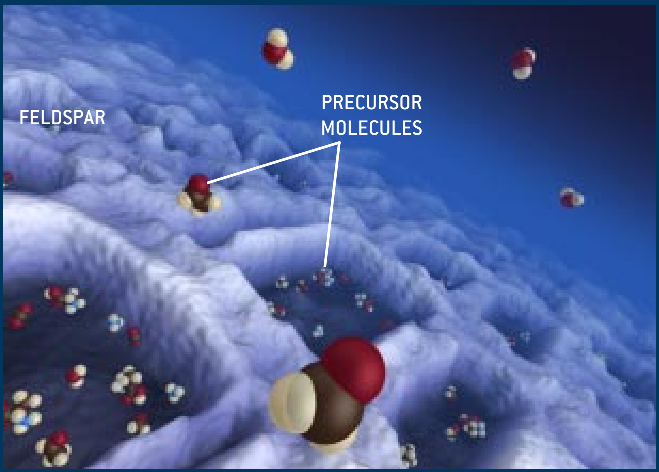
NOTHING COULD BE MORE lifeless than a rock, it seems. So how could rocks—or the minerals that constitute them—have assisted the emergence of life? The answer is chemistry. Minerals grow from simple molecules into an ordered structure because of chemical reactions. By the same token, all living organisms—from bacteria to bats—owe their ability to grow and function to the hundreds of chemical reactions that take place inside cells.

Four billion years ago the earth had no life: chemistry, not biology, altered the planet's surface. In that ancient time minerals—together with the oceans and atmosphere—were the only materials from which the first living entity could have arisen. Chemical reactions, then, must have been the first steps in the origins of life. A sequence of chemical transformations could have reconfigured the simplest components of air, water and rock into primitive collections of carbon-based molecules that could make copies of themselves.

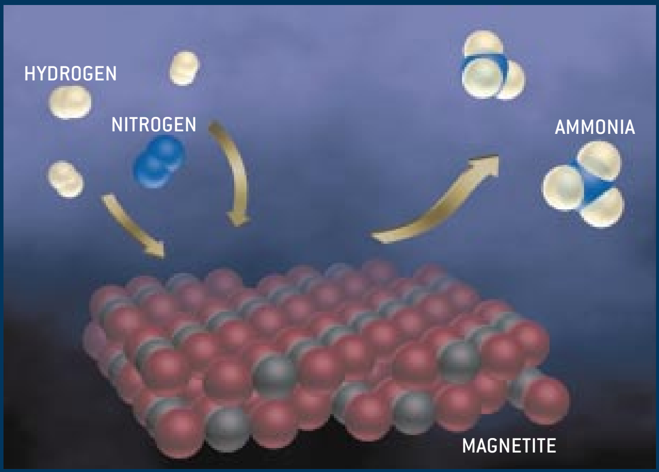
New experiments are revealing that the critical transformations might not have been possible without the help of minerals acting as containers, scaffolds, templates, catalysts and reactants.



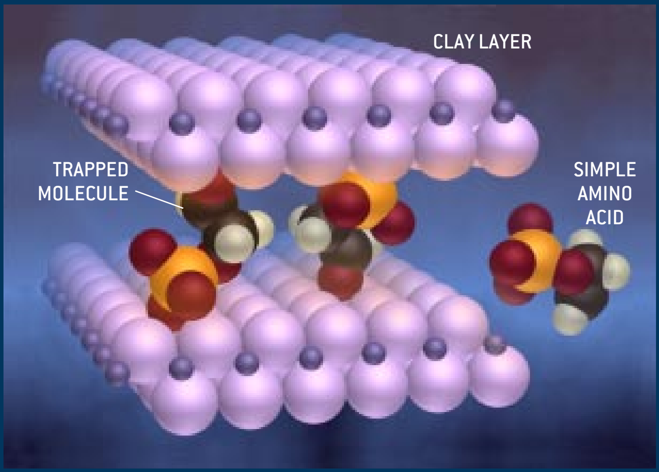
TEMPLATES—The mineral calcite tends to attract left- and right-handed amino acids to different crystal faces. Such a sorting process could explain why life makes use of only the left-handed variety.



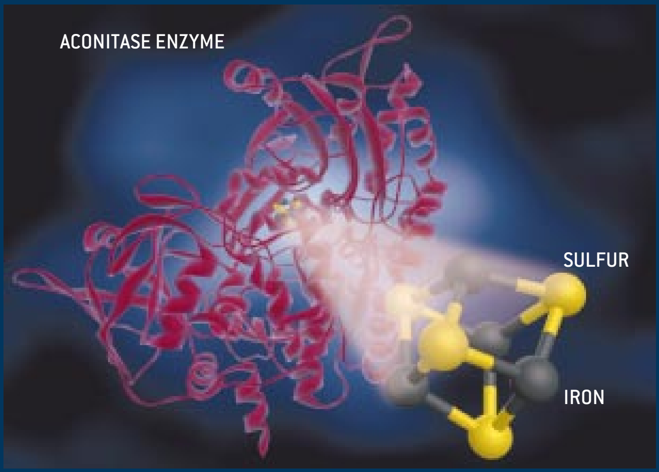
CONTAINERS—Microscopic pits appear in abundance on the weathered surfaces of feldspar and other common minerals. These tiny chambers could have sheltered life's precursor molecules from deadly radiation.



CATALYSTS—Magnetite, an iron oxide mineral, can trigger the recombination of nitrogen and hydrogen gases into ammonia, the essential compound from which living cells acquire nitrogen.



SCAFFOLDS—Layered minerals such as clays can trap stray organic molecules between their rigid sheets of atoms. Held close to one another, simple molecules can react to form more complex compounds.



REACTANTS—Iron and sulfur, the elements that form the active center of certain biological enzymes such as aconitase, can be dissolved from iron sulfide minerals under extreme heat and pressure.

ILLUSTRATIONS BY KENNETH EWARD *BioGrafx*

LAYERED MINERAL: SERVES AS A SCAFFOLD FOR GROWING MOLECULES

Miller and his colleagues have objected to the hydrothermal origins hypothesis in part because amino acids decompose rapidly when they are heated. This objection, it turns out, may be applicable only when key minerals are left out of the equation. The idea that minerals might have sheltered the ingredients of life received a boost from recent experiments conducted at my home base, the Carnegie Institution of Washington's Geophysical Laboratory. As a postdoctoral researcher at Carnegie, my colleague Jay A. Brandes (now at the University of Texas Marine Sciences Institute in Port Aransas) proposed that minerals help delicate amino acids remain intact. In 1998 we conducted an experiment in which the amino acid leucine broke down within a matter of minutes in pressurized water at 200 degrees Celsius—just as Miller and his colleagues predicted. But when Brandes added to the mix an iron sulfide mineral of the type commonly found in and around hydrothermal vents, the amino acid stayed intact for days—plenty of time to react with other critical molecules.

A Rock to Stand On

EVEN IF THE RIGHT raw materials were contained in a protected place—whether it was a tidal pool, a microscopic pit in a mineral surface or somewhere inside the plumbing of a seafloor vent—the individual molecules would still be suspended in water. These stray molecules needed a support structure—some kind of scaffolding—where they could cling and react with one another.

Simple molecules could have used RIGID MINERAL SURFACES as the scaffolding on which they reassembled into more complex structures.

One easy way to assemble molecules from a dilute solution is to concentrate them on a flat surface. Errant molecules might have been drawn to the calm surface of a tidal pool or perhaps to a primitive "oil slick" of compounds trapped at the water's surface. But such environments would have posed a potentially fatal hazard to delicate molecules. Harsh lightning storms and ultraviolet radiation accosted the young earth in doses many times greater than they do today. Such conditions would have quickly broken the bonds of complex chains of molecules.

Origins scientists with a penchant for geology have long recognized that minerals might provide attractive alternative surfaces where important molecules could assemble. Like the container idea, this notion was born half a century ago. At that time, a few scientists had begun to suspect that clays have special abilities to attract organic molecules [*see box on* *page 80*]. These ubiquitous minerals feel slick when wet because their atoms form flat, smooth layers. The surfaces of these layers frequently carry an electric charge, which might be able to attract organic molecules and hold them in place. Experiments later confirmed these speculations. In the late 1970s an Israeli research group demonstrated that amino acids can concentrate on clay surfaces and then link up into short chains that resemble biological proteins. These chemical reactions occurred when the investigators evaporated a water-based solution containing amino acids from a vessel containing clays—a situation not unlike the evaporation of a shallow pond or tidal pool with a muddy bottom.

More recently, separate research teams led by James P. Ferris of the Rensselaer Polytechnic Institute and by Gustaf Arrhenius of the Scripps Institution of Oceanography demonstrated that clays and other layered minerals can attract and assemble a variety of organic molecules. In a tour de force series of experiments during the past decade, the team at Rensselaer found that clays can act as scaffolds for the building blocks of RNA, the molecule in living organisms that translates genetic instructions into proteins.

Once organic molecules had attached themselves to a mineral scaffold, various types of complex molecules could have been forged. But only a chosen few were eventually incorporated into living cells. That means that some kind of template must have selected the primitive molecules that would become biologically important. Recent experiments show, once again, that minerals may have played a central role in this task.

Preferential Treatment

PERHAPS THE MOST mysterious episode of selection left all living organisms with a strange predominance of one type of amino acid. Like many organic molecules, amino acids come in two forms. Each version comprises the same types of atoms, but the two molecules are constructed as mirror images of each other. The phenomenon is called chirality, but for simplicity's sake scientists refer to the two versions as "left-handed" (or "L") and "right-handed" (or "D"). Organic synthesis experiments like Miller's invariably produce 50–50 mixtures of L and D molecules, but the excess of left-handed amino acids in living organisms is nearly 100 percent.

Researchers have proposed a dozen theories—from the mundane to the exotic—to account for this bizarre occurrence. Some astrophysicists have argued that the earth might have formed with an excess of L amino acids—a consequence of processes that took place in the cloud of dust and gas that became the solar system. The main problem with this theory is that in most situations such processes yield only the slightest excess—less than 1 percent—of L or D molecules.

Alternatively, the world might have started with a 50–50 mixture of L and D amino acids, and then some important feature of the physical environment selected one version over the other. To me, the most obvious candidates for this specialized physical environment are crystal faces whose surface structures are mirror images of each other [*see box on page 80*]. Last spring I narrowed in on calcite, the common mineral that forms limestone and marble, in part because it often displays magnificent pairs of mirror-image faces. The chemical structure of calcite in many mollusk shells bonds strongly to amino acids. Knowing this, I began to suspect that calcite surfaces may feature chemical bonding sites that are ideally suited to only one type of amino acid or the other. With the help of my Carnegie colleague Timothy Filley (now at Purdue University) and Glenn Goodfriend of George Washington University, I ran more than 100 tests of this hypothesis.

Our experiments were simple in concept, although they required meticulous clean-room procedures to avoid contamination by the amino acids that exist everywhere in the environment. We immersed a well-formed, fist-size crystal of calcite into a 50–50 solution of aspartic acid, a common amino acid. After 24 hours we removed the crystal from this solution, washed it in water and carefully collected all the molecules that had adhered to specific crystal faces. In one experiment after another we observed that calcite's "left-handed" faces selected L-amino acids, and vice versa, with excesses approaching 40 percent in some cases.

Curiously, calcite faces with finely terraced surfaces displayed the greatest selectivity. This outcome led us to speculate that these terraced edges might force the L and D amino acids to line up in neat rows on their respective faces. Under the right environmental conditions, these organized rows of amino acids might chemically join to form proteinlike molecules—some made entirely of L

> Crystal faces of certain minerals could have ACTIVELY SELECTED and concentrated molecules that were destined to become biologically important.

THE AUTHOR

ROBERT M. HAZEN has explored the behavior of minerals under high pressure at the Carnegie Institution of Washington's Geophysical Laboratory since 1976. In the past five years he has designed many of his mineral experiments to mimic the high-pressure environments of deep-sea hydrothermal vents. Rocks and minerals first piqued Hazen's curiosity as a child growing up in northern New Jersey, a region known for its unusual ore deposits. After receiving a doctorate in earth sciences at Harvard University in 1975 and spending a year at the University of Cambridge, he joined the staff at Carnegie. In 1990 Hazen took on a second position, as professor of earth science at George Mason University. He is also a part-time professional trumpeter and the author of numerous articles and books on science, education, history and music.

CALCITE: SELECTS FROM MIRROR-IMAGE MOLECULES

CALCITE SPECIMEN COURTESY OF LAWRENCE H. CONKLIN

amino acids, others entirely of D. If protein formation can indeed occur, this result becomes even more exciting, because recent experiments by other investigators indicate that some proteins can self-replicate. In the earth's early history, perhaps a self-replicating protein formed on the face of a calcite crystal.

Left- and right-handed crystal faces occur in roughly equal numbers, so chiral selection of L amino acids probably did not happen everywhere in the world at once. Our results and predictions instead suggest that the first successful set of self-replicating molecules—the precursor to all the varied life-forms on the earth today—arose at a specific time and place. It was purely chance that the successful molecule developed on a crystal face that preferentially selected left-handed amino acids over their right-handed counterparts.

Minerals undoubtedly could have acted as containers, scaffolds and templates that helped to select and organize the molecular menagerie of the primitive earth. But many of us in origins research suspect that minerals played much more active roles, catalyzing key synthesis steps that boosted the earth's early inventory of complex biological molecules.

Getting a Jump on the Action

EXPERIMENTS LED by Carnegie researcher Brandes in 1997 illustrate this idea. Biological reactions require nitrogen in the form of ammonia, but the only common nitrogen compound thought to have been available on the primitive earth is nitrogen gas. Perhaps, Brandes thought, the environment at hydrothermal vents mimics an industrial process in which ammonia is synthesized by passing nitrogen and hydrogen over a hot metallic surface. Sure enough, when we subjected hydrogen, nitrogen and the iron oxide mineral magnetite to the pressures and temperatures characteristic of a seafloor vent, the mineral catalyzed the synthesis of ammonia [*see box on page 80*].

The idea that minerals may have triggered life's first crucial steps has emerged most forcefully from the landmark theory of chemist Günter Wächtershäuser, a German patent lawyer with a deep interest in life's origins. In 1988 Wächtershäuser advanced a sweeping theory of organic evolution in which minerals—mostly iron and nickel sulfides that abound at deep-sea hydrothermal vents—could have served as the template, the catalyst and the energy source that drove the formation of biological molecules. Indeed, he has argued that primitive living entities were molecular coatings that adhered to the positively charged surfaces of pyrite, a mineral composed of iron and sulfur. These entities, he further suggests, obtained energy from the chemical reactions that produce pyrite. This hypothesis makes sense in part because some metabolic enzymes—the molecules that help living cells process energy—have at their core a cluster of metal and sulfur atoms.

For much of the past three years, Wächtershäuser's provocative theory has influenced our experiments at Carnegie. Our team, including geochemist George Cody and petrologist Hatten S. Yoder, has focused on the possibility that metabolism can proceed without enzymes in the presence of minerals—especially oxides and sulfides. Our simple strategy,

MORE TO EXPLORE

Beginnings of Cellular Life. Harold J. Morowitz. Yale University Press, 1992.

Origins of Life: The Central Concepts. David W. Deamer and Gail R. Fleischaker. Jones and Bartlett, 1994.

Emergence: From Chaos to Order. John H. Holland. Helix Books, 1998.

Biogenesis: Theories of Life's Origin. Noam Lahav. Oxford University Press, 1999.

much in the spirit of Miller's famous experiment, has been to subject ingredients known to be available on the young earth—water, carbon dioxide and minerals—to a controlled environment. In our case, we try to replicate the bone-crushing pressures and scalding temperatures typical of a deep-sea hydrothermal vent. Most of our experiments test the interactions among ingredients enclosed in welded gold capsules, which are roughly the size of a daily vitamin pill. We place as many as six capsules into Yoder's "bomb"—a massive steel pressure chamber that squeezes the tiny capsules to pressures approaching 2,000 atmospheres and heats them to about 250 degrees C.

One of our primary goals in these organic-synthesis experiments—and one of life's fundamental chemical reactions—is carbon fixation, the process of producing molecules with an increasing number of carbon atoms in their chemical structure. Such reactions follow two different paths depending on the mineral we use. We find that many common minerals, including most oxides and sulfides of iron, copper and zinc, promote carbon addition by a routine industrial process known as Fischer-Tropsch (F-T) synthesis.

This process can build chainlike organic molecules from carbon monoxide and hydrogen. First, carbon monoxide and hydrogen react to form methane, which has one carbon atom. Adding more carbon monoxide and hydrogen to the methane produces ethane, a two-carbon molecule, and then the reaction repeats itself, adding a carbon atom each time. In the chemical industry, researchers have harnessed this reaction to manufacture molecules with virtually any desired number of carbon atoms. Our first organic-synthesis experiments in 1996, and much more extensive research by Thomas McCollom of the Woods Hole Oceanographic Institution, demonstrate that F-T reactions can build molecules with 30 or more carbon atoms under some hydrothermal-vent conditions in less than a day. If this process manufactures large organic molecules from simple inorganic chemicals throughout the earth's hydrothermal zones today, then it very likely did so in the planet's prebiological past.

When we conduct experiments using nickel or cobalt sulfides, we see that carbon addition occurs primarily by carbonylation—the insertion of a carbon and oxygen molecule, or carbonyl group. Carbonyl groups readily attach themselves to nickel or cobalt atoms, but not so strongly that they cannot link to other molecules and jump ship to form larger molecules. In one series of experiments, we observed the lengthening of the nine-carbon molecule nonyl thiol to form 10-carbon decanoic acid, a compound similar to the acids that drive metabolic reactions in living cells. What is more, all the reactants in this experiment—a thiol, carbon monoxide and water—are readily available near sulfide-rich hydrothermal vents. By repeating these simple kinds of reactions—adding a carbonyl group here or a hydroxide group there—we can synthesize a rich variety of complex organic molecules.

Our 1,500 hydrothermal organic synthesis experiments at Carnegie have done more than supplement the catalogue of interesting molecules that must have been produced on the early earth. These efforts reveal another, more complex behavior of minerals that may have significant consequences for the chemistry of life. Most previous origins-of-life studies have treated minerals as solid and unchanging—stable platforms where organic molecules could assemble. But we are finding that in the presence of hot water at high pressure, minerals start to dissolve. In the process, the liberated atoms and molecules from the minerals can become crucial reactants in the primordial soup.

The Heart of the Matter

OUR FIRST DISCOVERY of minerals as reactants was an unexpected result of our recent catalysis experiments led by Cody. As expected, carbonylation reactions produced 10-carbon decanoic acid from a mixture of simple molecules inside our gold capsules. But significant

Minerals could have jump-started CRITICAL CHEMICAL REACTIONS that boosted the earth's early inventory of complex biological molecules.

MAGNETITE: CATALYZES BIOCHEMICAL REACTIONS

MAGNETITE SPECIMEN COURTESY OF LAWRENCE H. CONKLIN

PYRITE: FUELS BIOCHEMICAL REACTIONS

quantities of elemental sulfur, organic sulfides, methyl thiol and other sulfur compounds appeared as well. The sulfur in all these products must have been liberated from the iron sulfide mineral.

Even more striking was the liberation of iron, which brilliantly colored the water-based solutions inside the capsules. As the mineral dissolved, the iron formed bright red and orange organometallic complexes in which iron atoms are surrounded by various organic molecules. We are now investigating the extent to which these potentially reactive complexes might act as enzymes that promote the synthesis of molecular structures.

The role of minerals as essential chemical ingredients of life is not entirely unexpected. Hydrothermal fluids are well known to dissolve and concentrate mineral matter. At deep-sea vents, spectacular pillars of sulfide grow dozens of feet tall as plumes of hot, mineral-laden water rise from below the seafloor, contact the frigid water of the deep ocean and deposit new layers of minerals on the growing pillar. But the role of these dissolved minerals has not yet figured significantly in origins scenarios. Whatever their behavior, dissolved minerals seem to make the story of life's emergence much more interesting.

When we look beyond the specifics of prebiological chemistry, it is clear that the origin of life was far too complex to imagine as a single event. Rather we must work from the assumption that it was a gradual sequence of more modest events, each of which added a degree of order and complexity to the world of prebiological molecules. The first step must have been the synthesis of the basic building blocks. Half a century of research reveals that the molecules of life were manufactured in abundance—in the nebula that formed our solar system, at the ocean's surface, and near hydrothermal vents. The ancient earth suffered an embarrassment of riches—a far greater diversity of molecules than life could possibly employ.

Minerals helped to impose order on this chaos. First by confining and concentrating molecules, then by selecting and arranging those molecules, minerals may have jump-started the first self-replicating molecular systems. Such a system would not have constituted life as we know it, but it could have, for the first time, displayed a key property of life. In this scenario, a self-replicating molecular system began to use up the resources of its environment. As mutations led to slightly different variants, competition for limited resources initiated and drove the process of molecular natural selection. Self-replicating molecular systems began to evolve, inevitably becoming more efficient and more complex.

A long-term objective for our work at the Carnegie Institution is to demonstrate simple chemical steps that could lead to a self-replicating system—perhaps one related to the metabolic cycles common to all living cells. Scientists are far from creating life in the laboratory, and it may never be possible to prove exactly what chemical transformations gave rise to life on earth. What we can say for sure is that minerals played a much more complex and integral part in the origin of life than most scientists ever suspected. By being willing to cast minerals in starring roles in experiments that address life's beginnings, researchers may come closer to answering one of science's oldest questions. SA

THE *FURY* OF SPACE STO

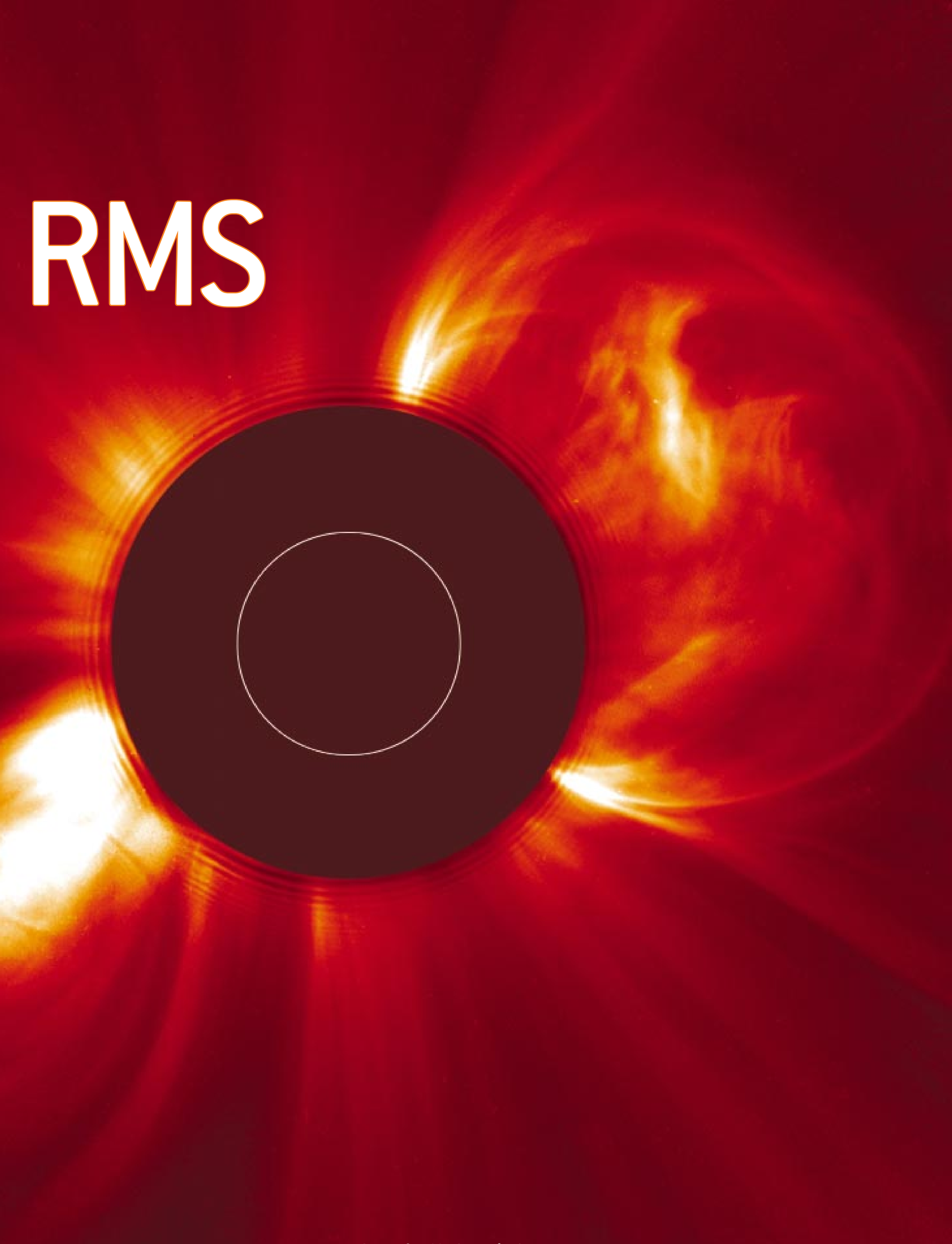
SHOCK WAVES FROM THE SUN CAN TRIGGER SEVERE TURBULENCE IN THE SPACE AROUND THE EARTH, ENDANGERING SATELLITES AND ASTRONAUTS IN ORBIT. NOW A NEW SPACECRAFT IS SHOWING HOW SPACE STORMS DEVELOP

BY JAMES L. BURCH

THE TEMPEST BEGAN ON A DATE KNOWN FOR ITS VIOLENT EVENTS: Bastille Day, the anniversary of the beginning of the French Revolution. On the morning of July 14 last year, the Space Environment Center in Boulder, Colo., detected a warning sign from the GOES-8 satellite, which monitors x-rays from the sun as well as weather conditions on the earth. At 10:03 Universal Time the center's forecasters saw a sharp jump in the intensity of x-rays emanating from active region 9077, a section of the sun's surface that had been roiling for the past week. The data indicated the onset of a solar flare, a brief but powerful burst of radiation.

The flare, which reached its maximum intensity at 10:24 UT, was also sighted by the Solar and Heliospheric Observatory (SOHO), a spacecraft stationed between the sun and the earth, about 1.5 million

VIOLENT ERUPTION in the sun's outer atmosphere on November 8, 2000, spewed billions of tons of charged particles toward the earth. The event was observed by the Solar and Heliospheric Observatory (SOHO); the spacecraft's coronagraph uses a disk (*dark circle*) to block direct light from the sun (*white circle*) so that its atmosphere can be seen.


RMS

kilometers from our planet. Half an hour later, as the flare was waning, SOHO observed an even more ominous phenomenon: a bright, expanding cloud that surrounded the sun like a halo. It was a coronal mass ejection (CME), an eruption in the corona—the sun's outer atmosphere—throwing billions of tons of electrically charged particles into interplanetary space. The halo signature meant that the particles were heading directly toward the earth, at an estimated speed of 1,700 kilometers per second.

As the CME plowed into the solar wind—the flow of ionized gas continuously streaming from the sun—it created a shock wave that accelerated some charged particles to even higher velocities. In less than an hour a deluge of high-energy protons struck SOHO, temporarily blinding its instruments. The bombardment also damaged the spacecraft's solar arrays, causing a year's worth of degradation in 24 hours. But this torrent of particles was only the leading edge of the squall. The CME-driven shock wave arrived the next day, slamming into the earth's magnetic field at 14:37 UT. The impact marked the start of a severe geomagnetic storm, whose full fury was unleashed by the arrival, a few hours later, of the CME itself. According to the index of geomagnetic activity used by the Space Environment Center, the Bastille Day storm was the largest such event in nearly a decade.

Most people on the ground were completely unaware of the celestial fireworks, but researchers were following the tempest closely, collecting data from instruments on the earth and in space. Among the satellites tracking the storm was the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE), which the National Aeronautics and Space Administration had launched just four months earlier. IMAGE is the first satellite dedicated to obtaining global images of the magnetosphere, the region of space protected by the earth's magnetic field. By providing an overall picture of the activity in the magnetosphere, IMAGE does for space what the first weather satellites did for the earth's atmosphere.

In 1996 I had been selected by NASA to lead a team of engineers and scientists in developing the IMAGE spacecraft and analyzing the data that it transmits. As the Bastille Day storm progressed, we received astounding images of ions circling the earth and pictures of the brilliant aurora borealis—the Northern Lights—that occurred when the charged particles struck the upper atmosphere. The results will help scientists answer long-standing questions about how CMEs and the solar wind interact with the earth's magnetosphere. The findings may also have practical applications. Space storms can disable satellites, threaten the safety of astronauts and even knock out power grids on the ground [*see box at left*]. Indeed, the Bastille Day storm caused the loss of the Advanced Satellite for Cosmology and Astrophysics, an x-ray observatory launched in 1993 by the Japanese space research agency. In hopes of mitigating such effects in the future, scientists are keenly interested in improving the accuracy of space weather forecasts.

OVERVIEW

THE EFFECTS OF SPACE STORMS

DURING GEOMAGNETIC STORMS, charged particles swirl around the earth and bombard the upper atmosphere, particularly at the higher latitudes. The gusts of particles can have severe effects on:

- POWER GRIDS. As electrons cascade toward the earth, they create a strong current in the upper atmosphere called the auroral electrojet. This current causes fluctuations in the geomagnetic field, which can induce electrical surges in power lines on the ground. During an intense geomagnetic storm on March 13, 1989, a surge knocked out the Hydro-Quebec power grid, plunging large parts of Canada into darkness.
- SATELLITES. When particles strike a satellite, the craft's surface becomes charged. This buildup sometimes triggers sparks that can short-circuit the satellite's electronics. Also, space storms heat the earth's atmosphere, causing it to expand. If the atmospheric density at a satellite's orbit becomes high enough, friction will slow the craft and drag it downward. This process led to the premature fall of Skylab in 1979.
- ASTRONAUTS. A severe storm could expose the International Space Station to protons that could penetrate a spacesuit or even the station's walls. To protect its astronauts, NASA monitors space weather data. If an oncoming storm poses a risk, NASA will postpone or cancel any planned space walks and may order the astronauts to seek shelter in a shielded part of the station.

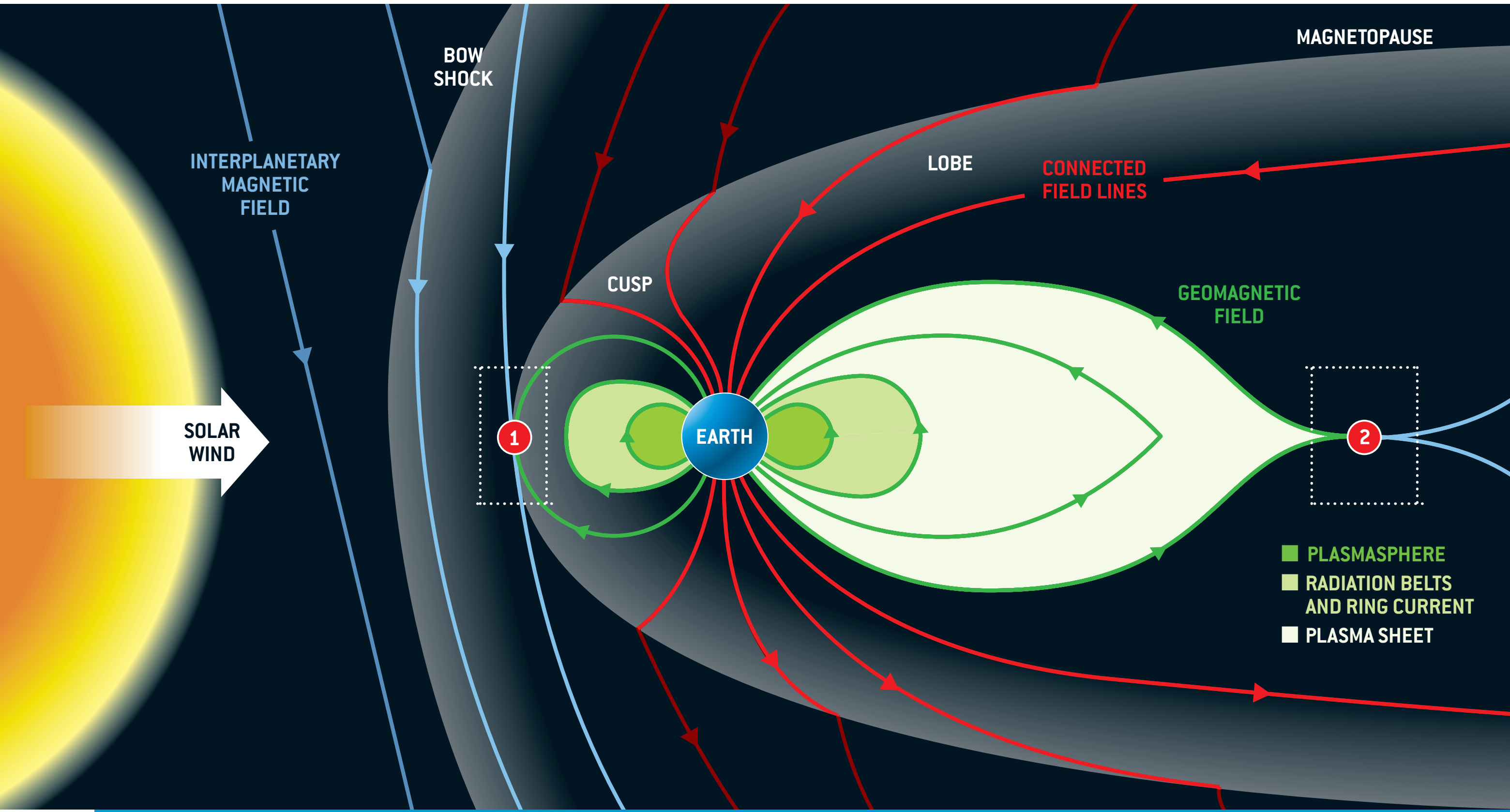
It's Not the Heat or the Humidity

LIKE WEATHER ON THE EARTH, weather in space is extremely variable. Conditions can turn from quiet to stormy in a matter of minutes, and storms can last for hours or days. And just as terrestrial weather changes with the seasons, space weather, too, follows its own cycles. Solar magnetic activity, which causes flares and CMEs, rises and falls every 11 years, and therefore geomagnetic storms follow the same pattern. The Bastille Day storm took place during the solar maximum, the most active part of the cycle. Space weather also varies, though less dramatically, according to the sun's 27-day rotation period, as alternating streams of fast and slow solar wind sweep past the earth.

Space weather, however, arises from physical processes that are profoundly different from those responsible for terrestrial weather. The medium for terrestrial weather is the dense, electrically neutral gas in the earth's lower atmosphere, whose behavior is governed by the laws of fluid dynamics and thermodynamics. The medium for space weather, in contrast, is plasma—very sparse gases consisting of equal numbers of positively charged ions and negatively charged electrons. Unlike the atoms and molecules of the atmosphere, these plasma particles are subject to the influence of electric and magnetic fields, which guide and accelerate the particles as they travel through the space surrounding the earth.

Terrestrial weather is driven by the sun's radiation as it heats the earth's atmosphere, oceans and landmasses. But in the

PRECEDING PAGE: COURTESY OF NASA/ESA, SOHO/LASCO CONSORTIUM



DISTURBANCES IN THE MAGNETOSPHERE occur when the interplanetary magnetic field (IMF) carried by the solar wind turns southward. In a process called reconnection, the field lines of the IMF connect with the northward geomagnetic field lines at the dayside of the magnetopause (*1*). Energy and particles from the solar wind rush into the magnetosphere, enlarging its northern and southern lobes and narrowing the plasma sheet. Then the geomagnetic field lines themselves reconnect (*2*), accelerating ions and electrons toward the earth.

ILLUSTRATION BY JOE ZEFF

magnetosphere, weather results from the interaction between the earth's magnetic field and the solar wind. The solar wind has its own magnetic field, which travels with the outflowing plasma into interplanetary space. As the wind carries this interplanetary magnetic field (IMF) away from the sun, the field lines typically stretch out so that they are directed radially (pointing toward or away from the sun). Under certain conditions, however, the IMF's field lines can tilt out of the equatorial plane of the sun, taking on a northward or southward component. A strong and sustained southward IMF direction is a key factor in triggering geomagnetic storms. The IMF was oriented southward for many hours during the Bastille Day storm.

Protons are the dominant constituents of the solar wind, accounting for about 80 percent of its total mass. Helium nuclei make up about 18 percent, and trace quantities of heavier ions are also present. The average density of the solar wind at the earth's orbit is nine protons per cubic centimeter. The wind's average velocity is 470 kilometers per second, and the average strength of the IMF is six nanoteslas (about one five-thousandth the strength of the earth's magnetic field at the planet's surface). These properties, along with the orientation of the IMF, are highly variable, and it is this variability that ultimately explains the changing weather in space.

All the bodies in the solar system are immersed in the solar wind, which continues flowing outward until it encounters the ionized and neutral gases of interstellar space. The solar wind does not impinge directly on the earth and its atmosphere, however. The earth is shielded by its magnetic field, which forms a kind of bubble within the stream of charged particles emanating from the sun. The shape of this cavity—the magnetosphere—is determined by the pressure of the solar wind and by the IMF [*see illustration above*]. The wind compresses the earth's magnetic field on the dayside of the planet—the side facing the sun—and stretches the field on the nightside to form a long tail resembling that of a comet. This magnetotail extends more than one million kilometers past the earth, well beyond the orbit of the moon.

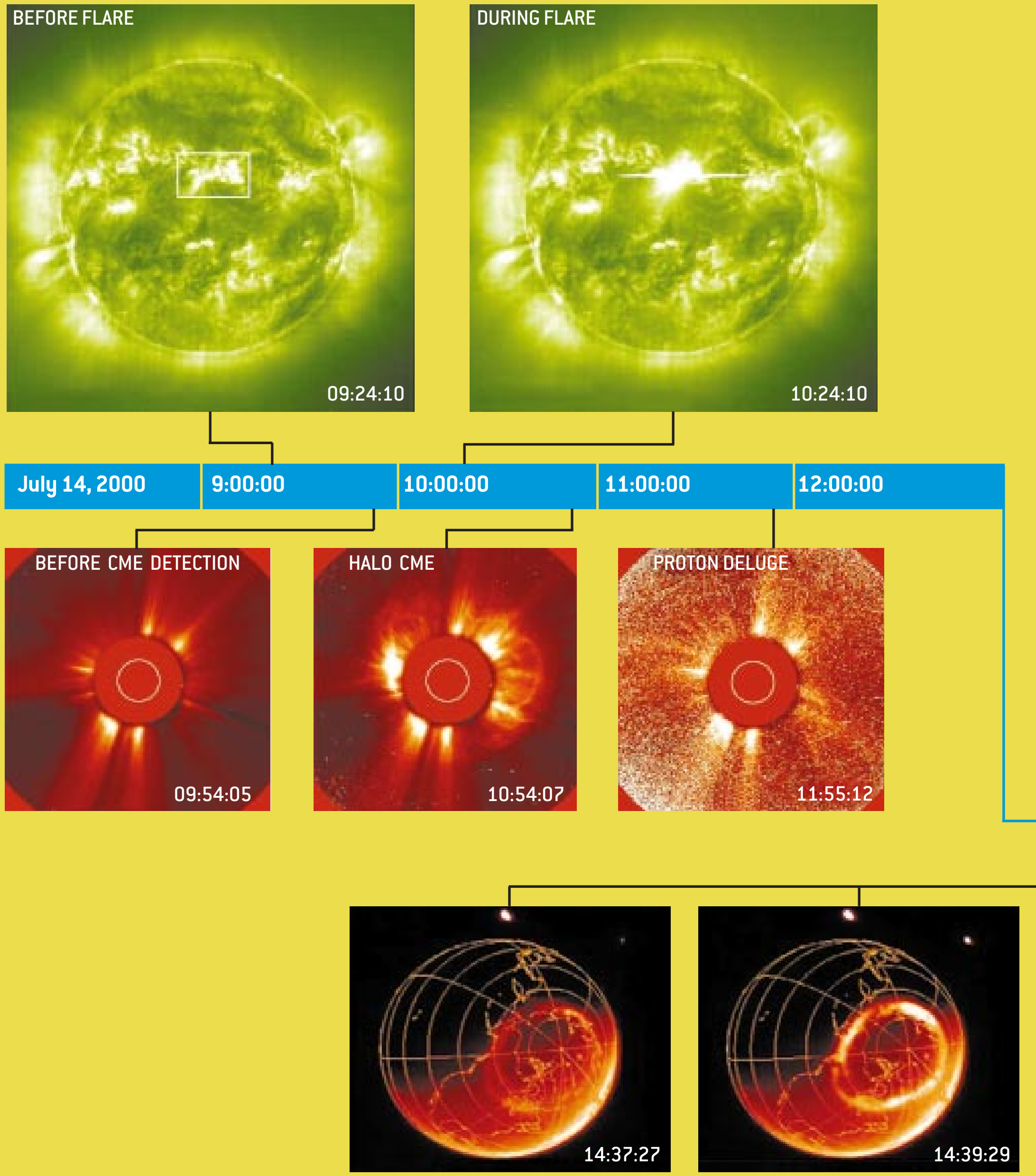
Between the solar wind and the magnetosphere is a thin boundary called the magnetopause, where the pressure of the geomagnetic field balances that of the solar wind. On the earth's dayside, this boundary is usually located about 64,000 kilometers from the planet's center, although the distance varies with changes in the solar-wind pressure. When the pressure increases, as occurred during the Bastille Day storm, the dayside magnetopause is pushed closer to the earth, sometimes by as much as 26,000 kilometers.

Just as the passage of a supersonic jet through the atmosphere produces a shock wave, the encounter of the solar wind with the magnetosphere forms a shock wave—known as the bow shock—some 13,000 kilometers upstream (that is, closer to the sun) from the dayside magnetopause. The region of solar-wind plasma between the bow shock and the magnetopause is known as the magnetosheath. Because of its passage through the shock, the magnetosheath plasma is slower, hotter and more turbulent than the plasma farther upstream.

Satellite detectors have indicated that the charged particles surrounding the earth are a mix of plasma from the magnetosheath (mostly protons) and plasma that flows out of the upper atmosphere above the North and South poles (mostly protons and oxygen ions). The proportions of this mix vary according to whether the magnetosphere is in a quiet or a disturbed state. During geomagnetic storms, charged particles bombard the earth at high latitudes. The resulting electric currents heat the upper atmosphere, pumping increased amounts of protons and oxygen ions into the magnetosphere. This plasma is stored, together with the solar-wind plasma that has gained entry into the magnetosphere, in a great reservoir known as the plasma sheet, which extends for tens of thousands of kilometers on the earth's nightside.

At the heart of the study of space weather is a question:

A SPACE STORM IN ACTION



FIRST WARNING of the Bastille Day storm was a solar flare on July 14, 2000. Images of the sun from SOHO's Extreme Ultraviolet Imaging Telescope (*top*) show active region 9077 (*in white box*) before and during the flare. At about the same time, SOHO's coronagraph observed a coronal mass ejection (CME) that soon deluged the spacecraft with high-speed protons, temporarily blinding its instruments (*middle*). The shock wave and CME slammed into the earth's magnetic field the next day, triggering auroras observed by the IMAGE spacecraft's Wide-band Imaging Camera (*bottom*) and a sharp drop in geomagnetic field strength at the planet's surface (*opposite page, middle*). In this graph, called the disturbance storm time index, zero represents the normal surface field strength. As the storm progressed, IMAGE's High Energy Neutral Atom instrument monitored the waxing and waning of the ring current around the earth's equator (*opposite page, top*).

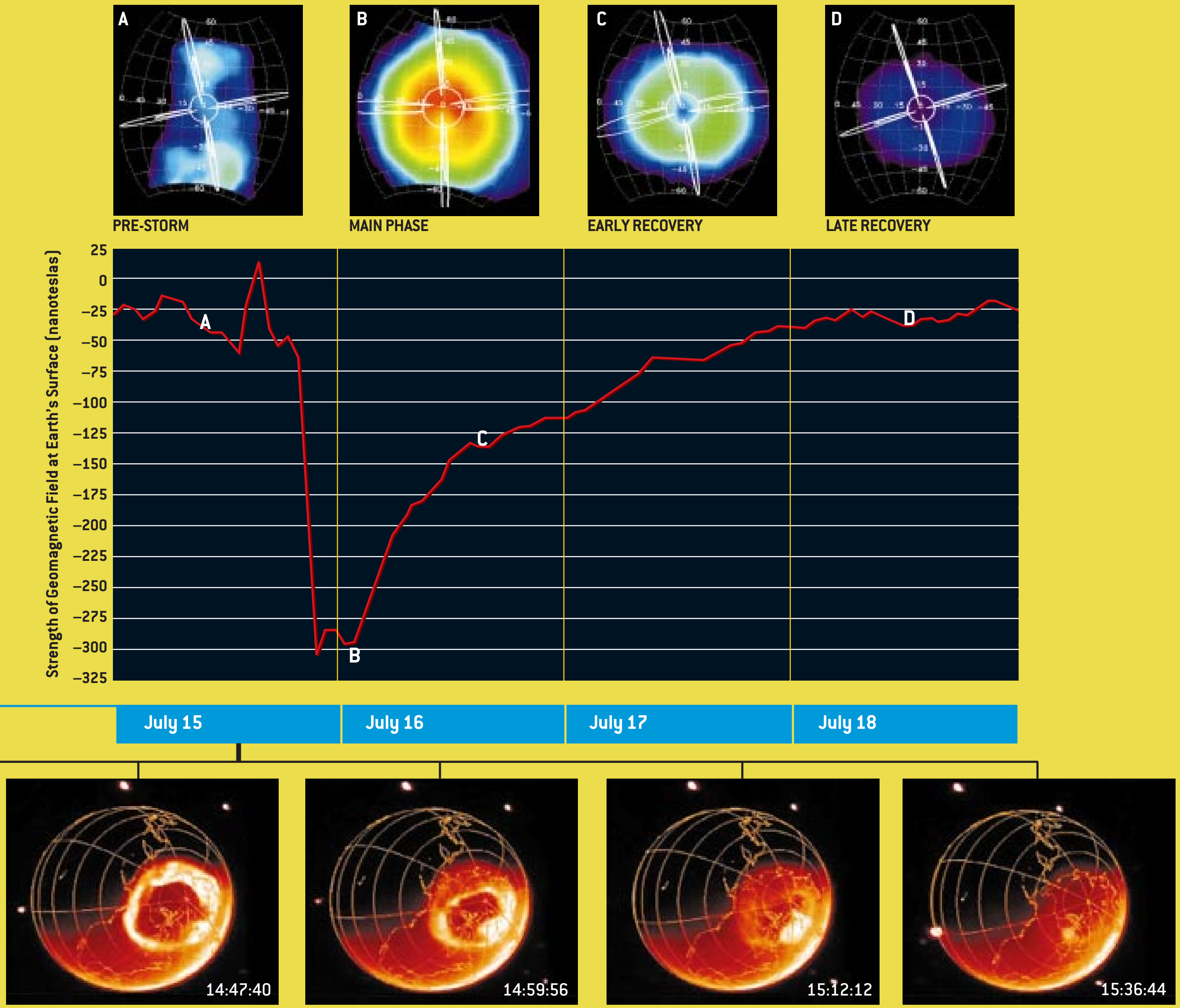
NASA/ESA, SOHO (*solar images*); NASA/IMAGE FUV TEAM (*auroral images*); NASA/IMAGE HENA TEAM (*ring current images*); WORLD DATA CENTER FOR GEOMAGNETISM, KYOTO, JAPAN (*graph*)

How do changes in the solar wind affect conditions in the space surrounding the earth? In other words, how can the wind overcome the barrier of the geomagnetic field and drive the motions of the plasma inside the magnetosphere?

Blowing in the Solar Wind

ONE ANSWER, PROPOSED IN 1960 by Frank Johnson of Lockheed Missiles and Space Division, is that the magnetosphere is essentially closed. According to this hypothesis, the solar wind could transfer energy and momentum to the plasma surrounding the earth only by wave motions along the magnetopause. The motions would be produced by viscous interaction between the solar-wind plasma and the magnetosphere plasma; the process is analogous to the generation of waves by the flow of wind over water. Waves are in fact observed along the magnetopause. But they do not seem capable of driving the large-scale circulation of the magnetosphere or the great disturbances that often occur there. Such waves also would not allow the efficient entry of accelerated solar-wind plasma into the magnetosphere.

For these reasons, magnetopause waves are not considered the primary means by which the solar wind affects the magnetosphere. An alternative mechanism called magnetic reconnection—first proposed in 1961 by British physicist James W. Dungey—is generally thought to be a better explanation. In this process, the field lines of the IMF become temporarily interconnected with the geomagnetic field lines on the dayside of the magnetopause [*see illustration on page 89*]. This tangling of the field lines allows large amounts of plasma and magnetic ener-



gy to be transferred from the solar wind to the magnetosphere.

Reconnection is most efficient when the IMF has a component that is directed southward—that is, opposite to the northward direction of the earth's magnetic field at the dayside of the magnetosphere. Under these circumstances, reconnection takes place along a wide equatorial belt, opening up nearly the entire outer boundary of the magnetosphere to the solar wind. For other orientations of the IMF, reconnection still happens, but it may be more localized in the higher latitudes, where the released energy mainly flows around the magnetosphere rather than into it.

The transfer of magnetic energy from the solar wind radically alters the shape of the magnetosphere. When reconnection is initiated on the dayside magnetopause, the interconnected IMF and geomagnetic field lines are swept back by the solar wind over the earth's poles, pouring energy into the northern and southern lobes of the long magnetotail on the nightside. As the lobes swell with the added magnetic energy, the plasma sheet that lies between them begins to thin. The process continues until the field lines of the northern and southern lobes, which have opposite directions, are pressed together and themselves reconnect.

This second reconnection releases the solar wind's magnetic field, enabling it to continue its flow through the solar system. At the same time, it allows the earth's magnetic field lines, which have been stretched tailward during the loading of the lobes, to snap back into their normal configuration. The abrupt movement of the field lines heats and accelerates the ions and electrons in the plasma sheet, injecting them into the inner part of the magnetosphere. Some of these particles, traveling along geomagnetic field lines, dive into the upper atmosphere above the earth's poles, stimulating auroral emissions at x-ray, ultraviolet, visible and radio wavelengths as they collide with oxygen atoms and nitrogen molecules. The entire sequence of events—from dayside reconnection to nightside reconnection to auroras—is known as a magnetospheric substorm.

In addition to transferring magnetic energy to the tail lobes, dayside reconnection also intensifies the electric field across the magnetotail. The stronger field, in turn, increases the flow of ions and electrons from the plasma sheet to the inner magnetosphere. This flow feeds into the earth's ring current, which is carried by charged particles circling the planet above its equator at altitudes between 6,400 and 38,000 kilometers. During longer periods of dayside reconnection—which occur when the IMF's orientation remains consistently southward—the sustained enhancement of the earthward plasma flow greatly increases the number and energies of the charged particles in the ring current. An extended period of southward IMF can also lead to a rapid succession of substorms, each of which injects more particles toward the earth. The resulting growth in strength of the ring current is the classic hallmark of a full-fledged geomagnetic storm.

THE AUTHOR

JAMES L. BURCH is vice president of the Space Science and Engineering Division of the Southwest Research Institute in San Antonio, Tex., and principal investigator for the IMAGE mission. Burch earned his Ph.D. in space science from Rice University in 1968. His main research interests are auroral processes, magnetic reconnection and magnetospheric imaging. He is a Fellow of the American Geophysical Union and current chairman of the Committee on Solar and Space Physics of the National Research Council.

Here Comes the Sun

THE ORIENTATION OF THE IMF turns southward quite frequently, so magnetospheric substorms are fairly common: on average, they happen a few times every day and last for one to three hours. But major geomagnetic storms such as the Bastille Day event are much rarer. Although they can occur anytime during the 11-year solar cycle, they are most frequent in the solar maximum period.

Until the early 1990s, it was widely believed that solar flares triggered geomagnetic storms. Space and solar physicists, however, had been assembling evidence that pointed strongly to another culprit, and in 1993 John T. Gosling of Los Alamos National Laboratory wove the various threads of evidence together in an article in the *Journal of Geophysical Research* that challenged the "solar flare myth." Gosling set forth a compelling argument for the central role of coronal mass ejections in setting off large geomagnetic storms. Scientists still do not know what causes these violent eruptions in the sun's corona, but the phenomenon most likely involves a reconfiguration of the magnetic field lines there. CMEs are often, but not always, associated with solar flares.

Not all CMEs cause geomagnetic storms. Most of the eruptions are not directed at the earth, and of those that are, only about one in six is "geoeffective"—strong enough to trigger a storm. The primary factor is the CME's speed relative to that of the solar wind. Only fast CMEs are geoeffective. Why? When fast CMEs plow through the slower solar wind, they produce interplanetary shock waves, which are responsible for the high-energy particle showers and the severe deformations of the earth's magnetic field. Even more important, a fast-moving CME compresses the solar wind ahead of it, thereby increasing the strength of the magnetic field in the compressed region and in the front part of the CME itself. Moreover, this draping of the field around the CME tends to tilt the IMF more along the north-south direction, which causes a stronger reconnection when the IMF encounters the earth's magnetic field.

A weaker kind of geomagnetic storm occurs during the declining phase of the solar cycle and near the solar minimum period. These disturbances, which tend to recur in phase with the sun's 27-day rotational period, are set off by the interaction between fast solar winds emanating from holes in the corona and slower winds arising from the sun's equatorial streamer belt. Although CMEs are not the primary cause of recurrent storms, they may contribute to their intensity.

With the launch of IMAGE last year, researchers finally had the means to obtain global views of the minute-by-minute progress of a large geomagnetic storm. The satellite travels in

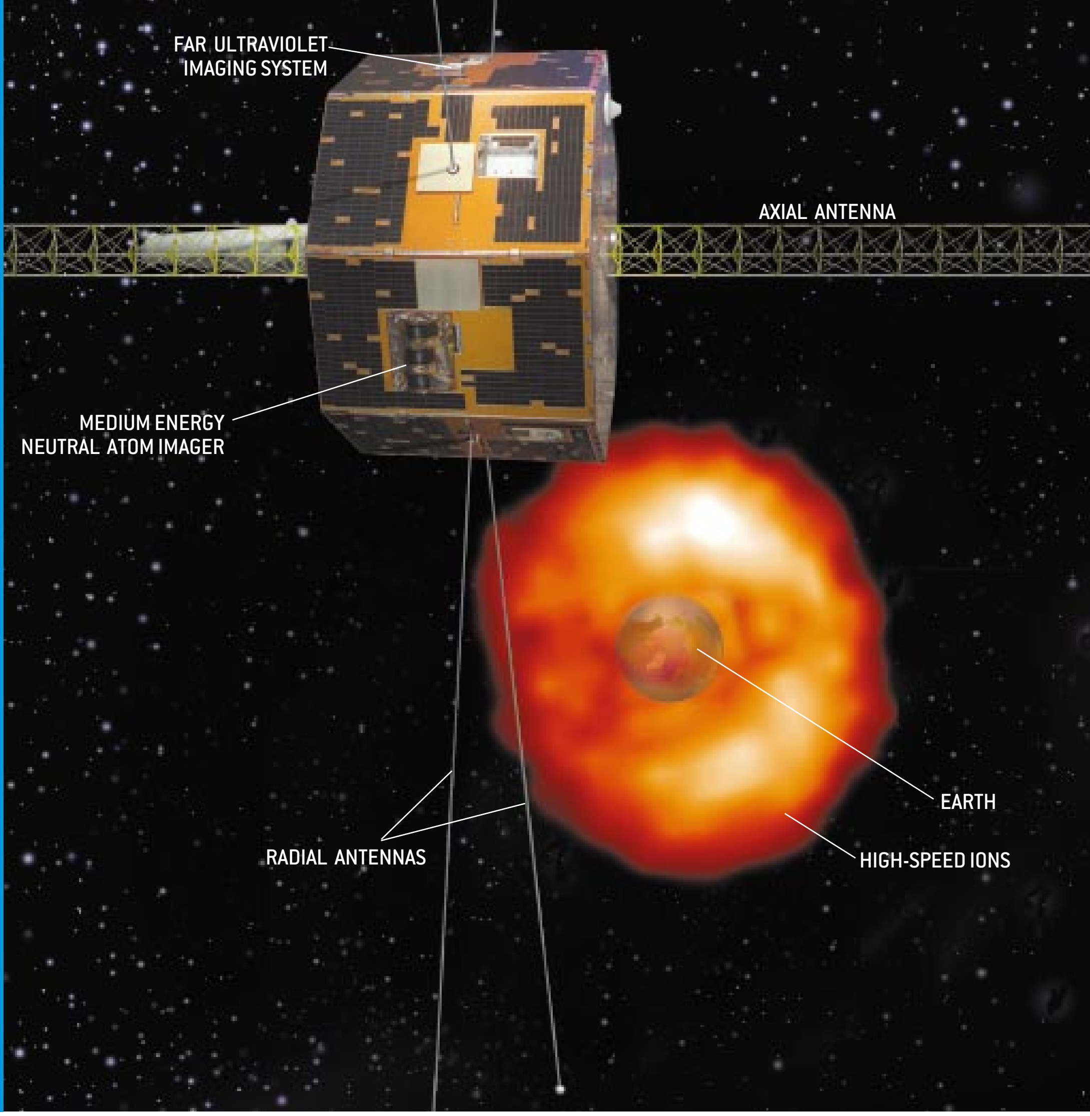


IMAGE SPACECRAFT is shown above a cloud of high-speed ions circling the earth in this composite illustration. Researchers produced the ion image using data from the satellite's High Energy Neutral Atom imager (the instrument is on the side of the spacecraft opposite from the Medium Energy Neutral Atom imager). IMAGE's Radio Plasma Imager charts the clouds of charged particles by sending pulses of radio waves from two 10-meter-long axial antennas and four 250-meter-long radial antennas. Although the spacecraft's body is only 2.25 meters wide, the antennas make IMAGE one of the biggest sensors ever flown in space.

an elliptical polar orbit, with its altitude varying from 1,000 to 46,000 kilometers. This orbit allows the craft to observe a large part of the magnetosphere, including the dayside magnetopause, the inner reaches of the magnetotail and the polar cusp regions, which are the main entryways for the particles from the solar wind.

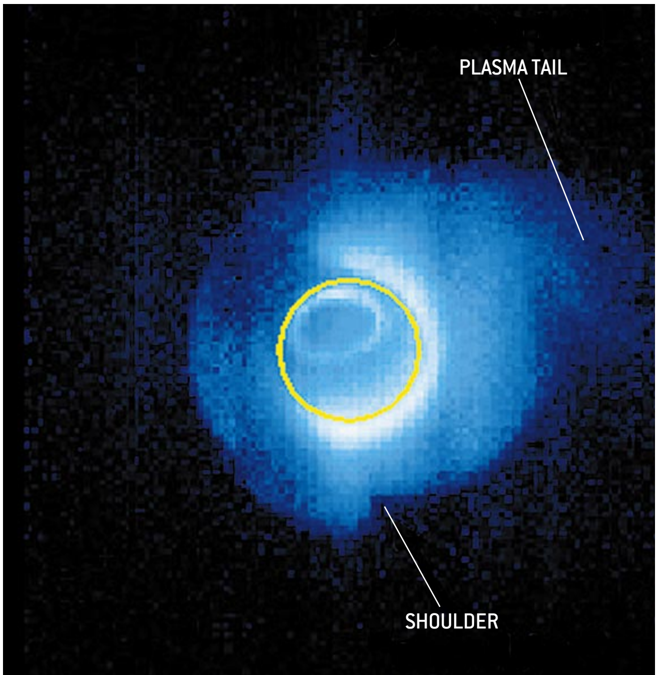
The Perfect Space Storm

IMAGE'S INSTRUMENTS ARE DESIGNED to observe the magnetosphere's plasmas, but they do so in different ways. The craft contains three Energetic Neutral Atom (ENA) imagers that indirectly measure ion flows. When a fast-moving ion (such as an oxygen ion) collides with one of the neutral hydrogen atoms in the magnetosphere, it sometimes strips away the hydrogen atom's lone electron and becomes an energetic neutral atom. Because this atom no longer carries a charge, it does not have to move along the geomagnetic field lines. Instead it travels in a straight path from where it was created. The ENA imagers record the number and energies of the neutral atoms coming from a particular region, and researchers can deduce from those data the mass, speed, direction and density of the ions in that region.

The satellite also carries several instruments that monitor emissions in the ultraviolet part of the spectrum. The Extreme Ultraviolet (EUV) imager measures the density of singly ionized helium atoms in the plasmasphere—a doughnut-shaped region of the inner magnetosphere containing low-energy plasma—by detecting the solar ultraviolet light that they absorb and then reradiate. The Far Ultraviolet (FUV) imaging system has two instruments for viewing auroras—the Wideband Imaging Camera and the Spectrographic Imager—as well as the Geocorona Photometers for detecting emissions from neutral hydrogen atoms. Last, the Radio Plasma Imager sends out pulses of radio waves that bounce off clouds of charged particles. It works like a state trooper's radar gun: the returning radio signals convey information about the direction, speed and density of the plasma clouds.

During the Bastille Day event, IMAGE began recording the storm's effects less than two minutes after the CME-driven shock wave hit the earth's magnetic field on July 15. The Wideband Imaging Camera sent back stunning photographs of the aurora borealis triggered by the compression of the field [*see bottom illustrations on pages 90 and 91*]. A movie created from the images shows a sudden dramatic brightening of a ring above the Arctic region—the auroral oval—with brilliant emissions racing like brushfires toward the North Pole. The aurora quieted less than an hour after the storm began but flared up again when a second shock hit at about 17:00 UT. Powerful substorms followed, as energy stored in the magnetotail was

NASA/IMAGE HENA TEAM (*ion cloud*); E. MAYFIELD (*spacecraft*)



PLASMASPHERE appears as a pale blue cloud of ions surrounding the earth (*yellow circle*) in this picture obtained by IMAGE's Extreme Ultraviolet instrument during a moderate geomagnetic storm on May 24, 2000. The results confirmed the existence of the hypothesized plasma tail and revealed an unexpected structure that was dubbed the "shoulder."

explosively released into the upper atmosphere. Substorms and the attendant auroral displays continued through the rest of July 15 and into the morning of July 16.

During the storm's main phase, which began four hours after its start, the magnetic field strength on the earth's surface fell precipitously, dropping 300 nanoteslas below its normal value. This phenomenon, the defining feature of geomagnetic storms, resulted from the rapid growth of the ring current. IMAGE's Energetic Neutral Atom imagers produced vivid pictures of this flow of ions and electrons around the earth as it reached its peak on July 16 and then began to diminish [*see top illustrations on page 91*]. Once the transfer of energy from the solar wind abates, the flow of plasma into the inner magnetosphere slows, and ions are lost from the ring current more rapidly than new ones arrive. As the current weakens, the magnetic field on the earth's surface rebounds. The return to pre-storm levels usually takes one to a few days but may require more than a month in the case of major tempests.

Geomagnetic storms also change the shape of the plasmasphere. The enhanced flow of plasma from the magnetotail toward the earth erodes the plasmasphere by sweeping its charged particles toward the dayside magnetopause. When a storm subsides, the plasmasphere is refilled by ion outflow from the upper atmosphere. Scientists had hypothesized from modeling studies that the eroded material from the plasmasphere would form a long tail extending to the dayside magnetopause and that from there it would become lost in the solar wind. Global images of the plasmasphere from IMAGE's EUV instrument have now confirmed this 30-year-old hypothesis [*see illustration at left*]. At the same time, the images have revealed structures in the plasmasphere that raise new questions about its dynamic response to magnetospheric disturbances.

On the Horizon

ALTHOUGH IMAGE HAS OPENED a new window on the magnetosphere, our view of space weather is still imperfect. Unlike terrestrial clouds, the clouds of plasma seen by IMAGE are completely transparent: nothing is hidden from sight, but depth perception is lacking. Thus, there will always be the need for satellites that make local measurements of the plasmas, as well as the fields and currents that govern their motion.

The next step for space weather observation will involve clusters of satellites acting like hurricane-hunter planes—they will go where the action is. The European Space Agency is conducting the first such mission, called Cluster II, which was launched in the summer of 2000. (A predecessor mission, Cluster I, was destroyed in a rocket explosion just after liftoff in 1996.) Cluster II consists of four closely grouped identical spacecraft designed to probe turbulent plasma phenomena in the magnetosphere and nearby solar wind. NASA is also planning a cluster mission for launch in 2006. The Magnetospheric Multiscale mission will study reconnection, charged particle acceleration, and turbulence at the dayside magnetopause and at specific locations in the magnetotail where substorms are triggered.

The space agencies are considering even more ambitious missions involving constellations of satellites: dozens of tiny spacecraft that will monitor large regions of space, just as the global weather networks now monitor conditions on the earth. The first constellations will most likely observe the inner magnetosphere and the dayside magnetopause, with each cake-size craft recording the basic characteristics of the plasmas and magnetic fields.

The earth's magnetosphere is at once protective and dangerous. Its strong magnetic field shields humans from penetrating radiation that would otherwise be lethal. But the field is not strong enough to ward off the most powerful shock waves from the sun. Like the tornado belt or the tropical cyclone zone, the magnetosphere is a place of sudden storms. And that's why storm watchers such as the IMAGE satellite are so important. SA

MORE TO EXPLORE

From the Sun: Auroras, Magnetic Storms, Solar Flares, Cosmic Rays. Edited by S. T. Suess and B. T. Tsurutani. American Geophysical Union, 1998.

The 23rd Cycle: Learning to Live with a Stormy Star. Sten Odenwald. Columbia University Press, 2001.

More pictures and data from the IMAGE mission are available at **http://pluto.space.swri.edu/IMAGE/** and **http://image.gsfc.nasa.gov/**

General information on space weather can be found at **www.spaceweather.com/**

NASA/IMAGE EUV TEAM

VIOLENT prIDe

Do people turn violent because of self-hate, or self-love?

by roy f. baumeister
photographs by tina west

Several years ago a youth counselor told me about the dilemma he faced when dealing with violent young men. His direct impressions simply didn't match what he had been taught. He saw his violent clients as egotists with a grandiose sense of personal superiority and entitlement, but his textbooks told him that these young toughs actually suffered from low self-esteem. He and his staff decided they couldn't go against decades of research, regardless of what they had observed, and so they tried their best to boost the young men's opinions of themselves, even though this produced no discernible reduction in their antisocial tendencies.

The view that aggression stems from low self-esteem has long been common knowledge. Counselors, social workers and teachers all over the country have been persuaded that improving the self-esteem of young people is the key to curbing violent behavior and to encouraging social and academic success. Many schools have students make lists of reasons why they are wonderful people or sing songs of self-celebration. Many parents and teachers are afraid to criticize kids, lest it cause serious psychological damage and turn some promising youngster into a dangerous thug or pathetic loser. In some sports leagues, everyone gets a trophy.

A number of people have questioned whether these feel-good exercises are really the best way to build self-esteem. But what about the underlying assumption? When my colleagues and I began looking into the matter in the early 1990s, we found article after article citing the "well-known fact" that low self-esteem causes violence. Yet we were unable to find any book or paper that offered a formal statement of that theory, let alone empirical evidence to support it. Everybody knew it, but nobody had ever proved it.

Unfortunately for the low self-esteem theory, researchers have gradually built up a composite image of what it is like to have low self-esteem, and that image does not mesh well with what we know about aggressive perpetrators. People who have a negative view of themselves are typically muddling through life, trying to avoid embarrassment, giving no sign of a desperate need to prove their superiority. Aggressive attack is risky; people with low self-esteem tend to avoid risks. When people with low self-esteem fail, they usually blame themselves, not others.

Faced with these incongruities, we cast about for an alternative theory. A crucial influence on our thinking was the seemingly lofty self-regard of prominent violent people. Saddam Hussein is not known as a modest, cautious, self-doubting individual. Adolf Hitler's exaltation of the "master race" was hardly a slogan of low self-esteem. These examples suggest that self-esteem is indeed an important cause of aggression—high, that is, not low self-esteem.

We eventually formulated our hypothesis in terms of threatened egotism. Not all people who think highly of themselves are prone to violence. That favorable opinion must be combined with some external threat to the opinion. Somebody must question it, dispute it, undermine it. People like to think well of themselves, and so they are loath to make downward revisions in their self-esteem. When someone suggests such a revision, many individuals—those with inflated, tenuous and unstable forms of high self-esteem—prefer to shoot the messenger.

Pride Comes before a Fall

IT WOULD BE FOOLISH to assert that aggression always stems from threatened egotism or that threatened egotism always results in aggression. Human behavior is caused and shaped by various factors. Plenty of aggression has little or nothing to do with how people evaluate themselves. But if our hypothesis is right, inflated self-esteem increases the odds of aggression substantially. For those aggressive acts that do involve the perpetrators' self-regard, we believe that threatened egotism is crucial. Obviously, this new theory could have implications for designing effective methods to reduce violence.

So how does a social psychologist establish whether low or high self-esteem leads to violence? Because there is no perfect, general method for understanding complex questions about human beings, social scientists typically operate by conducting multiple studies with different methods. A single study can be challenged, especially if competing views exist. But when a consistent pattern emerges, the conclusions become hard to ignore.

Researchers measure self-esteem by asking a standardized series of questions, such as "How well do you get along with other people?" and "Are you generally successful in your work or studies?" The individual chooses from a range of responses, and the overall score falls somewhere on the continuum from negative to positive. Strictly speaking, it is misleading to talk of "people high in self-esteem" as if they were a distinct type, but the need for efficient communication pushes researchers into using such terms. By "people high in self-esteem," I refer broadly to those who scored above the median on the self-esteem scale. Statistical analyses respect the full continuum.

Many laypeople have the impression that self-esteem fluctuates widely, but in fact these scores are quite stable. Day-to-day changes tend to be small, and even after a serious blow or boost, a person's self-esteem score returns to its previous level within a relatively short time. Large changes most often occur after major life transitions, such as when a high school athlete moves on to college to find the competition much tougher.

Quantifying aggression is trickier, but one approach is simply to ask people whether they are prone to angry outbursts and conflicts. These self-reported hostile tendencies can then be compared to the self-esteem scores. Most research has found a weak or negligible correlation, although an important exception is the work done in the late 1980s by Michael H. Kernis of the University of Georgia and his colleagues. They distinguished between stable and unstable self-esteem by measuring each person's self-esteem on several occasions and looking for fluctuations. The greatest hostility was reported by people with high but unstable self-esteem. Individuals with high, stable self-esteem were the least hostile, and those with low self-esteem (either stable or unstable) were in between.

THE AUTHOR

ROY F. BAUMEISTER specializes in using the empirical techniques of social science to tackle broad philosophical questions. His most recent book looked for a scientific solution to the problem of evil. Earlier works explored identity, love and sex, and the meaning that people find in their lives. Baumeister received his Ph.D. in social psychology from Princeton University in 1978. After a postdoctoral fellowship in sociology at the University of California, Berkeley, he came to Case Western Reserve University, where he now holds the E. B. Smith Chair in the Liberal Arts.

Violent criminals describe themselves as special, elite persons who deserve preferential treatment.

Take a Swig, Take a Swing

ANOTHER APPROACH is to compare large categories of people. Men on average have higher self-esteem than women and are also more aggressive. Depressed people have lower self-esteem and are less violent than nondepressed people. Psychopaths are exceptionally prone to aggressive and criminal conduct, and they have very favorable opinions of themselves.

Evidence about the self-images of specific murderers, rapists and other criminals tends to be more anecdotal than systematic, but the pattern is clear. Violent criminals often describe themselves as superior to others—as special, elite persons who deserve preferential treatment. Many murders and assaults are committed in response to blows to self-esteem such as insults, "dissing" and humiliation. (To be sure, some perpetrators live in settings where insults threaten more than their opinions of themselves. Esteem and respect are linked to status in the social hierarchy, and to put someone down can have tangible and even life-threatening consequences.)

The same conclusion has emerged from studies of other categories of violent people. Street-gang members have been reported to hold favorable opinions of themselves and to turn violent when these views are disputed. Playground bullies regard themselves as superior to other children; low self-esteem is found among the victims of bullies but not among bullies themselves. Violent groups generally have overt belief systems that emphasize their superiority over others. War is most common among proud nations that feel they are not getting the respect they deserve, as Daniel Chirot discusses in his fascinating book *Modern Tyrants*.

Drunk people are another such category. It is well known that alcohol plays a role in either a majority or a very large minority of violent crimes; booze makes people respond to provocations more vehemently. Far less research has examined the link with self-esteem, but the findings do fit the egotism pattern: consuming alcohol tends to boost people's favorable opinions of themselves. Of course, alcohol has myriad effects, such as impairing self-control, and it is hard to know which is the biggest factor in drunken rampages.

Aggression toward the self exists, too. A form of threatened egotism seems to be a factor in many suicides. The rich, successful person who commits suicide when faced with bankruptcy, disgrace or scandal is an example. The old, glamorous self-concept is no longer tenable, and the person cannot accept the new, less appealing identity.

Vanity Unfair

TAKEN TOGETHER, these findings suggest that the low-self-esteem theory is wrong. But none involves what social psychologists regard as the most convincing form of evidence: controlled laboratory experiments. When we conducted our initial review of the literature, we uncovered no lab studies that probed the link between self-esteem and aggression. Our next step, therefore, was to conduct some. Brad J. Bushman of Iowa State University took the lead.

The first challenge was to obtain reliable data on the self-concepts of participants. We used two different measures of self-esteem, so that if we failed to find anything, we could have some confidence that the null result was not simply an artifact of having a peculiar scale. Yet we were also skeptical of studying self-esteem alone. The hypothesis of threatened egotism suggested that aggressive behavior would tend to occur among only a subset of people with high self-esteem. In the hope of identifying this subset, we tested for narcissism.

As defined by clinical psychologists, narcissism is a mental illness characterized by inflated or grandiose views of self, the quest for excessive admiration, an unreasonable or exaggerated sense of entitlement, a lack of empathy (that is, being unable to identify with the feelings of others), an exploitative attitude toward others, a proneness to envy or wish to be envied, frequent fantasies of greatness, and arrogance. The construct has been extended beyond the realm of mental illness by Robert Raskin of the Tulsa Institute of Behavioral Sciences in Oklahoma and several of his colleagues, who have constructed a scale for measuring narcissistic tendencies.

We included that measure alongside the self-esteem scales, because the two traits are not the same, although they are correlated. Individuals with high self-esteem need not be narcissistic. They can be good at things and recognize that fact without being conceited or regarding themselves as superior beings. The converse—high narcissism but low self-esteem—is quite rare, however.

The next problem was how to measure aggression in the laboratory. The procedure we favored involved having pairs of volunteers deliver blasts of loud noise to each other. The noise is unpleasant and people wish to avoid it, so it provides a good analogue to physical aggression. The famous social psychology experiments of the 1960s [see "The Effects of Observing Violence," by Leonard Berkowitz; Scientific American, February 1964] used electric shock, but safety concerns have largely removed that as an option.

The noise was presented as part of a competition. Each participant vied with somebody else in a test of reaction time. Whoever responded more slowly received a blast of noise, with the volume and duration of the noise set by his or her opponent. This procedure differed from that of earlier studies, in which the subject played the role of a "teacher" who administered noise or shock to a "learner" whenever the learner made a mistake. Critics had suggested that such a method would yield ambiguous results, because a teacher might deliver strong shocks or loud noise out of a sincere belief that it was an effective way to teach.

"One of the Worst"

TO STUDY THE "THREAT" part of threatened egotism, we asked participants to write a brief essay expressing their opinion on abortion. We collected the essays and then (ostensibly) redistributed them, so the two contestants could evaluate each other's work. Each participant then received his or her own essay back with the comments and ratings that the other person had (supposedly) given it.

In reality, the essays that people graded were fakes. We took the real essays aside and randomly marked them good or bad. The good evaluation included very positive ratings on all counts and the handwritten comment, "No suggestions, great essay!" The bad evaluation contained low marks and the additional comment, "This is one of the worst essays I have read!" After handing back the essays and evaluations, we gave out instructions for the reaction-time test and the subjects began to compete. The measure of aggression was the level of noise with which they blasted each other.

The results supported the threatened-egotism theory rather than the low self-esteem theory. Aggression was highest among narcissists who had received the insulting criticism. Nonnarcissists (with either high or low self-esteem) were significantly less aggressive, as were narcissists who had been praised.

In a second study, we replicated these findings and added a new twist. Some participants were told that they would be playing the reaction-time game against a new person—someone different from the person who had praised or insulted them. We were curious about displaced aggression: Would people angered by their evaluation lash out at just anybody? As it happened, no. Narcissists blasted people who had insulted them but did not attack an innocent third party. This result agrees with a large body of evidence that violence against innocent bystanders is, despite conventional wisdom, quite rare.

A revealing incident illuminates the attitudes of the narcissists. When a television news program did a feature on this experiment, we administered the test to several additional participants for the benefit of the cameras. One of them scored in the 98th percentile on narcissism and was quite aggressive during the study. Afterward he was shown the film and given the opportunity to refuse to let it be aired. He said to put it on—he thought he looked great. Bushman then took him aside and explained that he might not want to be seen by a national audience as a highly aggressive narcissist. After all, the footage showed him using severe profanity when receiving his evaluation, then laughing while administering the highest permitted levels of aggression. The man shrugged this off with a smile and said he wanted to be on television. When Bushman proposed that the television station at least digitize his face to disguise his identity, the man responded with an incredulous no. In fact, he said, he wished the program could include his name and phone number.

Would our laboratory findings correspond to the outside world? Real-life violent offenders are not the easiest group of people to study, but we gained access to two sets of violent crim-

Narcissists blasted people who had insulted them but did not attack an innocent third party.

inals in prison and gave them the self-esteem and narcissism questionnaires. When we compared the convicts' self-esteem with published norms for young adult men (mostly college students) from two dozen different studies, the prisoners were about in the middle. On narcissism, however, the violent prisoners had a higher mean score than any other published sample. It was the crucial trait that distinguished these prisoners from college students. If prison seeks to deflate young men's delusions that they are God's gift to the world, it fails.

What about Deep Down?

A COMMON QUESTION in response to these findings is: "Maybe violent people seem on the surface to have a high opinion of themselves, but isn't this just an act? Mightn't they really have low self-esteem on the inside, even if they won't admit it?" This argument has a logical flaw, however. We know from ample research that people with overt low self-esteem are not aggressive. Why should low self-esteem cause aggression only when it is hidden and not when it is overt? The only difference between hidden and overt low self-esteem is the fact of its being hidden, and if that is the crucial difference, then the cause of violence is not the low self-esteem itself but the concealment of it. And what is concealing it is the veneer of egotism—which brings us back to the threatened egotism theory.

Various researchers have tried and failed to find any sign of a soft inner core among violent people. Martin Sanchez-Jankowski, who spent 10 years living with various gangs and wrote one of the most thorough studies of youth gang life, had this to say: "There have been some studies of gangs that suggest that many gang members have tough exteriors but are insecure on the inside. This is a mistaken observation." Dan Olweus of the University of Bergen in Norway has devoted his career to studying childhood bullies, and he agrees: "In contrast to a fairly common assumption among psychologists and psychiatrists, we have found no indicators that the aggressive bullies (boys) are anxious and insecure under a tough surface."

The case should not be overstated. Psychology is not yet adept at measuring hidden aspects of personality, especially ones that a person may not be willing to admit even to himself or herself. But at present there is no empirical evidence or theoretical reason that aggressors have a hidden core of self-doubt.

Although this conclusion contradicts the traditional focus on low self-esteem, it does not mean that aggression follows directly from an inflated view of self. Narcissists are no more aggressive than anyone else, as long as no one insults or criticizes them. But when they receive an insult—which could be a seemingly minor remark or act that would not bother other people—the response tends to be much more aggressive than normal. Thus, the formula of threatened egotism combines something about the person with something about the situation. Whatever the details of cause and effect, this appears to be the most accurate formula for predicting violence and aggression.

These patterns raise misgivings about how schools and other groups seek to boost self-esteem with feel-good exercises. A favorable opinion of self can put a person on a hair trigger, especially when this favorable opinion is unwarranted. In my view, there is nothing wrong with helping students and others to take pride in accomplishments and good deeds. But there is plenty of reason to worry about encouraging people to think highly of themselves when they haven't earned it. Praise should be tied to performance (including improvement) rather than dispensed freely as if everyone had a right to it simply for being oneself.

The person with low self-esteem emerges from our investigation as someone who is not prone to aggressive responses. Instead one should beware of people who regard themselves as superior to others, especially when those beliefs are inflated, weakly grounded in reality or heavily dependent on having others confirm them frequently. Conceited, self-important individuals turn nasty toward those who puncture their bubbles of self-love. SA

MORE TO EXPLORE

Relation of Threatened Egotism to Violence and Aggression: The Dark Side of High Self-Esteem. Roy F. Baumeister, L. Smart and J. M. Boden in *Psychological Review,* Vol. 103, No. 1, pages 5–33; January 1996.

Evil: Inside Human Violence and Cruelty. Roy F. Baumeister. W. H. Freeman, 1997.

Threatened Egotism, Narcissism, Self-Esteem and Direct and Displaced Aggression: Does Self-Love or Self-Hate Lead to Violence? Brad J. Bushman and Roy F. Baumeister in *Journal of Personality and Social Psychology,* Vol. 75, No. 1, pages 219–229; July 1998.

WORKINGKNOWLEDGE

TOUCH SCREENS

At Your Fingertips

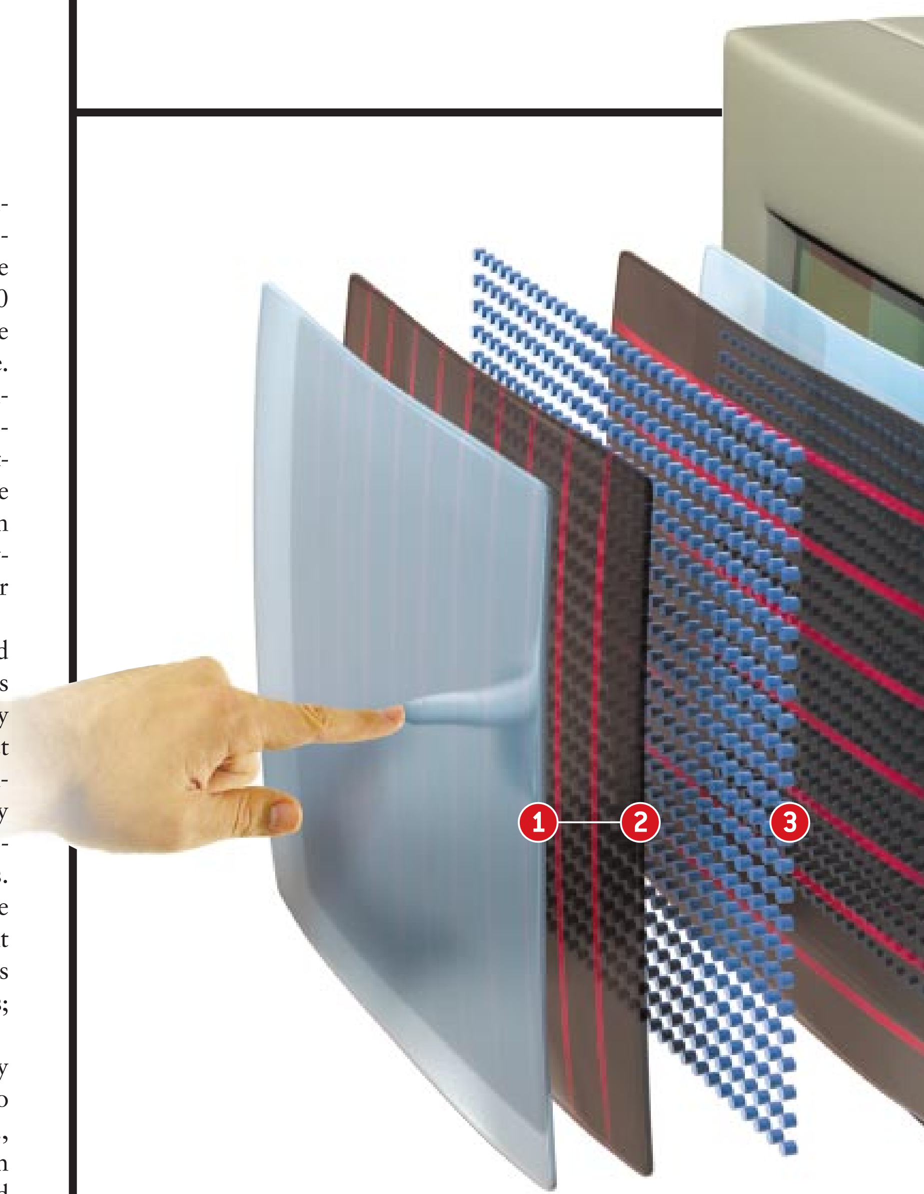
We use touch screens everywhere: tourist kiosks, automatic teller machines, point-of-sale terminals, industrial controls. Half a dozen vendors, plus in-house departments at major manufacturers, produced $800 million worth in 2000. The market is growing because the interfaces are easy-to-use, durable and inexpensive.

Touch screens employ one of three physics principles for detecting the point of touch. Pressing a "resistive" design with a finger or other stylus raises a voltage. In "capacitive" models, a finger draws a minute current (this method is often used for cursor pads on notebook computers). In other designs, a finger or stylus interrupts a standing pattern of acoustic waves or infrared lights that blanket the surface.

Resistive screens are the oldest, most widely used and least expensive, and they work with any stylus (finger, pen). Capacitive screens must be touched by a finger or an electrically grounded stylus to conduct current. Wave screens are the newest and most expensive. Surface acoustic wave screens must be touched by a finger or a soft stylus such as a pencil eraser to absorb energy; infrared screens work with any stylus. The different technologies may be used in the same applications, although pros and cons lead to prevalent combinations: resistive screens for industrial controls and Palm Pilots; capacitive screens for slot machines; wave screens for ATMs and indoor kiosks.

Most people are unaware of the type of screen they are using. But tricks can help you tell, according to Frank Shen of Elo TouchSystems in Fremont, Calif., the largest U.S. maker. Push the screen lightly with your fingernail (not your skin). If it responds, it could be resistive or infrared. In this case, place two separated fingers against the screen at the same time. If the cursor moves beneath one finger, the unit is infrared (software registers the first touch); if the cursor moves between the fingers, it is resistive (the points are averaged). If the unit does not respond to your fingernail, again place two separated fingers against it. If the cursor moves beneath one finger, the unit is acoustic wave; if the cursor moves between the fingers, it is capacitive.

—Mark Fischetti



RESISTIVE
A glass panel that lies against a cathode-ray tube (CRT) or liquid-crystal display (LCD) is coated with a conductive material. Tiny polyester spacer dots separate it from a polyester cover sheet, which has a conductive metal coating on its inside surface. A controller applies a small voltage gradient across the x-axis of the panel and the y-axis of the cover sheet. When a stylus presses the conductive layers together, the control electronics detect its x- and y-coordinates.

DID YOU KNOW . . .

➤ **BUTTERFLIES AND CHADS** The U.S. presidential recount fiasco might have been avoided if Florida had used common touch-screen voting machines instead of confusing paper butterfly ballots and unreliable poke-through chads. Several manufacturers aim to modernize the state. Global Election Systems released a report in December 2000 that said wryly, "The election has created numerous new opportunities for voting-system sales." The company already supplies 850 jurisdictions nationwide. The name of its product? AccuVote.

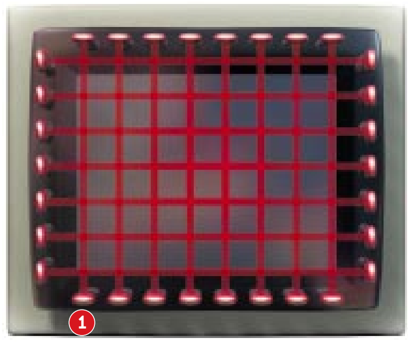
➤ **DOLPHINS** Biologist Ken Marten of Sea Life Park Hawaii is using the first underwater, infrared touch screen (made by Carroll Touch) and a Macintosh G4 computer to create a cross-species language. The computer generates dolphinlike whistles and clicks. The park's dolphins touch images with their rostrums (noses). When a dolphin mimics the computer sound for "up" and then swims upward, a bit of language is born. The dolphins get no food rewards, only recorded sounds and video they find intellectually stimulating.

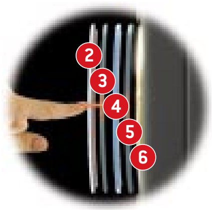
➤ **TOUCH TV** Bill Colwell, an engineer at Elo TouchSystems, developed the first touch screen in 1977. The key to commercializing the resistive design was a subsequent Elo patent for polyester "dots" that separated the screen's layers [*see diagram on opposite page*]. The company unveiled the technology on 33 televisions at the 1982 World's Fair in Knoxville, Tenn.

1 Polyester cover sheet, with scratch-resistant coating
2 Conductive coating
3 Spacer dots
4 Conductive coating
5 Glass panel
6 CRT/LCD

CAPACITIVE

A glass sheet is coated on both sides with a conductive material. The outer surface is covered with a scratch-resistant coating. Electrodes around the panel's edge distribute a low-voltage field uniformly across the outer conductive layer. (The inner layer provides shielding and noise reduction.) When a finger touches the screen, it causes a capacitive coupling with the voltage and draws a minute current. The electrodes measure the current flow from the corners, and a controller determines the finger's coordinates.



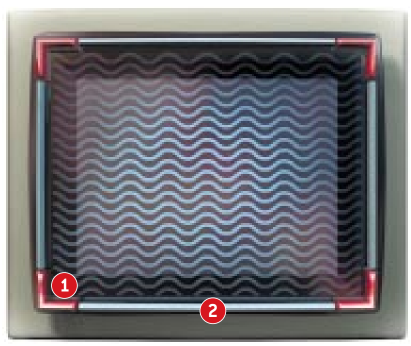


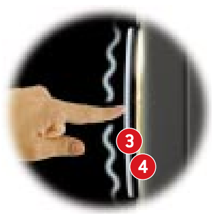
1 Electrodes
2 Scratch-resistant coating
3 Conductive coating
4 Glass panel
5 Conductive coating
6 CRT/LCD

SURFACE ACOUSTIC WAVE (AND INFRARED)

The screen is an uncoated glass panel. Transducers in the corners convert a signal from a controller into ultrasonic waves on the glass surface. Reflectors on the edges create a standing wave pattern. When a soft stylus touches the screen, it absorbs part of the wave. The transducers sense the attenuation, and the controller determines the stylus's coordinates.

On infrared screens, tiny light-emitting diodes and phototransistors on the edges set up a standing grid of invisible infrared light; a stylus obstructs the beam.



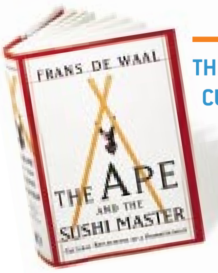


1 Transducers
2 Reflectors
3 Glass panel
4 CRT/LCD

ILLUSTRATIONS BY JOE ZEFF

Do Animals Have Culture?

AN EMINENT PRIMATOLOGIST CHALLENGES LONG-HELD CONVICTIONS ABOUT WHAT MAKES HUMANS DISTINCT **BY MEREDITH F. SMALL**



THE APE AND THE SUSHI MASTER: CULTURAL REFLECTIONS OF A PRIMATOLOGIST
by Frans de Waal
Basic Books, New York, 2001 ($26)

Science, and the tried-and-true scientific method, is supposed to be free of bias. But as primatologist Frans de Waal explains in *The Ape and the Sushi Master,* science, like all human endeavors, is warped by cultural ideology. Nowhere is this more in evidence than in the field of animal behavior and particularly in discussions of whether animals have culture. "We cannot discuss animal culture without seriously reflecting on our own culture and the possible blind spots it creates," de Waal writes.

He approaches this conundrum by taking us with him on a journey around the world, to watch primates and to talk with other scientists, engaging the reader in a conversation about where our biases come from and how they have influenced the history of animal behavior.

De Waal is the director of the Living Links Center for the study of ape and human behavior at Emory University; he has written extensively about his findings in both scientific journals and the popular press. But unlike his previous popular books on chimpanzee politics and reconciliation in primates, this time de Waal is not so much presenting a theory and providing data as stepping back from the entire field of animal behavior to take a broader look.

The Ape and the Sushi Master is a philosopher's tale—and one that could have a major impact on the future study of animal behavior. It questions the very way behaviorists go about their work and in the process undermines some comfortably held theories. In the West, for example, behaviorists embrace the idea that individuals act exclusively in self-serving ways in order to pass on their genes. But de Waal, a Dutch-born zoologist who has lived in the U.S. for two decades and has traveled extensively, has enough cultural distance to see that this view is intimately connected to the Western, especially American, ideology of individualism. Natural selection, he points out, can also produce cooperative behaviors, acts of kindness, and gentle creatures. And de Waal has the experience—27 years of observing apes in captivity—to question the accepted notion that only humans learn. The book's title refers to the way sushi-making skills are passed down from master to apprentice: like the apprentice, young apes also watch their elders and imitate their behavior.

De Waal begins by laying out the reasons that we Westerners have such an uncomfortable relationship with animals, especially primates. By historical and religious tradition, Europeans and Americans embrace the idea that humans are different from—better than—all other animals, establishing a dualism between us and them. "Whenever their abilities are said to approach ours, the reaction is often furious," de Waal points out.

This kind of dualism also means that Western scientists fear anthropomorphism and revere a disconnection from their subjects; we assume one must maintain separation to gather valid data. But de Waal feels that similarities, especially those among closely related species such as apes and humans, are profound and useful. Therefore, he finds that anthropomorphism is "not only inevitable, it is a powerful tool."

Eastern cultures fare better in their observations of animals because they don't buy the Western dualism of humans versus animals. "It can hardly be coinciden-

HAND-CLASP grooming posture spread slowly through a chimpanzee community.

PHOTOGRAPH BY FRANS DE WAAL; BOOK PHOTOGRAPHS BY BETH PHILLIPS tal," de Waal reasons, "that the push for cultural studies on animals initially came ... from primatologists untrained in the sharp dualisms of the West." Long ago the Japanese, for example, were not afraid of topics that Western scientists are just now taking seriously: "Thus, the Japanese did not hesitate to give each animal a name or to assume that each had a different identity and personality. Neither did they feel a need to avoid topics such as animal mental life and culture."

The issue of culture, in particular, as de Waal explains, has had a much more rocky history in the West. For decades, anthropologists and others have come up with various traits that separate humans from chimpanzees in an effort to define what is uniquely human. But chimpanzees keep nudging into our territory: tool use, complex social relationships, empathy and sympathy, sophisticated communication—they seem to have bits of it all. And now it seems they have culture, the last bastion of separation.

In a recent analysis of seven long-term chimpanzee sites, researchers were able to identify 39 behaviors that were learned from others. If culture can be defined as behavior that is socially transmitted, chimpanzees, and other animals, are cultural beings, de Waal argues. "What is the least common denominator of all things called cultural?" he asks. "In my view, this can only be the nongenetic spreading of habits and information. The rest is nothing else than embellishment." Cultural anthropologists might not like it, but the chimps are playing on our side now.

De Waal ends with a section on how we see ourselves. And we emerge as an unpleasantly self-important species. We pretend that a struggle for social power, which is a common behavior pattern among other primates, is "self-esteem" and therefore that it is found only in humans. We assume that humans are the only ones whose behavior is influenced by learning and experience and that we are the only ones who are altruistic, caring beings—such kindness exhibited by other animals is misguided pathology.

De Waal takes a different tack: "Instead of being tied to how we are unlike any animal, human identity should be built around how we are animals that have taken certain capacities a significant step farther. We and other animals are both similar and different, and the former is the only sensible framework within which to flesh out the latter."

Sensible, yes, but ideology dies hard. As de Waal so convincingly explains, we would have to navigate an identity crisis on the way to enlightenment, and this might be too scary for those invested in the supremacy of humankind. But for those ready for some self-scrutiny, and a less biased view of culture and learning in our fellow creatures, this book will be a revelation. In a sense, de Waal is our animal-behavior sushi master; look over his shoulder and learn what the animals tell us about ourselves. SA

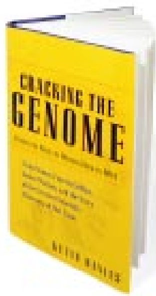
Meredith Small is a writer and professor of anthropology at Cornell University.

THE EDITORS **RECOMMEND**

ATOM: AN ODYSSEY FROM THE BIG BANG TO LIFE ON EARTH . . . AND BEYOND

by Lawrence M. Krauss. Little, Brown, New York, 2001 ($26.95)

Starting with one atom of oxygen that arises as an effect of the big bang, Krauss, chairman of physics at Case Western Reserve University, weaves a tale that reads as compellingly as a good novel. He traces the atom's travels from the early moments of the universe to its participation in life on Earth and then considers what might become of it after life on Earth ends. The result is nothing less than a history of the cosmos.



CRACKING THE GENOME: INSIDE THE RACE TO UNLOCK HUMAN DNA

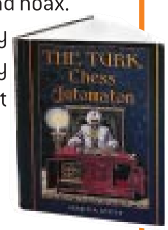
by Kevin Davies. Free Press, New York, 2001 ($25)

The massive effort of recent years to decode the human genome, Davies writes, "is, at the very least, an extraordinary technological achievement, and is at best perhaps the defining moment in the evolution of mankind." Davies, founding editor of *Nature Genetics* and now executive editor of *Current Biology*, gives a clear account of the "epic battle" between the public Human Genome Project and the private Celera Genomics to be the first to sequence the genome. He examines difficult issues that arise from the program, among them the legal issue of gene patenting and the moral issue of genetic engineering. And he foresees that "the explosion in genomic information fueled by the sequence will revolutionize the diagnosis and treatment of countless diseases."

THE TURK, CHESS AUTOMATON

by Gerald M. Levitt. McFarland & Company, Jefferson, N.C., 2000 ($50)

It was an impressive showpiece: a fierce-looking, turbaned puppet seated at a cabinet bearing a chessboard. Its successive owners from 1770 to 1854 would open the cabinet to display to an audience an array of gears and springs and then would invite a spectator to play a game of chess with the Turk, as the turbaned figure came to be known. The Turk usually won. Audiences and chess players were impressed. But it was a grand hoax. Jammed uncomfortably into the cabinet, kept from the audience's view by legerdemain, was a "director," a human chess player who observed by candlelight the moves made by the opponent and operated the pantograph that executed the Turk's responses.



All the books reviewed are available for purchase through www.sciam.com

Look, Ma, No Wires!

THE RICOCHET WIRELESS MODEM IS LIKE A FERRARI—FAST BUT PRICEY BY MARK ALPERT

Walking to work one morning last fall, I happened to notice an odd gray contraption fastened to a streetlight on Madison Avenue. It was about the size of a shoe box, with a short antenna hanging from it like a loose shoestring. The streets of midtown Manhattan are full of strange things, but for some reason this one caught my eye. I soon learned that the gray box is one of 3,000 transceivers that Metricom, a company based in San Jose, Calif., had recently installed on streetlights and utility poles across New York City. The transceivers, which relay low-power radio waves above the heads of unsuspecting pedestrians, are part of a high-speed wireless network called Ricochet.

Wireless networks allow users to connect to the Internet while they're away from the office or home—in a coffee shop, say, or barreling down the street in a taxi. Unfortunately, most of the wireless gadgets now being sold have serious drawbacks. Have you ever tried typing a Web address on the keypad of a cellular phone? Your fingers cramp from repeatedly pushing the buttons, and your eyes get rheumy from staring at the tiny screen. Web-connected handheld computers such as the Palm VII have bigger screens and better interfaces, but their transmission rates are glacial compared with those of desktop computers.

The Ricochet network raises the wireless speed limit with the help of a technology known as frequency hopping. The network divides each digital signal into packets of data and transmits them at many different radio frequencies instead of a single channel. When you connect to the Internet using a Ricochet modem, the device sends a barrage of data packets to the nearest transceiver, which then directs the packets to another transceiver connected to a high-speed landline. The first Ricochet networks, launched in 1995, delivered data to users at 28.8 kilobits per second (kbps). The newest networks—operating in New York City, the San Francisco Bay Area and about a dozen other U.S. cities—promise a transmission rate of 128 kbps, or more than twice the rate of a typical desktop modem (56 kbps), at least 80 percent of the time.

The palm-size Ricochet modem is designed to work with laptop computers; Velcro strips on the device allow you to attach it to the back of your laptop's screen. You can buy the modem for as little as $99, but the wireless service costs about $75 a month. Is it worth the money? To find out, I decided to try the device myself. The first step was to go to Ricochet's Web site (www.metricom.com/getricochet.htm), where you can determine whether your area is covered by one of the networks. The site also lists the authorized service providers (although Metricom built the networks, other companies sell the modems and service). I chose Wireless WebConnect!, a company based

ILLUSTRATION BY CHRISTOPH NIEMANN

in Clearwater, Fla., which lent me a Ricochet modem for a month.

Before going any further, I must confess that I'm a schlemiel when it comes to technology. Nothing ever works for me, at least not on the first try. So I wasn't too surprised when I had difficulty connecting the modem to my laptop. This computer (which actually belongs to *Scientific American,* not me) is a Macintosh PowerBook G3—not a state-of-the-art machine, perhaps, but not an antique either. The problem was that the laptop's operating system was OS 8-point-something, whereas the Ricochet modem requires OS 9.0 (and to get optimal performance with Windows machines, you'll need Windows 98, version 2, or better). I had to ask Vincent Salzillo, our magazine's invaluable Macintosh expert, to upgrade the operating system.

But my troubles were only beginning. The Ricochet modem can connect to laptops through either a serial port (the traditional interface for an external modem) or a Universal Serial Bus (a newer, faster type of interface). My PowerBook had only a serial port, and the serial cable included with the Ricochet modem didn't fit it. Although the technical support people at Wireless WebConnect! assured me that I could find an adapter at a computer store, I had no luck at the first few places I tried. I finally jury-rigged a connection using two different cables and an adapter between them. Turning on the modem, I muttered under my breath, "If this works, I am Houdini."

It didn't work, of course. But after a few more calls to the technical support folks (I needed a newer version of the installation software), the modem beeped to life, and my Internet Explorer home page appeared on the laptop's screen. I felt a surge of elation: I was wireless!

My first impulse was to check the modem's speed, so I went to the Microsoft Network's Bandwidth Speed Test (msn.zdnet.com/partners/msn/bandwidth/speedtest500.htm), which measures the transmission rate of an Internet connection by downloading a whopping data file to your computer. My elation ebbed somewhat when the result came in: 74 kbps, or less than 60 percent of the promised speed. When I tested the modem again an hour later, the data rate had risen to 98 kbps, but when I checked a third time the rate had fallen to 43 kbps.

I suspected that my Rube Goldberg–style cable hookup might be slowing the flow. A few days later, though, I clocked the modem at a blistering 168 kbps, or more than 30 percent faster than the advertised speed. I hadn't moved the modem at all (it was still sitting on my office desk), so I wondered what was causing the variation in transmission rates. The technical experts at Wireless WebConnect! speculated that the most likely cause was radio interference from devices such as cordless phones that use the same band of the spectrum as Ricochet. But the folks at Metricom said the real culprit was heavier usage of the network during peak times, which reduces everyone's transmission rate. After learning about my problem, Metricom upgraded my modem's software by sending a few therapeutic wireless signals over the network. My data rates became less variable, ranging from 120 to 188 kbps. The company said I'd get even better speeds if I had a Universal Serial Bus on my laptop.

Now I was ready to give Ricochet a road test. I tucked the laptop under my arm, left the office and hailed a taxi. The modem is designed to work in cars and trains moving up to 70 miles per hour, but this was impossible to confirm in New York traffic. Traveling at half that speed through Manhattan's Upper West Side, I got a connection of 86 kbps. I have to admit, it was exhilarating to be checking stock quotes while cruising down Columbus Avenue. I scrolled through a financial news Web site and learned that the Nasdaq index was falling again. I read an article about the woes of the semiconductor industry, then hopped over to a stock-trading Web site. But then I asked myself, What good is this? Am I really going to start trading stocks from the backseat of a cab? Who am I kidding?

Ultimately, the value of a wireless connection depends on how much you use it. If you want nonstop Internet access for buying stocks, sending e-mail, reading the news or booking airline reservations, then Ricochet may be for you. The modem may also come in handy if you travel frequently. But if you're a homebody and a schlemiel like me, you may not find the system very useful. SA

But then I asked myself, What good is this? Am I really going to start trading stocks from the backseat of a cab? **Who am I kidding?**

Mark Alpert is a member of Scientific American*'s board of editors.*

No Tipping

BY DENNIS E. SHASHA

As Archimedes famously observed, if you put an object on a lever arm, it will exert a twisting force around the lever's fulcrum. This twisting is called torque and is equal to the object's weight multiplied by its distance from the fulcrum (the angle of the lever also comes in, but that does not concern us here). If the object is to the left of the fulcrum, the direction of the torque is counterclockwise; if the object is to the right, the direction is clockwise. To compute the torque around a support, simply sum all the torques of the individual objects on the lever.

The challenge is to keep the lever balanced while adjusting the objects on it. First, let's try a warm-up problem: Assume you have a straight, evenly weighted board, 20 meters long and weighing three kilograms. The middle of the board is the center of mass, and we will call that position 0. So the possible positions on the board range from –10 (the left end) to +10 (the right end). The board is supported at positions –1.5 and +1.5 by two equal fulcrums, both two meters tall and standing on a flat floor. On the board are six packages, at positions –8, –4, –3, 2, 5 and 8, having weights of 4, 10, 10, 4, 7 and 8 kilograms, respectively [*see illustration A below*].

Your job is to remove the packages one at a time in such a way that the board rests on both supports without tipping. The board would tip if the net torque around the left fulcrum (resulting from the weights of the packages and the board itself) were counterclockwise or if the net torque around the right fulcrum were clockwise. One answer (there are several) is at the right.

Now for a trickier problem. Assume there are 15 packages on the same board, with the positions and weights indicated in illustration B. Some of the packages are at the same distances from the center of the board but sit side by side. Find an order for removing the packages such that the board never tips. One answer (again, there are several) will appear in next month's column. SA

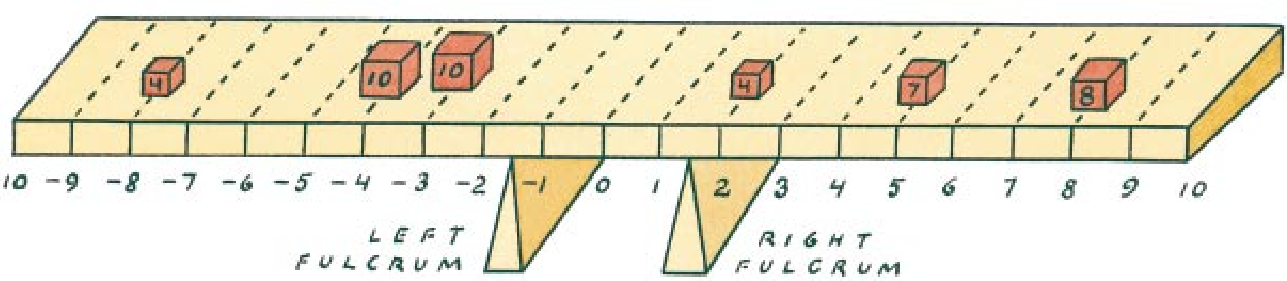
Dennis E. Shasha, professor of computer science at the Courant Institute of New York University, creates and solves puzzles for a living.

Web Solution: For a peek at the answer to the second problem and at readers' other solutions, visit www.sciam.com

Note to Sticklers: How can a 20-meter-long board weigh only three kilograms? Assume that it's made of a light titanium alloy.

Answer to Warm-up Problem: First remove the package at position –4, then the package at 8, then –8, then 5, then –3 and finally 2.

A



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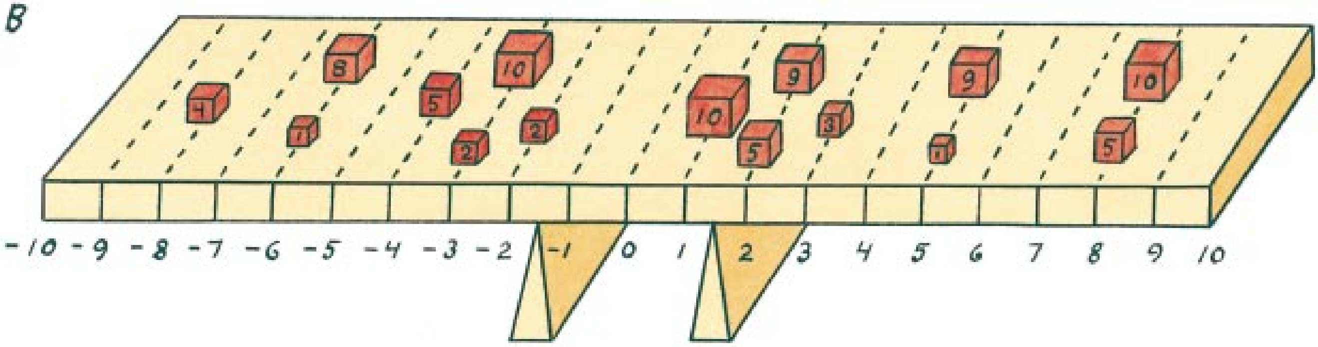


ILLUSTRATION BY MARIS BISHOFS

Charmed, I'm Sure

FOR THE SCIENTIFICALLY BRIGHT BUT SOCIALLY BEFUDDLED, A DAY OF ETIQUETTE INSTRUCTION MIGHT BE JUST WHAT THE PH.D. ORDERED **BY STEVE MIRSKY**

It's a classic problem for the average scientist-in-training: Do you pick your teeth with your acceptance letter from the Massachusetts Institute of Technology or with the envelope it came in? (The correct answer is neither: you use the paper clip holding together your orientation materials.)

But seriously, for a moment anyway, M.I.T. recognized the fact that it was sending some students out into the world who were apparently more comfortable crossing a Wheatstone bridge than crossing to the other side of a room to introduce themselves. They were more at ease asking for a Dewar flask than asking, "Do you want to dance?" They could insert a gene better than they could insert themselves into a conversation. Before I search for a geology reference, you get the idea. So in early February, M.I.T. invited any and all students to voluntarily attend its eighth annual charm school.

"We used to refer to it as 'Degeekifying M.I.T.,'" says Katherine O'Dair, charm school coordinator and assistant dean for student life programs. "But we got rid of any references to geeks. No one wants to be thought of that way." (So, O'Dair must have been thrilled with the *New York Times*. The headline of its charm school coverage included the phrase "Geeks at M.I.T.") It's not clear how many students showed up thinking it was a symposium on quarks, but about 800 did wind up attending—about 8 percent of the student body.

I was particularly interested in the M.I.T. event because of psychic etiquette wounds I experienced in my own scientific education. At the institution where I attended graduate school, the chemistry department rewarded the students with a weekly treat. Every Wednesday at 4:30 P.M. a big bag of bagels was delivered to the student lounge in an exercise that became known as "bagel minute." Not since buzz bombs rained down on London have people raced to a common destination with a greater sense of urgency. Bagel minute was nasty, brutish and short. If you showed up at 4:31, all that was left were some stray schmears of cream cheese and the guilty faces of the survivors.

M.I.T.'s charm school attempts, in a day, to at least expose students to the many guidelines of behavior that will help them move gracefully into the polite society that their postgraduate lives should include. Classes in table manners will most likely do away with any bagel-minute-like escapades. Dress-for-success instruction will come in particularly handy for the young man who showed up wearing a cap on which was written, simply, "PIMP."

Students were also free to sit at the feet of experts in both business and cell phone etiquette. Unfortunately, many more seemed interested in the former than the latter, a situation that needs quick remedy if my train trip from New York City was any indication: half a dozen loud cell phone conversations took place in my car all the way to Boston.

Perhaps the highlight of M.I.T.'s charm school was the half-hour class on flirting, which ran repeatedly during the day. (One might think that teaching college kids how to flirt would be as necessary as teaching a nightingale to sing, but one might be wrong.) In each session, the mentors separated the men from the women and asked members in each group how they could tell if someone they had just met at a party liked them. The top two reasons the men thought a woman might be interested was that she made eye contact and seemed genuinely engaged in the conversation. The top two reasons the women thought a man might be into them was that "they stare at me and they turn red." And so I was reminded that our tree-swinging origins still beckon. Which is all the more reason for learning how to flawlessly finger the fondue fork. SA

They were more at ease asking for a Dewar flask than asking, "Do you want to dance?"

ILLUSTRATION BY NICK DEWAR; PHOTOGRAPH BY FRANK VERONSKY

END POINTS

Q

Is there any evolutionary advantage to gigantism? Did the sauropod dinosaurs continue to grow throughout their lives, as some reptiles and fish do? —Alexandra Chang, Miami, Fla.

Gregory S. Paul, freelance scientist, artist, and editor of the *Scientific American Book of Dinosaurs,* offers this explanation:

Gigantism has been a common feature of land animals since the beginning of the Jurassic period, more than 200 million years ago. The first true giants of the land were small-headed, long-necked, sauropod dinosaurs. Toward the end of the Jurassic many sauropods reached 10 to 20 metric tons, some weighed as much as 50 metric tons, and a few may have exceeded 100 metric tons and 150 feet in length, rivaling the largest modern whales.

Why do animals become gigantic? Some reasons are simple. The bigger an animal is, the safer it is from predators and the better it is able to kill prey. Antelope are easy prey for lions, hyenas and hunting dogs, but adult elephants and rhinos are nearly immune—and their young benefit from the protection of their huge parents. For herbivores, being gigantic means being taller and therefore able to access higher foliage. Giraffes and elephants can reach over 18 feet high, and elephants can use their great bulk to push over even taller trees.

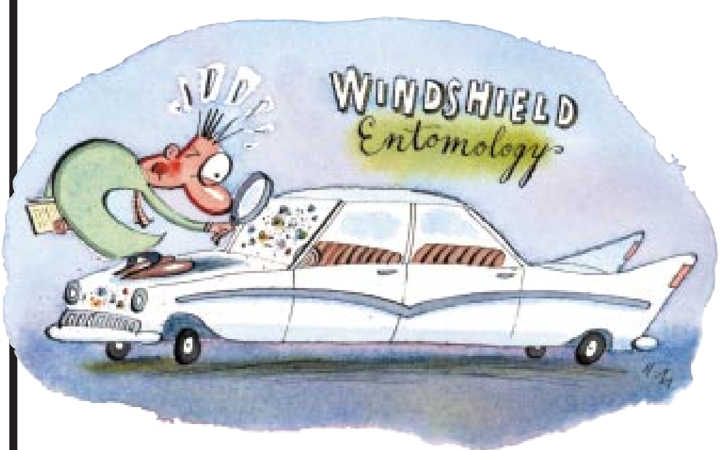
Other reasons for being gargantuan, though important, are less obvious. The cost of locomotion decreases with increasing size; thus, it is much cheaper for a five-metric-ton elephant to walk a mile than it is for a five-metric-ton herd of gazelle to move the same distance. Metabolic rate also decreases with increasing size. A shrew must therefore frantically eat more than its own weight each day. The elephant, on the other hand, needs to take in only 5 percent of its own weight. Also, as size increases, great bulk acts as a form of mass insulation, and so large animals are less affected by temperature extremes.

> "*Experiment is the sole interpreter of the artifices of Nature.*"
> —LEONARDO DA VINCI

But there are disadvantages to being big. Because big animals eat more, there cannot be as many of them. Before human hunting, the population of elephants and rhinos in Africa was in the low millions. Rodents, in contrast, number in the countless billions. Nor can giants do a lot of things that smaller creatures can do, such as burrow into the ground, climb trees or fly.

On land only dinosaurs and mammals have become gigantic; reptiles have never done so (the biggest tortoises and lizards have only weighed one metric ton). One reason may be the rate of growth. Land reptiles cannot grow rapidly. It takes many years for an alligator to reach 100 pounds, whereas an ostrich does so in less than a year. SA

For the complete text of this answer, and answers to many other questions, visit Ask the Experts (www.sciam.com/askexpert).



CARTOON BY HAL MAYFORTH

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