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october 2001

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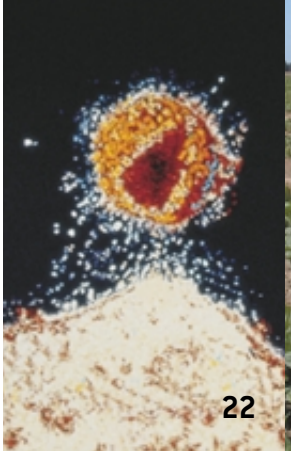

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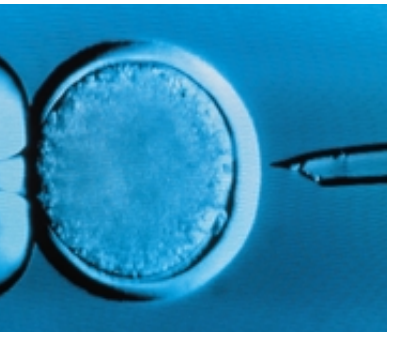
Cover painting by Ron Miller; preceding page: Max Aguilera-Hellweg; this page, clockwise from top left: C. Dauguet and C. Edelmann/Petit Format/Photo Researchers, Inc.; Michael Mullican; Charles O'Rear/Corbis

The Uncloned States of America?

Even opponents of cloning probably agree that the Weldon bill passed in July by the U.S. House of Representatives is extreme. It not only bans federal support for human cloning but criminalizes the activity and prohibits traffic in any products or services arising from it. It deliberately makes no distinction between reproductive cloning (aimed at producing new people) and therapeutic cloning (aimed at creating cell lines for medical treatments). The bill sends a message: "No human cloning, ever."



SHEEP EGG CELL ready for cloning.

Cloning technology is highly inefficient; cloned cells show puzzling irregularities; a cloned child would be raised in a psychologically murky environment. For all those reasons, responsible biologists agree with putting off reproductive cloning for the good of the clones. But they plead that therapeutic cloning is too promising to discard blindly.

The bill's backers answer that the ban must be comprehensive because cloned embryos from therapeutic projects could be waylaid to grow as babies. Still, condemning technology just because it might be abused is always a selective argument: cloning's opponents would not want that same logic applied to handguns or automobiles. Therapeutic and reproductive cloning are different enough that it should be possible to build and police barriers between the two.

The fundamental moral bottleneck, inevitably, is whether even very early stage embryos conceived in a laboratory deserve legal protection. Therapeutic cloning is unacceptable to those who believe that a human being is created at the instant of fertilization. That belief is sincere and powerful and ultimately transcends scientific disagreement. The question for our democracy is how tightly that spiritual belief should bind the hands of those who disagree with it.

What will happen if the U.S. banishes all human cloning? Various biotechnology advocates have predicted a "brain drain" of scientists fleeing to countries where therapeutic cloning is legal. If even a few nations support the practice, the U.S. biotech industry will unquestionably suffer.

A ban might also render moot much of the recent debate over embryonic stem cell experiments. Stem cell researchers could learn how to grow embryonic cells into medically useful tissue grafts, but if those cells need to be genetically identical to a patient's tissues, then such treatments could hit a brick wall without cloning. One can hope that scientists will be able to develop therapies based instead on adult stem cells, but it is a twistier avenue for investigation.

Surely the cloning decisions will have repercussions on the status of legal abortion. If the law sanctifies very early embryos, then cells in a petri dish conceived with no prospects of being brought to term will have *more* rights than an equivalent embryo in a woman's uterus. That schizoid arrangement won't be lost on either the pro-choice or antiabortion camps.

If the comprehensive ban does pass, its opponents can take faint consolation in this: it won't last. Suppose that scientists elsewhere eventually use cloning to develop a treatment for Alzheimer's, Parkinson's, diabetes or paralysis. Does anyone believe that the American public would let its own suffer and die while the rest of the world gets well? That it would do this out of concern for laboratory-bred cellular specks?

This is the tragedy of a comprehensive ban: that many of those now against cloning will someday embrace it, when their misgivings—like the patients who could have benefited earlier—are conveniently buried.

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Letters

EDITORS@SCIAM.COM

RESPONSES CAME IN fast and furious to June's editorial, "Faith-Based Reasoning," which observed that the Bush administration disdains scientists' conclusions about global warming and missile defense when they run counter to its ideology. Many critics of our column apparently share that disdain, dismissing even the climate change studies by the National Academy of Sciences as politically biased. On the other hand, most of those same readers maintain a blithe confidence that determined engineering can overcome any problem with missile defenses; humans would never have reached the moon if thinking like ours prevailed, they scold us. Perhaps. Yet we stand by our position that there should be far better proof that a proposed system could work before the U.S. abrogates treaties and spends hundreds of billions of dollars.

Thanks as always to our engaged readership for letters on this and other June articles.

THE SEMANTICS OF TERROR

For anyone who still thinks the word "terrorism" has meaning, Rodger Doyle's "The American Terrorist" [By the Numbers, News Scan] should convince them otherwise; his application of the term renders it totally useless.

KEVIN R. GREGG
Momoyama Gakuin University
Osaka, Japan

DOYLE REPLIES: There is no universally accepted definition of terrorism, and of the dozens of definitions used in recent years, many were contrived to fit a particular situation. My definition is, I believe, useful for the purpose of presenting the panorama of noneconomic, noninterpersonal violence in an American context.

Other readers objected to putting different categories of terrorism on the same chart. If the chart were showing original scientific work, I would agree with this protest. In a news context, however, it is useful to combine several different measures in one chart to make the point that terrorism, as defined in the article, covers a wide variety of actions.

THIS IS THE DAWNING OF... OH, NEVER MIND

I was surprised to see value-laden words throughout "Hair: Why It Grows, Why It Stops," by Ricki L. Rusting: "grappling," "remedies," "combating hair disorder." This may reflect some individuals' social values but not biological reality.

About 25 years ago, on a visit to Indianapolis, colleagues there pointed out to me that having a beard and no hair on top gave social signals that were not helpful for my career. (I probably shouldn't mention the handbag, which of course was not a normal accessory at that time.) My colleagues agreed when I asked if a full head of hair and a clean-shaven image were seen as positive. My reply to this was that my hair distribution is a normal male one, and I couldn't see why they all wanted to look like girls. Alas, this comment was not career-enhancing either.

Seriously, though, it is very curious to see social values making normalcy into a problem, and the tenor of this article continues to promote that irrational value system.

JAMES FRADGLEY
Wimborne, Dorset, England

NEGATIVE ON NAMIBIA DAM

In 1991, when the feasibility study into Namibia's Epupa Dam was published, I analyzed the impact of the variations in water level for the environmental group the Wildlife Society ["The Himba and the Dam," by Carol Ezzell]. I found that because the vast majority of the water flow occurs in just three months, there would be significant changes in the water level every year as the dam was refilled and drawn down. As the area upstream of the Epupa Dam site is quite flat, this meant that large areas of land would be inundated and then reexposed every year, with the water edge moving several kilometers

in places whenever it flooded. The lack of a reliable water supply for vegetation means that it would be impossible for riparian vegetation to become established. And given the desert climate, any silt that had been deposited would soon dry and turn to dust. As I stated at one of the public hearings, the Epupa Dam would also have a devastating effect on the environment and consequently on tourism.

DAVID PEARCE
Senior Mining Engineer, SRK Consulting
Cardiff, Wales

WITH OR WITHOUT THE WEST, TRIBAL CULTURES WANE

Tribal societies, with their enforced cohesion, rigid hierarchies and narrow horizons, are a colossal bore for their young people ["The Himba and the Dam"]; it is small wonder that whenever possible a tribal culture's young people flee. Western societies in their misguided attempts to preserve tribal societies are condemning women to second-class citizenship, a life of no choices and conditions very similar to slavery. The young men, at least those without a high-status lineage, are condemned to keeping the traditional cage firmly wrapped around themselves and their sisters. It is time the West stopped apologizing for making possible independence, opportunity and freedom.

CLIFF LEE
Councilor, Rotorua District Council
Rotorua, New Zealand

In time the Himba culture will be diluted and eventually die, but we should allow it to die naturally. There seems to be no need to sacrifice it on the altar of big money.

JEFF JACKSON
Lake Worth, Fla.

DEFINING DEFLECTION DOWN

"Solving the Mystery of Insect Flight," by Michael Dickinson, offers only a half-true explanation of how an aircraft wing generates lift by steady-state aerodynamics: "Smooth flow over the top of the wing is faster than under the wing [true], producing a region of low pressure [true] and an upward force [half true]." Lift by suction, however, is weak and insufficient to lift and sustain level flight of a heavy plane. What really holds a plane up is the deflection downward of a mass of air exceeding the weight of the plane.

HARRY LAPHAM
Cape Coral, Fla.

DICKINSON REPLIES: *The Bernoulli equation (the inverse relation between pressure and velocity within a fluid) and the "deflect air downward" explanation of aircraft flight are, in fact, the same argument—one from the perspective of the wing, the other from the perspective of the fluid, tied neatly together by Newton's laws. Although air must indeed be deflected downward at a rate equal to the upward force on the wing, that reaction force on the wing is enacted through a pressure differential across the wing. The most important equation in aerodynamics is the Kutta-Joukowski theorem, which is derived by integrating the Bernoulli equation around a wing. If the forces calculated using that theorem are insufficient to lift a heavy plane, then all those 747s should fall from the sky.*

Insects also deflect air downward when they fly. My group's studies of how the lift forces on insects' wings are generated could be equivalently expressed as studies of how flying insects propel masses of air downward.

CAN THE HIMBA **survive a dam?**

KARIN RETIEF

ARSENIC STANDARDS: REAL OR IDEAL?

In a world of boundless resources, where no worthwhile project went undone for lack of funding or attention, we could reduce arsenic and a host of other environmental poisons to arbitrarily small tolerances with impunity ["A Touch of Poison," by Mark Alpert, News Scan]. Outside of utopian fiction, however, limited resources must be allocated, and what is used for one thing is unavailable for another.

Based on the numbers you reported, the Environmental Protection Agency estimates that the new guidelines would require some combination of public and private spending of $6 million for each avoided death, and "some researchers" think it might be as low as $600,000.

In either case, imagine what the same money could do to alleviate human suffering if it were instead directed at inoculations against preventable disease, or reducing emissions from the dirtiest power plants and automobiles, or increasing sustainable food yields in impoverished areas, or promoting proper diet, or any one of a number of other environmentally sound public health projects—or even just stimulating the economy to raise the general standard of living. It may be that as a society we conclude that reducing arsenic levels is the best use for those resources, but that conclusion is neither obvious nor unanimous.

AUGUSTUS P. LOWELL
Sunnyvale, Calif.

ERRATA In "The Himba and the Dam," by Carol Ezzell, the proposed dam would have a capacity of 360 megawatts, not "megawatts per day."

The first sentence in "A License for Copycats," by Gary Stix [Staking Claims], should have read: "Should someone be able to manufacture [not 'patent'] an invention that blatantly duplicates a previously patented creation except for some minor alterations?"

The volume number was given incorrectly in the August issue. It is Volume 285.

50, 100 & 150 Years Ago

New Economics ▪ Better Housing ▪ Nifty Boat

OCTOBER 1951

INPUT-OUTPUT ECONOMICS—"This article is concerned with a new effort to combine economic facts and theory, known as 'interindustry' or 'input-output' analysis. Essentially it is a method of analysis that takes advantage of the relatively stable pattern of the flow of goods and services among the elements of our economy to show a much more detailed statistical picture. This method can portray both an entire economy and its fine structure by plotting the production of each industry against its consumption from every other. The method has had to await the modern high-speed computing machine as well as the propensity of government and private agencies to accumulate mountains of data. —Wassily W. Leontief" [*Editors' note: Leontief won the 1973 Nobel Prize in economics for this system.*]

OCTOBER 1901

MODEL TENEMENTS—"One of the greatest problems that the large cities are called upon to solve is the housing of the poor. In London and New York in particular, attention is now given to the problem, due not only to the general spirit of altruism, but also to a realization that the old methods of housing the poor directly contributed to the spread of vice and pestilence. Plans have been filed with the Building Department of New York for a new model tenement to be erected at Avenue A, 78th and 79th Streets by the City and Suburban Homes Company, an association of practical business men and philanthropists. The building will be attractive architecturally, and there will be nothing to suggest the repulsive tenement so common in the congested districts."

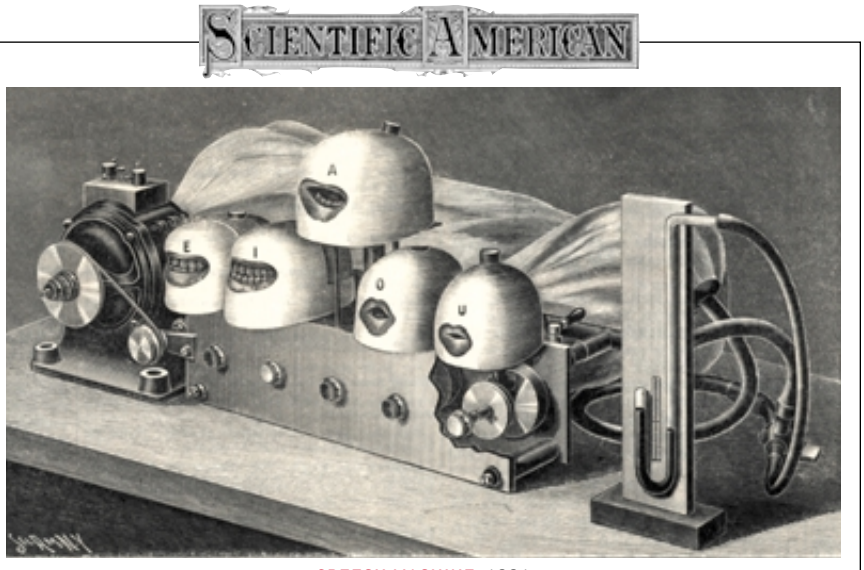
THE AMERICAN SAURIANS—"The vast region known as the Western Plains is the paradise of the paleontologist, for here lived and died the uncounted generations of reptiles that peopled the ancient earth. Prof. Edward Drinker Cope, the celebrated paleontologist, has furnished a very graphic description of the elasmosaurs. 'Far out on the expanse of the ancient sea, might have been seen a huge snake-like form which rose above the surface and stood erect with tapering throat and arrow-shaped head. Plunging into the depths naught would be visible but the foam caused by the disappearing mass of life. An extraordinary neck arose from a body of elephantine proportions. The limbs were two pairs of paddles like those of the plesiosaurus, from which this diver chiefly differed in the arrangement of the bones in the breast.' "

DAISY, DAISY—"Dr. Marage has constructed an apparatus which is a step in the direction of producing a practical talking machine, although it is limited to the production of vowels [*see illustration*]. Not only the larynx but also the cheeks play an important part in the production of sound, adding the harmonies which give the voice its character. Dr. Marage has constructed an apparatus, using the plastic substance employed by dentists, to reproduce the interior of a person's mouth while pronouncing the different vowels."

OCTOBER 1851

KAYAK—"The American Arctic expedition has brought back a number of curiosities from the northern regions of Melville Bay and Greenland. The boats used by the Esquimaux are curious pieces of sea furniture. They are made by stretching sealskins over a light frame-work of wood. The length of a boat is about 12 feet, by 14 inches in width. By a dexterous movement with his oar, an expert boatman will completely turn his boat over, and come up on the opposite side. In this fragile vessel he pursues his avocation of spearing seals in the roughest weather."

MASS PRODUCTION—"Our ancestors made things to endure for more than a summer's sunshine or a winter's storm, and when we wish to procure solid and durable articles, good prices have to be paid, as of old. Stockings and stuff of that kind are rattled off with surprising dexterity, and manufactured at reduced rates, but the knit work of our grandmothers, the idolized socks which were woven in the looms of their trembling fingers, are worth a dozen of the modern nether garments."



SPEECH MACHINE, 1901

FROM *SCIENTIFIC AMERICAN*

POLICY

Climate of Uncertainty

THE UNKNOWNS IN GLOBAL WARMING RESEARCH DON'T HAVE TO BE SHOWSTOPPERS **BY GEORGE MUSSER**

WITH NOTHING TO SAY, U.S. delegates Paula Dobriansky and Mark Hambley looked on as the rest of the world agreed in Bonn to implement the Kyoto Protocol.

Denying uncertainty makes life so much easier, as many have discovered when it comes to climate change. Between skeptics' insistence that global warming is just hot air and radical environmentalists' advice to start selling the beachfront property, responses to climate change tend to be predicated on claims of absolute knowledge. Who wants to deal with the messy reality? There is plenty of evidence that temperatures are rising and will continue to do so but lots of uncertainty about the details and amount of future change.

The good news is that politicians are finally confronting the messiness. Following the environmental summit this past July in Bonn, Germany, every nation but one is pressing ahead with the Kyoto Protocol, which caps industrialized countries' output of greenhouse gases. The U.S. is pressing ahead with a close approximation to nothing, although on June 11 President George W. Bush stated, "I've asked my advisers to consider approaches to reduce greenhouse gas emissions." A policy could materialize by the next summit this month in Marrakech, Morocco. Already some 31 resolutions, amendments and bills—from endorsements of Kyoto to modifications of the Clean Air Act—are kicking around Capitol Hill.

The bad news is that uncertainty still paralyzes discussion, especially in the U.S. Scientists naturally generate a range of results. Not all of these results are equally likely to be true, and none is definitive, but people tend to latch onto those that suit their preconceptions.

To inject some rigor into the debate, the latest Intergovernmental Panel on Climate Change (IPCC) report adopted a consistent set of terms to convey how much confidence researchers had in their conclusions, ranging from "virtually certain" to "exceptionally unlikely." But climatologist Stephen Schneider of Stanford University and economist John Reilly of the Massachusetts Institute of Technology and his colleagues contend that the IPCC didn't go far enough. In particular, it failed to express the likelihood of predictions that the global temperature would rise by 1.4 to 5.8 degrees Celsius by 2100. That widely quoted range looks like an error bar—a span

HERMANN J. KNIPPERTZ *AP Photo*

MORE TO EXPLORE:
CLIMATE@HOME

Inspired by SETI@home, researchers are calling for volunteers to help simulate the climate. Each participant will download a screensaver that runs a full three-dimensional climate model. Register at www.climateprediction.com

of values with a well-defined probability of encompassing the true value—but it is actually just a grab bag of model results.

"I'm very worried about chicanery," Schneider says. "I'm worried about people grabbing these IPCC numbers and then going out there and saying, 'Oh, it's only going to warm up by one degree,' and somebody else saying 'It's going to warm up by six.'"

Last year Myles R. Allen of the Rutherford Appleton laboratory in Didcot, England, and his colleagues took the first stab at quantifying the probability. They reasoned that the response of the climate to perturbations (such as adding greenhouse gases) is nearly linear, at least over the short haul.

So if models have been less than, say, 10 percent off in the past, they should be less than 10 percent off in the future. By comparing the output of leading models to 20th-century climate records and extrapolating present trends in gas emissions, the researchers calculated a 90 percent chance that the planet will warm by 1.0 to 2.5 degrees C by the 2040s (including the 0.6 ± 0.2 degree of warming over the past century). "We are still not in a position to quantify likelihoods objectively to 2100, because the problem becomes more nonlinear," Allen says, referring to the possibility that new effects could amplify or counteract the warming.

Much the same numerical result emerged from a complementary approach described in the July 20 *Science*. Two teams—Reilly's group and Tom M. L. Wigley of the National Center for Atmospheric Research and Sarah C. B. Raper of the University of East Anglia—systematically varied parameters in simplified climate models. Unlike the historical approach, this method could evaluate the probability of effects that haven't yet manifested themselves. On the other hand, the simplified models might omit something crucial. They are used because full-blown models are too computationally intensive, a limitation that researchers are now working to overcome.

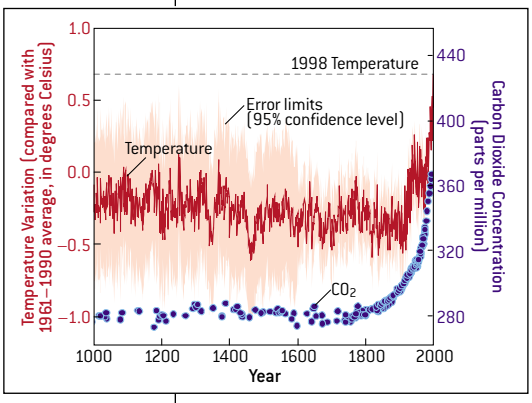
These quantitative analyses transform the yes-no debate over global warming into an actuarial decision: probability times expected damage equals how much we should spend now on mitigation. But putting that principle into practice might require changes to Kyoto. The protocol does not specify how much money nations should pay to limit gas emissions.

That brings up the other great uncertainty about climate change: the economics. Although Kyoto explicitly aims to minimize the burden of emissions control by using market-based incentives rather than government intervention, nobody knows for sure how much curtailing greenhouse gas production will cost. It could yield a net benefit (for example, by improving energy efficiency), or it could stop the economy cold.

Yet prominent critics of the protocol—notably economist William Pizer of Resources for the Future, a Washington think tank, and political scientist David G. Victor of the Council on Foreign Relations—have argued that the best response isn't to deep-six Kyoto but to add a safety valve. If emissions reductions ever got too expensive, governments would allow companies to emit more carbon dioxide by paying a flat rate per ton. That idea gives environmentalists the shivers, but by making nations more willing to participate, it may well clear the way for deeper reductions.

Last year climatologist James E. Hansen of the NASA Goddard Institute for Space Studies and his colleagues championed another way to cut costs: shift the onus from carbon dioxide to other heat trappers, such as methane, that are more potent, more threatening to local air quality and less crucial to economic activity. Kyoto already puts more weight on methane than on carbon dioxide, but is that enough? As economists Alan S. Manne of Stanford and Richard G. Richels of the Electric Power Research Institute discuss in the April 5 *Nature*, it isn't an either-or question. Even though carbon dioxide is less insulating than methane, it stays in the atmosphere longer, so we may want to get cracking on it right away. Reilly, who has done similar work, agrees: "We can save methane abatement until we need a quick, short-term fix."

The tragedy is that President Bush's outright dismissal of Kyoto has so alienated other countries that it would be hard to muster support for modifying the protocol. "If the administration knew what it wanted to do, then the time to build a coalition in favor of that would have been before Bonn," Victor says. "The U.S. blew an opportunity."



WARMEST DECADE of the millennium was the 1990s, researchers now say with a fairly high degree of confidence, based on direct and indirect temperature readings (*red*). Scientists also say with the same degree of confidence that carbon dioxide levels, measured in ice cores (*blue*), are the highest in 20 million years.

JOHNNY JOHNSON, SOURCE: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

SKEPTICISM

ABOUT SKEPTICS

Many conservatives regard the "scientific consensus" about global warming as a media concoction. After all, didn't 17,100 skeptical scientists sign a petition circulated in 1998 by the Oregon Institute of Science and Medicine? (See www.oism.org/pproject and www.prwatch.org/improp/oism.html on the World Wide Web.)

SCIENTIFIC AMERICAN took a random sample of 30 of the 1,400 signatories claiming to hold a Ph.D. in a climate-related science. Of the 26 we were able to identify in various databases, 11 said they still agreed with the petition—one was an active climate researcher, two others had relevant expertise, and eight signed based on an informal evaluation. Six said they would not sign the petition today, three did not remember any such petition, one had died, and five did not answer repeated messages. Crudely extrapolating, the petition supporters include a core of about 200 climate researchers—a respectable number, though rather a small fraction of the climatological community.

MEDICINE

All in the Mind

FACT OR ARTIFACT? THE PLACEBO EFFECT MAY BE A LITTLE OF BOTH **BY W. WAYT GIBBS**

Facts are only facts until they are not, especially in medicine. That people who suffer from all sorts of illnesses generally improve when they get a sham treatment has been a fact since at least 1955. That year Henry K. Beecher published a study called "The Powerful Placebo" in the *Journal of the American Medical Association*. Reviewing 15 clinical trials, Beecher claimed that on average about one out of three patients found relief from placebos alone. Although some specialists have challenged the placebo effect for years, in the minds of most physicians and in the public consciousness, it remained a fact—until this past May.

That's when Peter Gøtzsche and Asbjørn Hróbjartsson of the University of Copenhagen concluded in the *New England Journal of Medicine* that "there is no justification for the use of placebos" in medical practice. They had pooled data from 114 previously published clinical trials that compared patients who received placebos with those who got no treatment whatsoever. Sifting the numbers through statistical sieves, the doctors found no significant overall difference in how the two groups fared. The media responded to the Danish study by gleefully vivisecting the placebo effect. "It's a scam," sneered the *Boston Globe*. "More myth than science," pronounced the *New York Times*. Within several weeks, a new medical fact was born: placebos don't do diddly.

Most likely, both facts are wrong. People who participate in clinical trials often get better (or seem to) regardless of whether they receive experimental therapy, dummy treatment or nothing at all, for numerous reasons. But there are also good reasons to doubt the new charge that placebos are worthless.

"Their own data show that placebo is significantly better for pain than no treatment is," observes Walter A. Brown, a psychiatrist at Brown University. That result seems credible, because 27 of the 114 trials measured the effect on pain. But the remaining trials lumped into the analysis looked at 39 other maladies, ranging from infertility and compulsive nail biting to marital discord, orgasmic difficulties and fecal soiling. For each of these problems the number of patients was too small to allow any firm conclusion except that placebos do much more for some illnesses than for others. "One placebo cannot be more effective than another unless placebos are capable of producing an effect," argues Irving Kirsch, a psychologist at the University of Connecticut. "It makes no sense to evaluate the magnitude of the placebo effect in general," he says. And Brown agrees: "If you tested penicillin on 40 different clinical conditions, you would get similar results: it works for some infections, but it won't do anything for arthritis."

Other meta-analyses have shown measurable placebo effects for depression, asthma and phobic anxiety, Kirsch points out. Parkinson's disease now joins that list. In mid-August, A. Jon Stoessl and his co-workers at the University of British Columbia in Vancouver reported in *Science* that they could see the effect of placebo treatment in brain scans of people with Parkinson's disease.

The neurologists used positron emission tomography (PET) to estimate dopamine activity inside the diseased part of six patients' brains after they were injected with either inactive saline solution or apomorphine, a drug that mimics dopamine. When the subjects were given a placebo shot, their brains released as much dopamine (which is suppressed in Parkinson's disease) as when they got active drugs, Stoessl says. This is one of very few studies ever to look beyond *whether* a placebo works to *how* it works. Until many more like it are done, the placebo effect will remain a mystery—and that's a fact.

BRYAN MULLENNIX *Stone*

ILLUSORY EFFECTS

Measuring the placebo effect is difficult because research subjects often get better on their own, for several reasons:

Natural course of the disease
Humans heal and crises pass, so some symptoms tend to clear up spontaneously, regardless of treatment.

Reversion to the mean
People tend to see doctors—and enroll in studies—when ailments are most acute. A return to average can look like an improvement.

Stress of the unfamiliar
As subjects become more familiar with their new physicians and tests, they may feel better simply because they are less anxious.

The attention effect
Knowing that their condition is closely monitored, patients frequently take better care of themselves than they normally would.

SOFTWARE

Symmetry Breaking

A LEGAL JOB IN ONE COUNTRY IS GROUNDS FOR ARREST IN ANOTHER **BY PAUL WALLICH**

Imagine Carl Djerassi, inventor of the birth-control pill, arrested at an endocrinology conference in Japan during the decades before 1999, when oral contraceptives were illegal there. Or an engineer for Smith & Wesson facing jail in Washington, D.C., where most traffic in handguns is outlawed. Absurd scenarios? Not to Russian cryptographer Dmitry Sklyarov, who spent three weeks this summer shuttling from Las Vegas to Oklahoma City to San Jose in federal custody after his arrest on charges of trafficking in "circumvention devices" inimical to the interests of U.S. copyright holders.

Sklyarov's crime? Writing a program that his employer, the Moscow software company ElcomSoft, briefly sold to American customers via two U.S. Internet companies. The software removes cryptographic protection from electronic books produced by Adobe Systems so that people who have purchased the eBooks can make backup copies of them, transfer their eBooks to another computer, or feed their content into text-to-speech software for the blind. Oh, and make illegal copies.

Sklyarov's research and software writing were perfectly legal in Russia but not in the U.S., where he came to give a talk at a security conference. The arrest helps to explain why several computer-security organizations have moved workshops and other events originally scheduled to be held in the U.S. to other locations. Although the Digital Millennium Copyright Act ostensibly omits researchers from its grasp, any researcher whose work produces a marketable product could be at risk.

What makes the case even stranger from the Internet watcher's point of view is a bizarre symmetry between ElcomSoft's product and Adobe's. In the U.S., making or selling a circumvention device is illegal, but in Russia the law forbids interfering with the rights of software purchasers to make backups, move programs from one computer to another, or modify them to work with text-to-speech programs. Such a "clear violation of customer rights," says Mikhail Genin, counsel for high-tech publisher CompuTerra and a specialist in computer-related law in Russia, would be grounds for a class-action suit against the eBook seller or Adobe itself. "The chances of winning such a case are very high," he states. And while the suit was getting under way, the Customer's Right Protection Organization or the State Anti-Monopolist Committee—Russian government bodies—would most likely take steps to prevent further sales until the software complied with the law.

The European Union's Copyright Directive, says law professor Bernt Hugenholtz of the University of Amsterdam, provides similar rights for users, and so circumvention tools would be legal there, too. Hugenholtz predicts that a legal challenge to software that prevented legitimate copying would succeed, albeit under consumer-protection statutes rather than the copyright law: "It's like selling a car that can't shift into reverse."

In the U.S., however, the law upholds whatever cryptographic locks eBook and software publishers put on their products. Pamela Samuelson, a professor of law at the University of California at Berkeley, explains that archiving and fair-use rights (including those protecting the making of copies and excerpts for educational or critical purposes) can let you escape liability if you're sued for copyright infringement, but courts consider the rights more as privileges than as rights that can be actively enforced.

In the absence of circumvention tools, the final arbiter of what a purchaser can do is the program code that Adobe and other companies employ to protect their interests. And, as cyberlawyer Lawrence Lessig of Stanford University points out, while courts must consider claims of fair use, program code doesn't even recognize its existence.

Paul Wallich is a contributing editor.

BEN MARGOT AP Photo

SUPPORTERS OF DMITRY SKLYAROV, arrested Russian programmer, rallied in front of the Phillip Burton Federal Building in San Francisco this past July 30. Sklyarov was later freed on bail.

CODE VIOLATIONS' STIFF PENALTIES

In 1998 Congress passed the Digital Millennium Copyright Act. It not only reinforces the fact that pirating software, DVDs and other copyrighted works is illegal but also—unlike the antipirating laws in other nations—sanctions up to five years of jail time and a fine of up to $500,000 for anyone who sells hardware or software that defeats technology meant to prevent unauthorized copying (such as encryption). Second-time offenders risk 10 years of prison and a $1-million fine.

CONSERVATION

Sound Judgments

WILL A POWERFUL NEW NAVY SONAR HARM WHALES? **BY WENDY WILLIAMS**

The beaching of some 14 Cuvier's beaked whales in the Bahamas in March 2000 brought to critical mass a long-seething controversy. At least eight of the whales died, and the cause of death for many was cranial hemorrhaging, probably from exposure to intense sound waves. After investigating, the U.S. Navy took responsibility. "In fact, there was some cause and effect" between the deaths and the navy's sonar, said Admiral William J. Fallon, vice chief of naval operations, in a congressional hearing on May 9.

BEACHED WHALE in the Bahamas is examined by David Ellifrit of the Center for Whale Research. The whale probably died as a result of sonar from naval antisubmarine exercises.

DIANE CLARIDGE *AP Photo*

The incident couldn't have come at a worse time for the navy, which is struggling to gain public acceptance of its new low-frequency active (LFA) sonar. For decades, the navy has relied mainly on passive sonar, or simple listening with hydrophones, which could detect sound generated by a ship's boiler or even by pots and pans from the galley.

But by the 1980s the Soviet Union had built up a fleet of superquiet nuclear-powered submarines for which passive sonar proved inadequate. Midfrequency active sonar—the classic "pinging" of World War II submarine movies—wasn't an option, either, because it required targets to be close to the source: midfrequency sounds (between one and 10 kilohertz) attenuate quickly in water. But low-frequency sound (below about one kilohertz) travels more efficiently, enabling the LFA sonar, according to a navy official, to detect targets "an order of magnitude"—at least 10 times—farther away.

The current version of LFA sonar consists of sound projectors placed 300 to 500 feet deep. Lasting from six to 100 seconds and interspersed with somewhat longer periods of silence, the tones are emitted in the 100- to 500-hertz band. The navy wants to deploy LFA sonar arrays in both the Atlantic and Pacific oceans.

No one doubts that marine mammals will hear the system; sonar arrays can generate sound-pressure levels of up to 230 decibels in water near the source. The argument is over the severity of the animals' response, if any. Some environmentalists claim that LFA sonar will interfere with whales that use the same frequency bands. The Natural Resources Defense Council has circulated a petition among scientists, sponsored by board member and noted ecologist George M. Woodwell, calling for global efforts to control undersea noise in general—and for an end to LFA in particular. (Woodwell admits, though, that he knows little about the LFA system itself.)

Whale biologist Kenneth C. Balcomb of the Center for Whale Research in Friday Harbor, Wash., who tried to rescue a few of the Bahamian whales, says that the pressure of the low-frequency waves will cause the organs of certain animals to resonate. Commenting on the navy's environmental impact statement, Balcomb noted that there are several examples of "hemorrhagic injuries and death occurring in humans when they are inadvertently exposed to loud sound."

But extrapolating the human experience to undersea life is an unsubstantiated jump, many scientists argue. They add that the strandings in the Bahamas involved mid- rather than low-frequency sonar: the navy was conducting exercises in the area with sonar buoys and says that the only extant LFA was in Hawaii at the time and was not being used. And besides, low-frequency sound occurs quite regularly in the oceans because of landslides, earthquakes, lightning strikes and other events. Biologist Roger Payne of the Whale Conservation Institute, who discovered the "song" of the humpback in the early 1970s, believes the whales must have evolved a way to filter out unwanted sound, much as we can block out background conversations in a restaurant.

As for the beached beaked whales, their deaths may be more of an isolated incident than a portent of things to come. Harvard University biologist Darlene Ketten, who has

NEED TO KNOW: THE NOISY SEAS

Amid the cacophony over navy sonar lies a bigger problem: background noise in the ocean may have risen by as much as 10 decibels over the past 50 years, thanks largely to shipping and seismic exploration. "There are highways across the ocean that are just glowing with noise," says Cornell University biologist Christopher Clark. Little definitive science exists on how—or even whether—ambient noise bothers marine mammals. So far the results have been bewilderingly inconclusive; sometimes whales shifted their paths away from sound sources by a few hundred yards, and sometimes they did not. Part of the problem is that humans don't fully grasp the scale of the whale habitat: a herd of humpbacks might stretch for hundreds of miles.

studied the Bahamian incident, concludes that the animals appear to have been caught in a sound duct created by "physical parameters that were seasonal." Moreover, the whales were swimming in a canyon, which helped to create "an unusually intense sound field" during the naval exercises, Ketten says. "To say that a different sonar is going to impact other animals in the same way is going way off on a limb. Sonars have been around for decades."

Wendy Williams writes on ecology and conservation from Mashpee, Mass.

ASTRONOMY

Catching Some Sun

THE GENESIS SPACECRAFT WILL RETURN WITH A PIECE OF SOL **BY STEVEN ASHLEY**

Sometime late this month a robotic deep-space probe will begin gathering up bits of the sun—specifically, the solar wind. Twenty-nine months afterward NASA's Genesis spacecraft will begin the long trip back home bearing a precious hoard of pristine solar-wind samples weighing no more than a few grains of salt. On arrival in Earth's atmosphere in April 2004, the spacecraft's 210-kilogram return capsule and its fragile cargo will ride the winds on a special high-lift parachute to a dramatic midair capture by helicopter over the Utah desert. The specimens will be the first extraterrestrial material collected from beyond the orbit of the moon.

Solar wind consists of invisible charged particles ejected from the sun's surface at high velocities. Whereas the sun's interior has been modified by nuclear reactions, the outer layers are thought to be composed of the same material as the original solar nebula, the cloud of interstellar gas and dust that gave rise to the solar system some 4.6 billion years ago. Prospecting the sun's surface is impossible, so the next best thing is to collect material flung out from its hot, turbulent exterior.

The ideal place to accomplish this task is way out beyond Earth's magnetic field, which deflects the solar wind away from its environs. The most stable location for collection is one million miles away, where the sun's and Earth's gravities are balanced—the so-called Lagrangian sun-Earth libration (L1) point. Once in position, Genesis will uncover its collectors. Of greatest interest to researchers are the elemental and isotopic oxygen, nitrogen, carbon and noble-gas components of the solar wind. When they are brought to Earth, the samples—about 10 to 20 micrograms' worth—will be analyzed, stored and catalogued in ultraclean rooms.

In addition to determining the makeup of the solar nebula, the $209-million Genesis mission is expected to reveal how the terrestrial planets came to be, notes Donald Burnett, the mission's principal investigator and a professor of geochemistry at the California Institute of Technology. "There are unexplained variations in the isotopic composition of oxygen within the inner solar system from which we have specimens—Earth, the moon, Martian meteorites and meteoritic samples of the asteroid belt," he says. Hence, scientists are unsure whether the terrestrial planets formed primarily from the dust of the primordial solar nebula or whether they evolved from a mixture of its gas and dust.

Genesis should help answer that fundamental question and others. Says Chester Sasaki, Genesis project manager at the Jet Propulsion Laboratory in Pasadena, Calif.: "This mission will be the Rosetta stone of planetary science data."

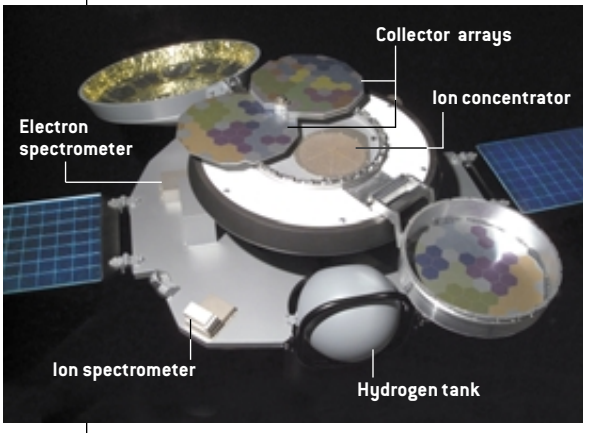
THE SOLAR PROSPECTING KIT

The Genesis probe (*shown at right in model form*) has several main scientific instruments:

Solar-wind collector arrays, which are the size of bicycle tires and reside on an apparatus that resembles a compact-disc changer. Each array is a stable grid supporting hexagonal wafers of superpure silicon, germanium, industrial diamond and sapphire coated variously with gold, silicon and aluminum.

Ion and electron spectrometers, which characterize the various solar-wind "regimes" by recording the speed, density, temperature and approximate composition of the charged elemental particles and the electrons that accompany them.

Ion concentrator, an "electrostatic mirror" that uses high voltages to separate out and focus charged ionic elements such as oxygen onto a special collector tile of high-purity diamond and silicon carbide ceramic.



NASA/JPL

Magnetic Revelations

FUNCTIONAL MRI HIGHLIGHTS NEURONS *RECEIVING* SIGNALS BY GRAHAM P. COLLINS

We've all seen the images: a grainy picture of the brain's contours with one or two areas lit up, supposedly indicating the regions that are active while the subject carries out a specific task. First developed about a decade ago, functional magnetic resonance imaging (fMRI) has become the leading research tool for mapping brain activity. The technique works by detecting the levels of oxygen in the blood, point by point, throughout the brain. Until now, however, there has been no proof that those oxygen levels truly correspond to neurons getting busy. Researchers at the Max Planck Institute for Biological Cybernetics in Tübingen, Germany, have now supplied that proof, and in addition they have shown that the fMRI signal largely comes about when neurons are receiving input and depends less on whether they are sending out signals.

The Tübingen group, led by Nikos K. Logothetis, monitored the electrical activity of neurons directly through implanted electrodes while simultaneously taking fMRI scans. That is no easy task: MRI uses pulses of radio waves and a very strong, changing magnetic field, both of which interfere severely with nearby circuitry. The group built special devices to sense and compensate for some of the interference; computer processing filtered out what remained.

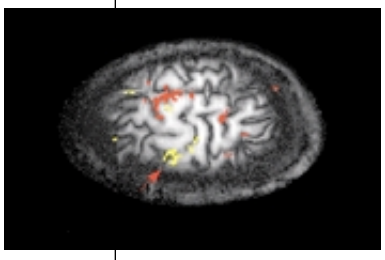
The team worked with macaque monkeys. Each monkey looked at a rotating checkerboard pattern, which activated the monkey's primary visual cortex. The researchers compared the fMRI signal with two different types of electrical signal. One, called the local field potential, corresponds to signals being input to the region by other neurons and to signals of the local neurons interacting among themselves. The other type, action potentials, reflects the characteristic spikes, or pulses, emitted as the output from the region. Both signals turned on in the visual cortex a fraction of a second after the visual stimulus began. The fMRI signal, in contrast, took a few seconds to grow to a significant level. The local field potential and the fMRI signal always remained strong until the visual stimulus was turned off. In contrast, the action potential, which was always less intense than the local field potential, often fell back essentially to zero after a few seconds, even if the visual stimulus was still on. In short, the fMRI signal depended mostly on the local field potential but responded slowly.

The fMRI scans used in this experiment are more specifically called BOLD fMRI, for "blood oxygen level dependent." The subtle magnetic difference between oxygenated and deoxygenated hemoglobin produces the signal and implies an excess of oxygen there, thanks to increased blood flow. Curiously, the heightened neural activity uses only a very small amount of this extra oxygen (if the oxygen were used up, it would not show up in the BOLD signal). Marcus E. Raichle, a brain-scan expert at Washington University, points to other research that suggests that neural activity associated with signal inputs burns glucose without using oxygen. This anaerobic activity may power the recycling of the neurotransmitter glutamate.

Another significant finding by Logothetis and his co-workers is that the fMRI signal is much weaker, relative to noise, than the corresponding electrical activity. Consequently, an fMRI scan might not indicate areas that are only moderately active.

Nora Volkow, a neuroscientist at Brookhaven National Laboratory, says the research addresses a question "that is very basic for all the work that is done right now using functional MRI." It is the first unequivocal demonstration that the signal that "everybody measures to understand how the brain works with fMRI in fact reflects neuronal activity."

Much more work lies ahead to determine what neural activities produce what fMRI signals (or not) in all situations. For example, the monkeys in the experiments were unconscious—the visual cortex processes what the eyes see even in such anesthetized animals (or people). Conscious animals might produce different results. Logothetis says his longer-term goal is to develop imaging systems that look not at oxygen levels but at other molecules whose concentrations may be more directly related to electrical neural activity.



REGIONS LIGHT UP with extra oxygen when a subject moves fingers (*yellow*) or toes (*red*). Researchers have now verified that this MRI signal reflects active neurons, not just enhanced blood flow.

SEONG-GI KIM AND KAMIL UGURBIL *University of Minnesota*

news SCAN

WHEN THE BRAIN GOES TO WORK

Over the years, scanning technology has pinpointed areas of the brain that are active during different tasks. Among the most recent findings from functional magnetic resonance imaging are:

- **When people try to do two dissimilar mental tasks at once, such as comprehending speech and visualizing an object rotating in space, the amount of brain activity devoted to each task is less than if the tasks were tackled separately—so rules against using a cell phone while driving have a neurological basis.**
- **When listening to music, musicians make greater use of a region associated with language processing than do nonmusicians.**
- **The lateral occipital complex, involved in object recognition, responds to the overall shapes of objects rather than to individual elements of the shapes.**

DATA POINTS: CONCEIVED

Fifty years ago, on October 15, 1951, Carl Djerassi and his colleagues at Syntex, a small pharmaceutical firm in Mexico City, created the first oral contraceptive: a steroid called 19-nor-17α- ethynyltestosterone, or norethindrone. Other formulations now exist, but all work in the same way: by tricking the body into thinking it is pregnant. Since its FDA approval in May 1960, the Pill has become the most popular form of reversible birth control in the U.S.

- **Percent of women born after 1945 who have used the Pill: 80%**
- **Pregnancy rate from using:**
  - **Diaphragm/spermicide: 20%**
  - **Condom: 14%**
  - **The Pill, when used correctly: < 5%**
- **Percent of women on the Pill using it correctly: 28%**
- **Odds of pregnancy with no contraception: 85%**

SOURCES: Planned Parenthood; U.S. Food and Drug Administration; This Man's Pill, by Carl Djerassi (Oxford University Press, 2001)

AIDS VIRUS breaks out of a cell to infect other cells.

BIOLOGY

A Bad Raft for HIV

HIV rides out of infected cells on so-called lipid rafts—rigid parts of a cell's membrane that are high in cholesterol. Now researchers have found that HIV also needs the fat to infect cells. Removing the cholesterol from the raft evidently disrupts the receptors in the raft that HIV needs to infect cells. Of course, removing the body's cholesterol does not constitute a treatment for any disease, but a cream containing the cholesterol stripper could prevent viral transmission during sex. In preliminary experiments with mice published in the July 20 *AIDS Research and Human Retroviruses*, such a chemical condom reduced vaginal HIV transmission by about 90 percent. A better model than mice may soon be transgenic rats. Researchers from the University of Maryland have engineered rodents to contain the genome of HIV-1. Unlike mice, these rats produce viral RNA and proteins in the same organs as humans and exhibit a similar immune response. Moreover, the rats are larger than the mice, making tissue and organ sampling easier. The work appears in the July 31 *Proceedings of the National Academy of Sciences*. —*Diane Martindale*

PHYSICS

A Warmer Superconductor?

One of the foremost challenges of modern physics is to create a superconductor that operates closer to room temperature. Thus far the warmest are copper oxide superconductors, which work at a chilly –109 degrees Celsius at best. Chemists Roald Hoffmann and Wojciech Grochala of Cornell University suggest that fluoroargentates, materials that contain fluorine and silver, could be the medium to heat things up, although the researchers don't predict by how much. The theorists base their idea in part on the similarity of fluoroargentates to copper oxides. Scientists have already begun the formidable task of producing fluoroargentates, which are highly unstable. If correct, Hoffmann and Grochala's theory—presented in the August 3 German journal *Angewandte Chemie*—would represent perhaps the only instance of a prediction preceding the discovery of a high-temperature material. —*Alison McCook*

CHILLED OUT: Conventional superconducting magnets float next to another magnet.

GENETICS

Genes Are Not Enough

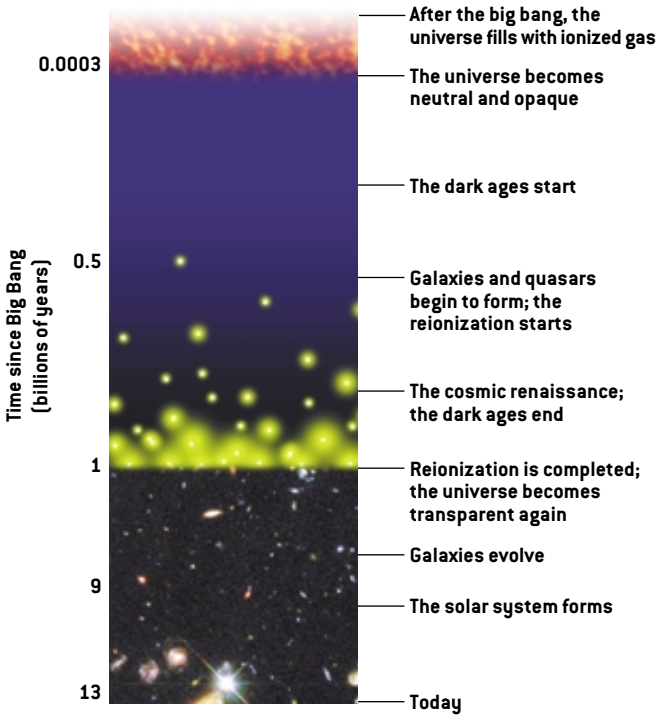
Switching genes on and off sometimes depends on the addition of molecules called methyl groups to DNA. Researchers have now found a second methylation switch. This one is located on histones—proteins once thought to merely package DNA into a structure called chromatin. In fact, chemical modification of histones seems to act as a master switch that is able to turn large stretches of the genome on or off and override DNA methylation. Figuring out when methylation of histones takes place has far-reaching implications; acting as a second genetic code, histone methylation may determine genetic traits such as susceptibility to disease. The findings were published in a series of papers in the August 10 *Science*. —*Diane Martindale*

C. DAUGUET AND C. EDELMANN *Petit Format/Photo Researchers, Inc. (top)*; CHARLES O'REAR *Corbis (bottom)*; ILLUSTRATION BY MATT COLLINS

COSMOLOGY

Burning through the Fog

Two new observations, announced independently within days of each other, may shed light on what astronomers call the cosmic dark ages—the era before the first stars and quasars began to light up the universe—and the cosmic renaissance that followed. The two teams say they have detected a set of characteristic features, called the Gunn-Peterson effect, in the spectra of two distant quasars. Predicted in 1965 but until now never observed, the Gunn-Peterson effect marks the detection of an important change in the early history of the universe. For the first 300,000 years after the big bang, ionized gas filled the universe. Then it cooled enough for protons and electrons to combine into hydrogen. These neutral hydrogen atoms, which absorb light energy, shrouded the universe until about 900 million years after the big bang. Then the hydrogen became ionized again, perhaps by the energy of ultraviolet radiation, allowing light from new stars and quasars to stream across the cosmos.



One team used the Keck Telescope and the Sloan Digital Sky Survey, a census of 200 million celestial objects (see arXiv.org/abs/astro-ph/0108097). The other team also used Keck (see arXiv.org/abs/astro-ph/0108069).

—Mariette DiChristina

CIVIL ENGINEERING

Road Rage

To engineer a quieter, gentler nation, scientists at Purdue University are attempting to reduce the impact of one of the largest sources of noise on our highways: tires. The vibrations resulting when tire meets asphalt cause the sound, but not all sections of a tire vibrate the same way. The Purdue researchers have designed a mathematical model that indicates the region of the tire from which each vibration originates, in effect fingerprinting a tire's sound profile. The logic: determine the noisiest areas of a tire, and you're one step closer to creating a quieter one. So far the model represents only the tire tread band (consisting of the reinforcing belts and tread pattern); the researchers are working on a more accurate model that incorporates the three-dimensional shape of a tire. They presented their work on August 27 at the Internoise 2001 meeting in the Hague, the Netherlands.

—Alison McCook

BANE OF THE HIGHWAY: New analyses could make for a quieter tire.

WWW.SCIAM.COM/NEWS
BRIEF BITS

- In mouse cells, two old malarial drugs show promise as treatments for prion diseases—fatal, brain-wasting conditions such as Creutzfeldt-Jakob disease. Human clinical trials are to begin this fall. /081401/1.html
- Some 51 light-years away lies an extrasolar system similar to our own: a yellow star in Ursa Major has a Jupiter-size planet orbiting it at a distance comparable to that of Jupiter from our sun. /081701/2.html
- Physicists have imaged objects with antimatter—specifically, positrons; scanning positron microscopes reveal certain details hidden to more conventional electron microscopes. /080101/2.html
- Juggling several different projects at once may be necessary, but such multitasking diminishes productivity because the mind needs time to shift its focus from one activity to the next. /080701/1.html

S. G. DJORGOVSKI ET AL. AND DIGITAL MEDIA CENTER *Caltech* (*top*); MICHAEL BANKS *Stone* (*bottom*)

BY THE NUMBERS

Can't Read, Can't Count

UP TO ONE THIRD OF AMERICAN HIGH SCHOOL SENIORS AREN'T READY FOR THE REAL WORLD **BY RODGER DOYLE**

MODERN-DAY SURVIVAL SKILLS

The National Assessment of Educational Progress categorizes mathematics and reading competency for high school seniors in three achievement levels.

Mathematics ability as defined by the *Nation's Report Card: Mathematics 2000*, August 2001:

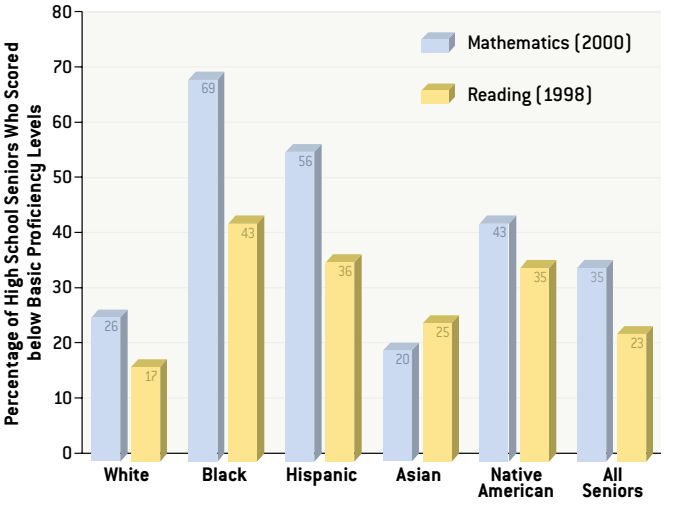
- **Basic: "Demonstrate procedural and conceptual knowledge in solving problems" in five subject areas: number sense, properties and operations; measurement; geometry and spatial sense; data analysis, statistics, and probability; and algebra and functions. (48% of students fall into this category)**
- **Proficient: "Consistently integrate mathematical concepts and procedures into the solutions of more complex problems" in the five subject areas. (14%)**
- **Advanced: "Consistently demonstrate the integration of procedural and conceptual knowledge and the synthesis of ideas" in the five subject areas. (2%)**

Reading skills as defined by the *1998 Reading Report Card*, March 1999:

- **Basic: "Partial mastery of prerequisite knowledge and skills that are fundamental for proficient [schoolwork]." (37%)**
- **Proficient: "Solid academic performance [with] demonstrated competency over challenging subject matter, including subject-matter knowledge, application of such knowledge to real-world situations, and analytical skills appropriate to the subject matter." (35%)**
- **Advanced: "Superior performance." (6%)**

For years, we have heard that Europeans and the Japanese so outshine Americans educationally that U.S. economic and technological dominance is threatened. But such pronouncements are dubious for several reasons, including the technical difficulty of making valid comparisons between Americans and others whose cultures and circumstances differ markedly.

In the hullabaloo over the supposed educational inferiority of the U.S., another, better-documented problem has suffered comparative neglect: the failure of a large number of high school students to acquire the rudimentary skills needed for economic survival in today's world. The chart, which highlights findings from the U.S. Department of Education test on mathematics issued in August, shows that more than one third of all high school seniors and more than two thirds of black seniors don't have even a basic competency in mathematics. This means, for example, that they don't understand elementary algebra, have little conception of probability and can't make simple measurements of the kind required of a beginning carpenter.



SOURCE: U.S. Department of Education, National Center for Education Statistics. The data for whites exclude white Hispanics; Asians include Pacific Islanders.

A similar Department of Education study on reading showed that 23 percent of high school seniors tested in 1998 lacked rudimentary reading skills. These students could sign their name and read road signs, but they had difficulty with such tasks as filling out a 1040EZ tax form or comprehending a relatively simple passage from a book.

Other studies have shown that many students lack a basic knowledge of science, history and geography. But the poor math and reading skills are most troubling, for a grasp of these subjects is essential to participating in an information-based economy. High school graduates can function in today's job market even if they hold nonscientific notions such as creationism or don't know the difference between Lyndon Johnson and Andrew Johnson, but without math and reading skills, they are at an immense disadvantage.

Although the tests of math and reading ability conducted by the Department of Education do not directly measure the ability of 12th-graders to function in adult jobs, they clearly indicate that a substantial minority of students are unprepared to hold them. This conclusion is consistent with a 1999 study by the American Management Association, which found that more than 38 percent of job applicants tested for basic skills were deficient in reading, writing or math and hence unlikely to be hired. Lack of basic skills portends higher unemployment and lower pay, probably retards overall productivity growth of the U.S. economy and almost certainly is a major contributor to poverty. In the 1980s the proportion of high school seniors without basic skills declined, particularly among blacks and Hispanics, but in the 1990s there was no substantial progress among white, black or Hispanic students.

Rodger Doyle can be reached at rdoyle2@adelphia.net

RODGER DOYLE

Tobacco Pharming

A quest to turn the killer crop into a treatment for cancer

By TABITHA M. POWLEDGE

NICOTIANA BENTHAMIANA, a tobacco plant, serves as a biofactory for producing antibodies against cancer.

MICHAEL MULLICAN

A small California biotechnology company with the big name of Large Scale Biology Corporation (LSBC) wants to convert a system for producing death and disease into a system for preserving life and health. It is trying to use tobacco not to make cigarettes and promote lung disease but to create medicines and cure cancer.

LSBC is different from other biotech companies that pursue pharming—the genetic engineering of animals and plants to turn them into production systems for medically valuable molecules. Unlike other pharmers, LSBC has shunned permanent genetic modification of plants or animals. Instead the company inserts genes that make a therapeutic protein into the tobacco mosaic virus (TMV). It then infects tobacco with the transgenic virus and gets the virus-plant combination to serve as a temporary factory for churning out the desired molecule, which is then extracted from chopped-up plants and purified.

LSBC hopes that its first success will be using this biofactory to produce a vaccine that prevents recurrence of non-Hodgkin's lymphoma (NHL). A cancer of the lymph system, NHL accounts for 4 percent of all diagnosed malignancies and more than 4 percent of cancer deaths and is one of the few cancers increasing in incidence; no one knows why.

Work on the lymphoma vaccine began after Daniel Tusé joined the company in 1995 as vice president of pharmaceutical development. At that time, LSBC's story was typical for the biotech industry: it was taking much longer to make a salable product than anybody had planned. Tusé looked for a project that could demonstrate the efficacy of the TMV technology while quickly filling a real medical need.

At the time, antibodies, the body's major combatants in fighting disease, looked intriguing. They are big, complicated proteins, but the business ends that make an antibody specific to its target are on the tips of a Y-shaped structure. For therapeutic purposes, most of the protein molecule can be jettisoned and the remaining two ends connected by a linker of 10 to 20 amino acids. This process yields a small protein called a single-chain antibody fragment and is much simpler than making the whole antibody. LSBC had successfully produced single-chain antibodies with its TMV system, and Tusé hired pharmacologist Alison McCormick to investigate their medical potential.

The two went to see Ronald Levy, a world-renowned cancer researcher at Stanford University. Levy had been looking for a single-chain antibody fragment vaccine against non-Hodgkin's lymphoma that would stimulate a recovering patient's immune system to recognize and then zap new tumor cells.

Unlike many cancers, NHL tumors are immunologically unique in each patient. A one-size-fits-all vaccine won't work. A patient needs a vaccine custom-tailored to recognize a particular antigen, the distinctive marker on that person's tumor.

Another unusual feature of NHL is that the antigen is actually an antibody. So a single-chain antibody vaccine does not work as antibodies normally would, by attacking the tumor directly. Instead the vaccine (which is called an anti-idiotype vaccine) imitates the structure of the NHL antigen/antibody, provoking the immune system to make other antibodies against the tumor marker—a defense that works against any lurking tumor cells.

When Levy first heard about therapy from tobacco, he thought it was a pipe dream—and he said so. When Tusé and McCormick told him that they could produce antibody fragments in just a few weeks, he said frankly that he didn't believe it. Levy challenged the LSBC staffers to prove their claim, using the well-established mouse model of lymphoma as a test case.

McCormick took the antibody fragment gene from a standard mouse lymphoma cell line, inserted it into TMV, infected the plants and in just three weeks presented Levy with the working single-chain antibodies. Four weeks later the infected tobacco had produced enough antibody for testing in lymphoma-prone mice. Working in Levy's lab, McCormick showed that the protein induced an immune response just like a vaccine and protected the animals against the tumor. A paper describing the mouse experiment appeared in 1999 in the *Proceedings of the National Academy of Sciences*.

Even after the paper was published, Levy remained skeptical. "Maybe you got lucky," he recalls telling the researchers. "But to do this for patients in a clinical trial, you're going to have to do this repetitively and do it for many and you're going to have to have a high throughput." LSBC did those things, too, though not so smoothly. When the company first put genes from Levy's patients into the virus, they didn't make antibodies. The difficulty related to defects in the linker molecule that joins the two antibody fragments. So the researchers decided to create multiple distinct linkers.

The LSBC scientists found that for each patient, they could come up with a unique set of amino acids for linkers that resulted in good proteins. "I was really quite impressed with that, because I didn't think that [the linker] was the problem," Levy says. "But they set up a strategy for generating and rapidly screening all combinations of amino acids in the linkers and solved the problem that way."

Other technical hurdles arose, too, but in 1999 LSBC began to obtain usable antibody yields from more than 90 percent of the patient tumor samples, according to Tusé. During the fall of 2000 they started putting the antibodies through phase I clinical trials to determine safety and dosage levels for humans; testing the vaccine for efficacy in phase II trials might begin as early as next year.

Because every lymphoma vaccine is personalized, LSBC must take a sample from each patient's tumor, extract the antibody gene, insert it into TMV, infect the plant—in this case, a weedy relative of smoking tobacco called *Nicotiana benthamiana*—and produce custom antibodies in small individual batches in a greenhouse. Thus, to carry out safety tests on Levy's 16 patients, LSBC had to produce 16 different vaccines. That may seem cumbersome, but it is much less costly and time-consuming than other approaches that have been tried for making NHL vaccines.

Tobacco plants infected with transgenic tobacco mosaic virus produce custom antibodies in small individual batches.

Even if the vaccine works, that designer approach is not LSBC's only aim. Since 1991 the company has paid farmers around Owensboro, Ky., to grow many acres of tobacco that is infected with TMV carrying all kinds of genes that may produce therapeutic proteins. McCormick thinks that the single-chain antibodies can be adapted easily to one-size-fits-all therapies, perhaps against cancers of the pancreas, colon and other organs.

The viral pharming system has safety features that make it different from methods used to produce plants by genetic engineering. The virus is unlikely to spread because local farmers who supply the tobacco companies grow varieties resistant to TMV. Also, the virus can infect plants only through mechanical injury to the leaves, so transmission can be prevented by washing down farm machinery with bleach. (The plant viruses do not infect humans.) Moreover, the genetic alterations are transient. They affect only the tobacco mosaic virus, not the DNA of the plant itself. Now that supposed defect may be an advantage. The transgenic virus is not liable to persist and spread, even in field-grown tobacco.

Whether the lymphoma vaccine passes clinical trials remains to be seen. But LSBC has already proved that with the help of a viral pest, tobacco plants can be converted into machines for churning out potentially useful medical compounds. SA

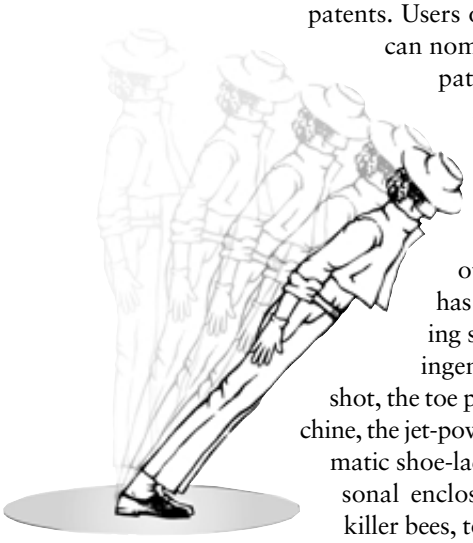
Tabitha M. Powledge is a freelance science journalist who writes mostly about genetics, neuroscience and science policy.

Patently Bizarre

Eccentric inventions may not make their owners rich. But the Gallery of Obscure Patents ensures that the best of the weird will not be forgotten By GARY STIX

Tom Griffin develops new products for Delphion, a top Web-based patent database company that is a spin-off from IBM. Every few weeks, though, he takes a little time off to don another hat as the curator of the Gallery of Obscure Patents, one of the world's leading pantheons of outlandish intellectual property.

Griffin's second job requires him to sort through the more than 100 nominations every month for unusual patents. Users of the Delphion database can nominate any U.S. or foreign patent to become an exhibit in the gallery, a section of the company's Web site (www.delphion.com/gallery). So Griffin—aided by the opinions of other Delphion staffers—has had a hand in immortalizing such testaments to human ingenuity as the human slingshot, the toe puppet, the braille slot machine, the jet-powered surfboard, the pneumatic shoe-lacing apparatus and a personal enclosure for protection from killer bees, to name but a few.



PATENT No. 5255452

The gallery got its start in 1997, when IBM made its internal database of 26 years of U.S. patents available for reference on the Web. Griffin and other IBMers who maintained the database conceived of the gallery as a way to get the public interested in the dry subject of patents. As curator, Griffin has attempted to choose patents based on likely general interest, lack of offensiveness and some real-world usefulness—up to a point. (The utility of a Santa Claus detector is open to debate.)

Only about 50 patents have actually made it into the gallery. "Originally, the yield was quite good. The number of usable weird ones was quite high," Griffin says. Now he finds fewer good candidates and many repeat votes. Moreover, patents coming from outside the U.S. seem to lack the same eccentric cast, perhaps because of the absence of a thriving independent inventor community. Most candidates are simply too dull—Griffin is sick of entertaining nominations for new types of golf bags. Some are simply too weird or just in poor taste: an apparatus for keeping a severed animal head alive or a patent for a means of transmitting e-mail messages after the sender has died.

Perhaps the most interesting new exhibit is U.S. Patent No. 5255452: "Method and Means for Creating Anti-Gravity Illusion." The patent outlines how a special pair of shoes attaches to a stage to allow a straight-legged performer to lean over at very sharp angles, seemingly in defiance of gravity. Remember the unnatural tilt of some of Michael Jackson's dance moves? In fact, in addition to making platinum records and building a home zoo, Jackson, along with two of his costume designers, is the holder of this patent.

Of the patents that have made it into the gallery, some have proved more useful than you might think. While on a trip with his family near his childhood hometown in Tennessee, Griffin remembers coming across an amusement area where he found a row of working human slingshots—each seat attached to a pair of bungee cords that propels the user straight up. Daredevils may find the realization of their dreams in human slingshots and jet-powered surfboards. But the usability of at least one other invention (a seeming patent office goof) is much less certain. An antenna that transmits and receives electromagnetic radiation faster than the speed of light may find commercial application only in some alternative universe. Until the advent of *Seinfeld* reruns at hyper light speed, however, the Gallery of Obscure Patents will continue to show the best of the bizarre that is largely of this world. SA

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

SARA CHEN

I Was Wrong

Those three words often separate the scientific pros from the posers By MICHAEL SHERMER

My friend James Randi speculates—with only partial facetiousness—that when one receives a Ph.D., a chemical secreted from the diploma parchment enters the brain and prevents the recipient from ever again saying "I don't know" and "I was wrong." As one counterexample I hereby confess that in my column on Chinese science in the July issue I was wrong in my conversion of Chinese yuan as 80 to the dollar (it is eight).

More serious was a statement I made in the June issue about a Fox television program claiming that the moon landing was faked. I said that the lunar lander rocket showed no exhaust because there is no oxygen-rich atmosphere on the moon. I was partially wrong. The lack of an atmosphere plays a minor role; the main reason is that the lander's engine used hypergolic propellants that burn very cleanly. In both instances, readers were kind enough to provide constructive criticism.

Social critics who decry science as dogmatic are mistaken.

Critical feedback is the lifeblood of healthy science, as is the willingness (however begrudgingly) to say "I was wrong" when faced with persuasive evidence. It does not matter who you are or how important you think your idea is—if it is contradicted by the evidence, it is wrong. In contrast, pseudoscientists typically eschew the peer-review process in order to avoid the inevitable critical commentary. Consider Immanuel Velikovsky's controversial theory about planetary collisions, first proffered in 1950. Velikovsky was not a scientist, and he rejected the peer-review process after submitting a paper to the prestigious journal *Science:* "My [paper] was returned for rewriting after one or two reviewers took issue with my statement that the lower atmosphere of Venus is oxidizing. I had an easy answer to make … but I grew tired of the prospect of negotiating and rewriting."

Nearly a quarter of a century later, after a special session devoted to his theory was organized by Carl Sagan at the 1974 AAAS meeting, Velikovsky boasted, despite all the errors and mistakes that experts had identified in his book, that "my *Worlds in Collision* as well as *Earth in Upheaval* do not require any revisions, whereas all books on terrestrial and celestial science of 1950 need complete rewriting … and nobody can change a single sentence in my books." Unwillingness to submit to peer review and inability to admit error are the antitheses of good science.

A splendid example of honorable science can be found in the May 11 issue of *Science,* in a report on the "African Origin of Modern Humans in East Asia." A team of geneticists took samples from 12,127 men from 163 Asian and Oceanic populations, tracking three genetic markers on the Y chromosome. They discovered that every one of their subjects carried a mutation at one of those three sites that can be traced back to a single African population some 35,000 to 89,000 years ago. Their paper marks a major victory for the "Out of Africa" hypothesis that all modern people can trace their heritage to Africa. It is also a significant blow to the "Multiregional" hypothesis that modern human populations have multiple origins dating back many hundreds of thousands of years.

One of the chief defenders of Multiregionalism, anthropologist Vincent M. Sarich of the University of California at Berkeley, is well known for his vigorous and energetic defense of his beliefs and theories. (I know Vince and can attest that he is a tenacious fighter.) Yet when this self-proclaimed "dedicated Multiregionalist" saw the new data, he confessed in *Science:* "I have undergone a conversion—a sort of epiphany. There are no old Y chromosome lineages [in living humans]. There are no old mtDNA lineages. Period. It was a total replacement." In other words, in a statement that takes great intellectual courage to make, Sarich said that he was wrong. Whether he is right to have converted remains to be seen, as additional studies confirm or belie the findings.

The point is that creationists and social critics who decry science as dogmatic obedience to authority and an old-boys network of closed-minded fogies are simply mistaken. Science is in constant flux, theories are batted about by the ever shifting winds of evidence, and scientists really do change their minds. Of course, I could be wrong.… SA

Michael Shermer is the founding publisher of Skeptic *magazine (www.skeptic.com) and the author of* How We Believe *and* The Borderlands of Science.

BRAD HINES

Finding *Homo sapiens*' Lost Relatives

Continuing a family tradition, Meave G. Leakey uncovers the skeletons in your closet By KATE WONG

NAIROBI, KENYA—When Meave Leakey first saw the 3.5-million-year-old human skull, she couldn't help feeling pessimistic. Grass and tree roots had invaded the specimen, and what little of it peeked out through the rocky matrix was riddled with tiny cracks. "It really was a horrible mess," she recalls, an English accent coloring her quiet voice. The veteran paleoanthropologist turns her gray-green gaze from me to the fossil cast sitting on her desk. "I never thought we'd get anything looking as good as this out of it."

This past March, after spending more than a year cleaning and analyzing the skull and a partial upper jaw, unearthed in northern Kenya's Turkana district, Leakey and her colleagues announced that they had assigned the remains to a new hominid genus and species, *Kenyanthropus platyops*. The fossil possesses a constellation of features—notably a flat face, small teeth and a crest atop its head—that Leakey believes set it entirely apart from the only hominid previously known from that time: *Australopithecus afarensis,* the species to which the Lucy skeleton belongs. Lucy and her kind have long been considered ancestral to all later hominids—including us—if for no other reason than that *A. afarensis* appeared to be the only game in town between 3.8 million and three million years ago. If Leakey is correct, however, then at least two hominid lineages existed as far back as 3.5 million years ago. Thus, according to Leakey, it's just as likely that *Kenyanthropus*—not *Australopithecus*—gave rise to our own genus, *Homo*.

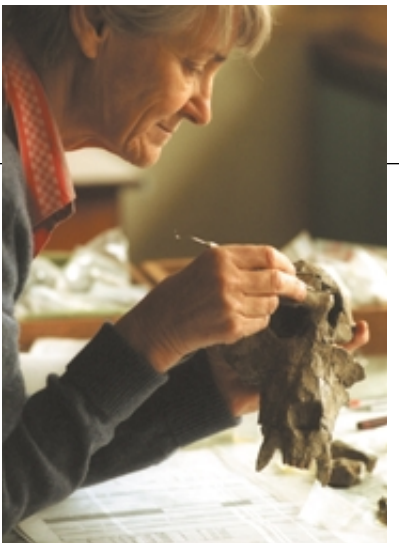
PHOTOGRAPHS BY KARIN RETIEF

MEAVE G. LEAKEY: IN SEARCH OF OUR ANCESTORS

- **Born in London in 1942, attended a convent and then a boarding school that didn't teach science. "In those days they didn't really think that girls needed to know anything other than literature and the arts."**
- **Two daughters, Samira and Louise. Louise co-led the most recent expeditions to Kenya's Lake Turkana.**
- **"We are basically apes; it's just we walk on two legs and have got a fancy head."**

Not everyone agrees with her assessment. Paleoanthropologist Tim D. White of the University of California at Berkeley, an expert on early hominids, remains to be convinced that the fossils represent anything but a variant of *A. afarensis*. Other researchers accept the new species designation but question the new genus. For her part, Leakey notes that time—and more fossils—will tell whether she and her colleagues are right about *Kenyanthropus*. But she insists that just as later stages of human evolution are characterized by multiple lineages, diversity among early hominids should be expected. Indeed, upending the perception of human evolution as a unilinear progression from quadrupedal ape to upright modern human seems to rank high on Leakey's to-do list.

That a Leakey find has upset a popular view of human evolution is no surprise. In the more than 70 years that the family has searched East Africa for remnants of our past, discov-



NONHOMINID REMAINS also intrigue Leakey, shown examining a fossil baboon skull.

eries that have been made by Louis and Mary Leakey, and later by their son Richard, have forced scholars to revise a number of long-held ideas.

Meave joined the famous family when she married Richard in 1970. Taking over leadership of the annual expeditions to Lake Turkana in 1989, when Richard was appointed head of the Kenya Wildlife Service, she has carried on the family's fossil-hunting tradition ever since. Today, viewed against the site maps and posters of celebrated Leakey fossils adorning the walls of her office at the National Museums of Kenya, Meave seems the very embodiment of her field. So I am somewhat surprised when she reveals that she ended up in it by default.

The eldest of three children, Meave Epps exhibited a keen interest in natural history early on, spending countless hours as a little girl collecting beetles and other insects from the back porch of her family's tiny cottage in Kent, England. She eventually enrolled at the University of North Wales, where she fell in love with marine zoology. But after graduating, a dearth of positions for women in that field led her to consider other options.

Meave's shift to paleontology began when a friend pointed out a job ad on the back page of *The Times* one afternoon, announcing that Louis Leakey was looking for someone to work at a primate research center in Kenya. Meave raced to the nearest phone booth. She couldn't hear much of what he was saying—she was too busy feeding coins into the phone—but managed to arrange an interview and ended up working for him at the primate center while at the same time doing her Ph.D. research on the forelimb skeleton of modern monkeys.

Meave would soon meet Richard, who had taken over several of his father's many meagerly funded projects while Louis was overseas. Richard was trying to make the finances more manageable, Meave recollects. The first thing he did, she says with a grin, "was call me and say, 'You're spending too much money.' " He later invited her to join the paleontological fieldwork at Lake Turkana. That was 1968; she's worked there ever since.

The early years at Turkana were heady times. "Pretty much every week we were finding a hominid," Meave recalls. Although the tempo of hominid fossil discoveries has slowed since those days—a natural progression considering how little was known and how little had been explored back then—the pace of discoveries about human evolution has not. Under Meave's direction, the fieldwork has become much more focused. Rather than explore new areas, she and her team have revisited previously worked sites, to address specific questions about early hominids.

What prompted our quadrupedal forebears to move from the forests into different environments is one such question. According to evidence Meave and her colleagues have gathered from a site called Lothagam, the evolution of new plants might have played a significant role. Those data indicate that prior to seven million years ago, bushes, trees, shrubs and other plants that use the so-called C3 metabolic pathway dominated the landscape. After that, however, tropical C4 grasses took over—a shift that would have led to the evolution of new grass-eating animals, Meave says, including insects and small vertebrates favored by many primates.

This, in turn, may have set the stage for bipedalism. Standing on two legs, she explains, would have expanded our ancestors' range of gathering when it came to collecting food such as berries, insects and birds' eggs; natural selection favored the giraffe's long neck for the same reason. (Meave is currently preparing several papers relevant to her bipedalism hypothesis.)

Of course, other hypotheses exist. Some propose that two-legged locomotion was more efficient than the quadrupedal variety, others surmise that standing up afforded a better view of potential predators, and still others posit that bipedalism emerged as a way to keep cool, because less of the body is exposed to the sun in an upright position. But as far as Meave is concerned, "they're all fairytales." Moreover, some of these explanations rest on what she believes to be a false notion. "The assumption has always been that our ancestors went straight from the forest into open grassland," she observes. Yet the data indicate that they sometimes occupied more wooded areas.

Meave's own efforts revealed evidence of this when her team found hominid fossils at Kanapoi, another Turkana site, in 1994. These remains and others from nearby Allia Bay revealed a new species she named *Australopithecus anamensis*. This hominid exhibited clear indications of upright walking, and at 4.1 million years of age, it pushed the earliest evidence of bipedalism—as well as the earliest evidence of the genus—back half a million years. Like *A. afarensis, A. anamensis* appears to have lived in bushland and open woodland, as indicated by the contemporaneous remains of fauna found at the sites. (Recent discoveries by other researchers have extended the record of two-legged locomotion back further still—to perhaps as many as six million years ago.)

Looking forward, Leakey hopes to uncover additional details of both the bipedalism story and what she considers the next major development in hominid evolution: the emergence of manual dexterity. To that end, she plans to return to the *Kenyanthropus* site and similarly ancient localities to look for postcranial remains of her new hominid. "If you look at what we knew in 1969 compared to what we know now, it's absolutely incredible. Every month, practically, somebody's found something new," she remarks. "You have no idea which way it's going to go or how it's going to turn out." SA

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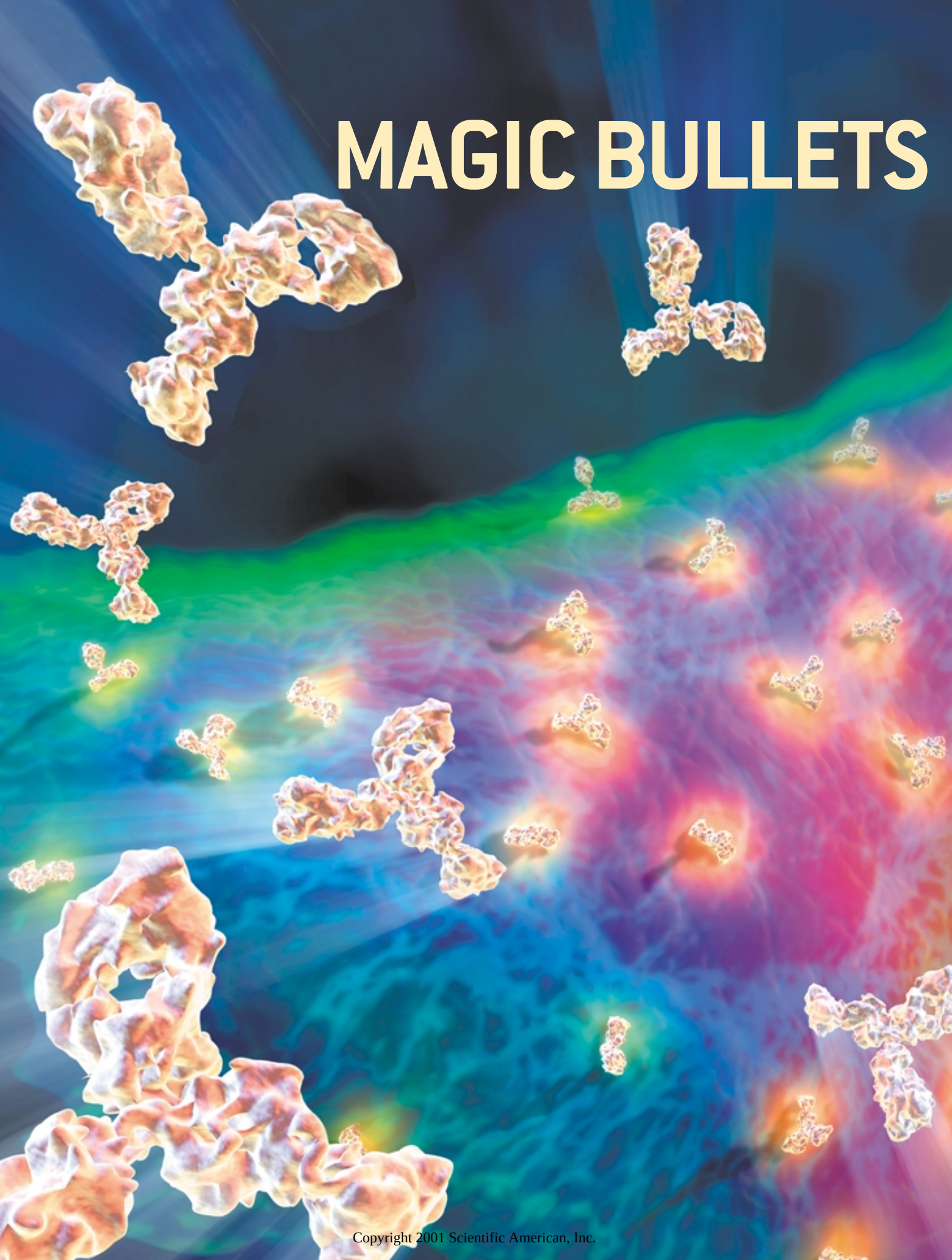

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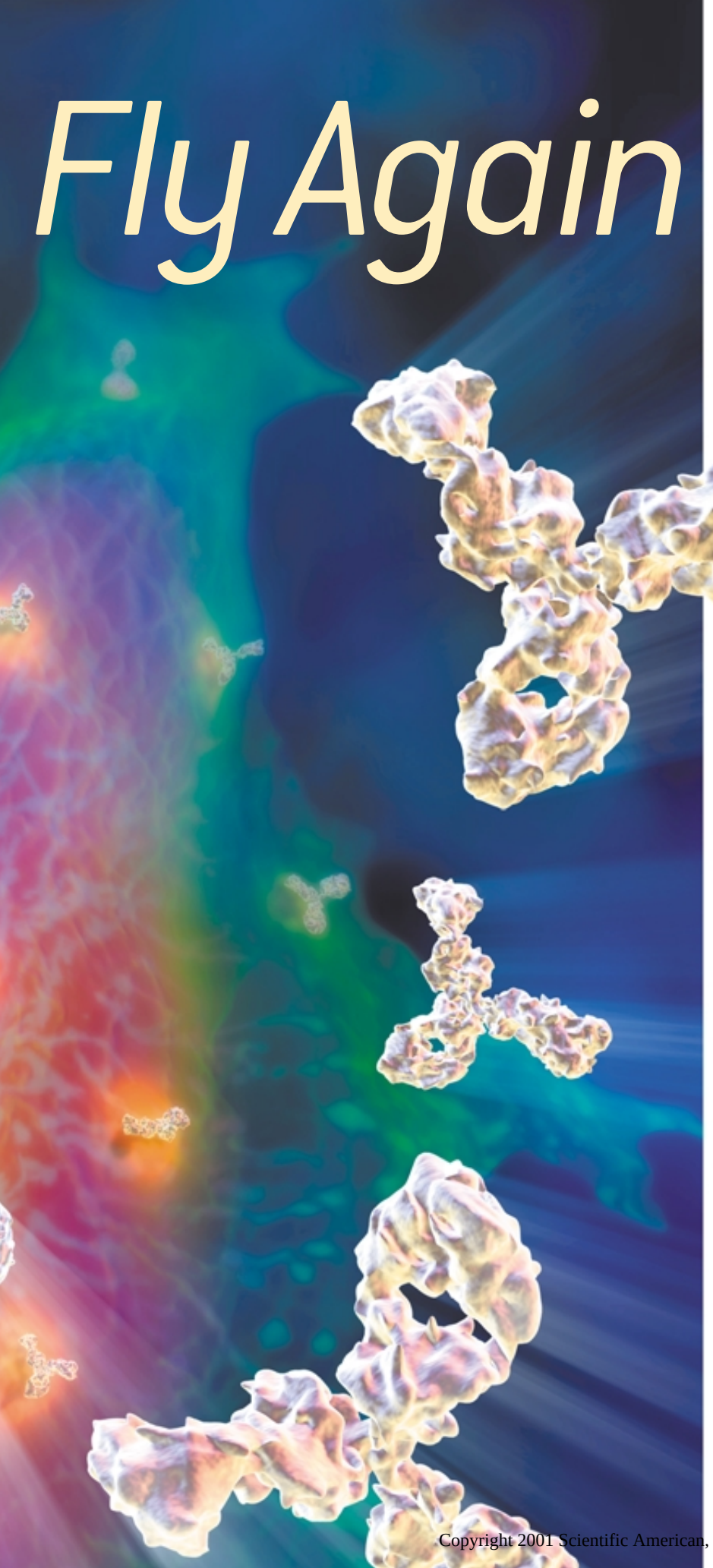


Molecular guided missiles called monoclonal antibodies were poised to shoot down cancer and a host of other diseases—until they crashed and burned. Now a new generation is soaring to market

By Carol Ezzell

THE UNBRIDLED OPTIMISM THAT SURROUNDED MONOCLONAL ANTIBODIES

in the 1980s was infectious. You had to be the world's toughest cynic not to be dazzled. Got cancer? No problem. Like heat-seeking missiles, monoclonal antibodies tipped with poisons or radioactive isotopes would home in on malignant cells and deliver their deadly payloads, wiping out cancer while leaving normal cells intact.

How about an infectious disease? All would be well. Monoclonals would surround marauding viruses and bacteria like goombahs from Tony Soprano's crew, muscling them into secluded byways where killer cells of the immune system would make them an offer they couldn't refuse.

If only things had been so simple. Monoclonal antibodies are highly pure populations of immune system proteins that attack specific molecular targets. Unfortunately, people who received infusions of the early therapeutic monoclonal antibodies tended to develop their own antibodies against the foreign ones, which caused them to become even sicker for reasons that are not entirely clear. And the liver showed a predilection for these early monoclonals, sopping them up before they could target their quarries. Clinical trials failed. Stocks plunged. Millions of dollars were lost. And a generation of scientists and biotechnology businesspeople developed the skepticism shared only by the once burned, twice shy.

Luckily, some of those individuals soldiered on despite the bad news and found ways to overcome the failings of the early versions of the drugs. Now many are hoping that 2001 will be the Year of the Monoclonals, when their perseverance will pay off in the form of lots of effective monoclonal antibody–based drugs approved or under evaluation by the U.S. Food and Drug Administration. "Antibodies will be surging ahead," says Franklin M. Berger, a biotech analyst with JP Morgan Securities. He predicts that soon there will be so many monoclonal antibodies awaiting approval by the FDA that they will cause a bottleneck in the review process.

Ten monoclonals have reached the market, and three await FDA approval, including the first two that would be equipped to deliver a dose of radiation [*see table on page 41*]. Another 100 or more antibodies are being tested in humans, having already shown promise in tests involving animals.

But this summer the FDA sent a message that could slow the monoclonal juggernaut. In July the agency told Genentech, located in South San Francisco, Calif., that it would have to present additional data from human (clinical) trials to prove the long-term safety of its monoclonal antibody for asthma, Xolair, which mops up the antibodies that play a role in asthma and allergies. Some observers have interpreted the move as an indication that the FDA might be particularly rigorous in scrutinizing the side effects of monoclonal antibodies, especially those that patients would take for years for chronic conditions. The announcement sent a brief chill through investors, who drove down the stocks of monoclonal developers for a week or so.

Overview/*Monoclonal Antibodies*

- Antibodies are large, Y-shaped molecules that cells of the immune system called B lymphocytes produce to fight invaders. Monoclonal antibodies are made by identical copies, or clones, of one single B lymphocyte, so they attack only one specific target.
- There are 10 monoclonal antibodies now on the market, to do everything from preventing organ-transplant rejection to treating cancer. Three more are waiting in the wings for Food and Drug Administration approval.
- Although monoclonal antibodies are usually produced by mammalian cells called hybridomas, scientists are working to derive them from the milk of genetically engineered animals and from transgenic plants.
- Monoclonal antibodies—also called MAbs—are cheaper and faster to ready for clinical trials than traditional drugs, which are made of small, inorganic molecules.

JEFF JOHNSON (*preceding pages*)

Nevertheless, the advantages of monoclonals are hard to ignore. Donald L. Drakeman, president and CEO of monoclonal maker Medarex in Princeton, N.J., says that antibodies are simply easier to develop than traditional drugs composed of small, inorganic molecules. Because they are large molecules, they might not be suitable for every disease, but he emphasizes that it takes only one or two years to come up with a monoclonal antibody suitable for testing, versus the five years required for small molecules. That speed translates into savings: it costs only $2 million to ready a monoclonal antibody for clinical testing, Drakeman estimates, compared with $20 million for a traditional drug. And despite the FDA's hesitancy to approve Genentech's asthma therapy, he states that monoclonals have so far had a higher success rate than small-molecule drugs in clearing regulatory hurdles. "Antibodies are almost never toxic," he explains.

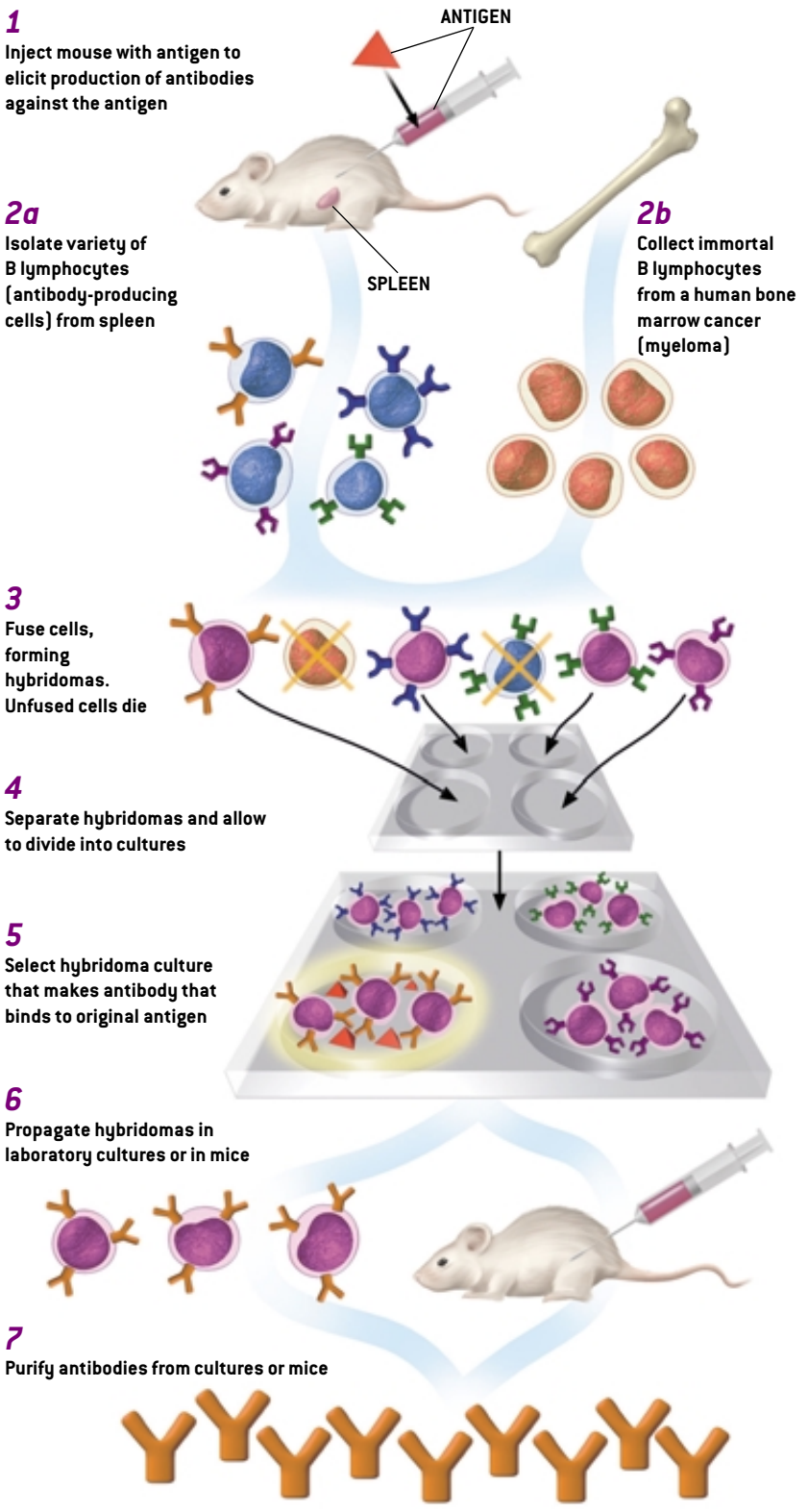
Ironically, monoclonals might be victims of their own success: market analysts are predicting that companies won't have sufficient production facilities to make them all. But the biotechnology industry has anticipated this problem. Some of the more inventive proposals include the manufacture of monoclonals in the milk of livestock or in plants.

Monoclonal Methods

THE PAST FAILURE of monoclonals stemmed in part from the way they were originally made. The classic manufacturing technique was devised in 1975 by immunologists Georges J. F. Köhler and César Milstein of the Medical Research Council's Laboratory of Molecular Biology in Cambridge, England, who were awarded the 1984 Nobel Prize in Physiology or Medicine for their innovation. The basic process involves injecting an antigen—a substance the immune system recognizes as foreign or dangerous—into a mouse, thereby inducing the mouse's antibody-producing cells, called B lymphocytes, to produce antibodies to that antigen. To harvest such antibodies, scientists would ideally pluck only the B cells that make them. But finding the cells and getting them to make large quanti-

MAKING MONOCLONALS—PART ONE

The traditional technique involves fused cells called hybridomas.



CRAIG FOSTER

ties of the antibodies takes some doing.

Part of the complex procedure involves fusing B cells from the mice to immortalized (endlessly replicating) cells in culture to create cells called hybridomas [*see illustration on preceding page*]. The drawback of these particular hybridomas is that they produce murine antibodies, which the human immune system can perceive as interlopers. Patients who have received infusions of murine monoclonals have experienced a so-called HAMA response, named for the human anti–mouse antibodies they generate. The HAMA response includes joint swelling, rashes and kidney failure and can be life-threatening. It also destroys the antibodies.

To avoid both the HAMA response and the premature inactivation of mouse antibodies by the immune system, scientists have developed a variety of techniques to make murine antibodies more human. Antibodies are Y-shaped molecules that bind to antigens through the arms, or FAb regions, of that Y. The stem of the Y, the Fc region, interacts with cells of the immune system. The Fc region is particularly important in eradicating bacteria: once antibodies coat a bacterium by binding to it through their FAb regions, the Fc regions attract microbe-engulfing cells to destroy it.

One approach involves replacing all but the antigen-binding regions of murine monoclonals with human components. Four of the monoclonals now for sale in the U.S. are such chimeric—part mouse, part human—antibodies. Among them is ReoPro, made by Centocor in Malvern, Pa., which prevents blood clots by binding to a specific receptor on platelets; it had sales last year of $418 million. (The body usually doesn't make antibodies targeted to healthy tissues, or autoimmune disease would result. But such antibodies, delivered as drugs, can help treat certain disorders.)

Another strategy, called humanization, is behind five more products on the market, including Herceptin, the breast cancer–targeting monoclonal antibody developed by Genentech. Humanization entails using genetic engineering to selectively replace as much as possible of the murine antibodies—including much of their antigen-binding regions—with human protein [*see illustration below*]. Campath—thought by its maker, Millennium Pharmaceuticals in Cambridge, Mass., to be the first humanized antibody ever made—received FDA approval in May for people with B cell chronic lymphocytic leukemia for whom other therapies haven't worked. Campath binds to a receptor found on various types of normal and cancerous immune cells, but patients make more of the normal cells after treatment ends. The other monoclonal on the market is a purely murine antibody.

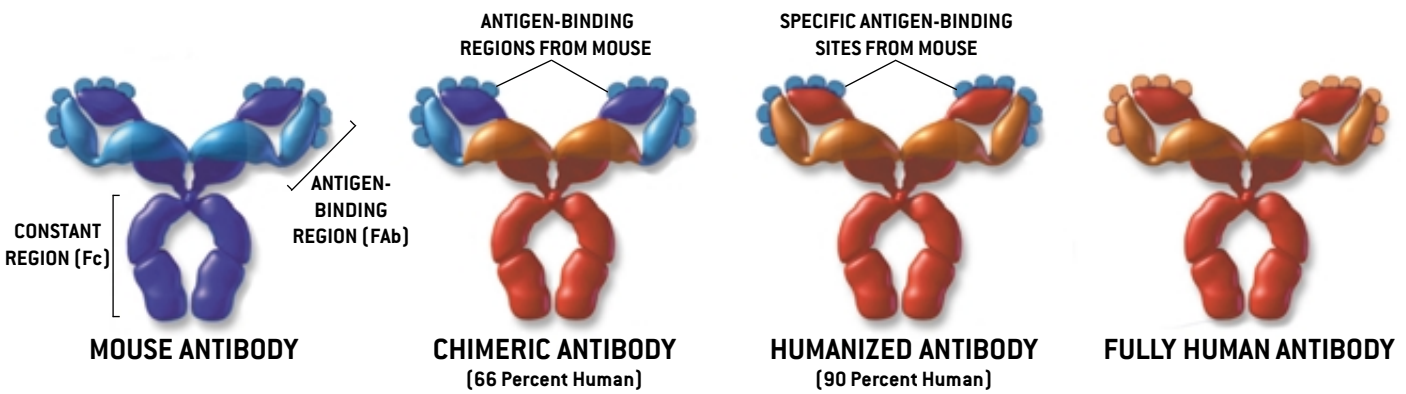
After more than 25 years of trying, researchers have also finally fused human B cells to immortalized cells to create hybridomas that generate fully human antibodies. In February, Abraham Karpas of the University of Cambridge and his colleagues reported accomplishing the feat, although it is too soon to tell whether the monoclonals made using human cells will be safer, more effective or cheaper to manufacture than those generated using other technologies.

Medarex and Fremont, Calif.–based Abgenix have devised ways to induce mice to produce fully human antibodies. The companies genetically alter the mice to contain human antibody genes; when they inject the mice with antigens, the animals produce antibodies that are human in every way. "The technology to humanize or make fully human monoclonal antibodies was one of those changes that made [monoclonals] more commercially viable," suggests Walter Newman, senior vice president of biotherapeutics and nonclinical development for Millennium Pharmaceuticals, which is also developing monoclonal antibody therapeutics.

Abgenix is conducting clinical tests of

Many are hoping that 2001 will be the Year of the Monoclonals, when their perseverance will pay off in the form of lots of effective monoclonal antibody–based drugs approved for sale.

TYPES OF ANTIBODIES that can be produced at present include mouse, chimeric, humanized and fully human.



a fully human antibody against interleukin-8 (IL-8), a naturally occurring chemical known as a cytokine that normally activates cells of the immune system. When the body produces too much IL-8, inflammatory autoimmune diseases such as rheumatoid arthritis or psoriasis can result. Medarex has a variety of clinical trials of fully human monoclonals ongoing for cancer and autoimmune conditions. It is also developing so-called designer antibodies that have been engineered either to deliver a toxin directly to a diseased cell or to recruit immune cells specifically to attack tumors.

Other investigators are attempting to mass-produce monoclonals without the aid of mice. Cambridge Antibody Technology in England and MorphoSys AG in Munich are using a technique called phage display that does just that—and also helps to find the most specific monoclonals against a particular antigen [*see illustration at right*].

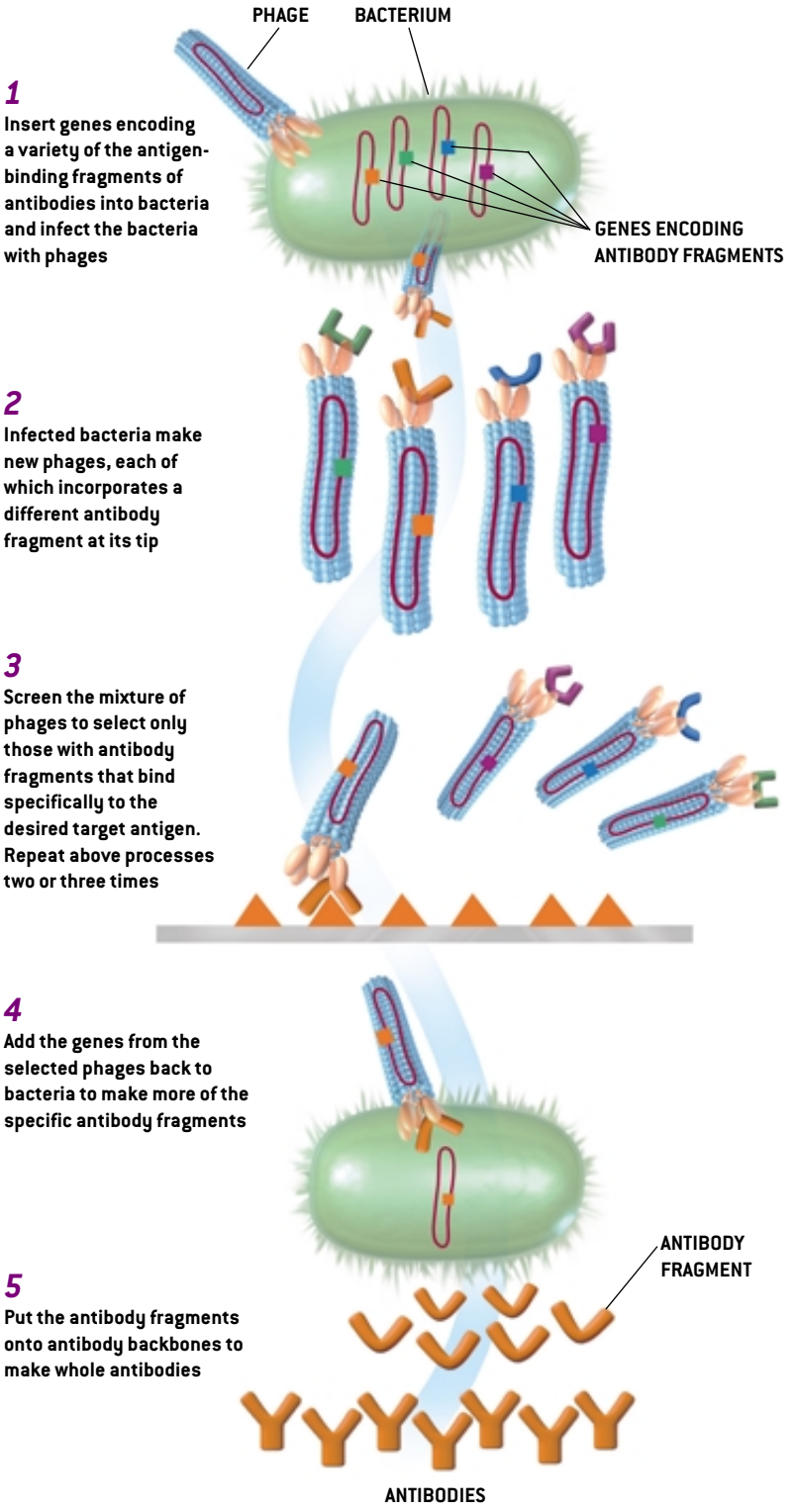
Phage display takes advantage of a long, stringy virus called a filamentous phage that infects bacteria. Researchers can isolate DNA from human B lymphocytes (each cell of which makes antibodies against only one antigen), insert this DNA into bacteria such as *Escherichia coli* and then allow filamentous phages to infect the bacteria. As the phages produce new copies of themselves, they automatically make the proteins encoded by the antibody genes of the various B lymphocytes and add them to the surfaces of newly forming phage particles. Scientists can then use the antigen they intend to target, such as a receptor on cancer cells, to fish out the phages containing the gene for the most specific antibody to that antigen. To produce a lot of that antibody, they can either have one phage infect more bacteria or insert the antibody gene into cultured cells.

Zeroing In on the Targets

TOGETHER the newer forms of monoclonals—chimeric, humanized and human—are looking good against an array of diseases. Two such drugs, if they pass muster with the FDA this year as expected, will finally fulfill the dream of deploying so-called conjugated monoclonals—ones that carry radioactive chemi-

MAKING MONOCLONALS—PART TWO

Viruses called phages that infect bacteria can be used instead of hybridomas.



ILLUSTRATIONS BY CRAIG FOSTER

cals or toxins directly to tumors as a new form of cancer therapy. Zevalin (developed by San Diego–based IDEC Pharmaceuticals and Schering AG) and Bexxar (devised by Corixa in Seattle and GlaxoSmithKline) both target an antigen called CD20 on the surfaces of B lymphocytes, cells that grow uncontrollably in the cancer known as non-Hodgkin's lymphoma. And both pack a hot punch: Zevalin totes an isotope of yttrium (^{90}Y), and Bexxar carries a radioactive form of iodine (^{131}I).

Many other monoclonals now in clinical trials also target molecules on immune cells that play a role in a variety of diseases. For example, Genentech is in the late stages of testing Xanelim, its monoclonal against CD11a. This protein exists on the surfaces of T lymphocytes and helps them to infiltrate the skin and cause the inflammation of psoriasis, which afflicts an estimated seven million people in the U.S. In a study of nearly 600 psoriasis sufferers that was reported at the American Academy of Dermatology conference in July, researchers found that 57 percent of patients on the highest dose of the drug experienced at least a 50 percent decrease in the severity of their disease. Several companies are also pursuing monoclonals against CD18, a protein on T lymphocytes that underlies inflammation as well as the tissue damage resulting from a heart attack.

A molecule called the epidermal growth factor (EGF) receptor is an additional tempting target for monoclonal developers. One third of patients with solid tumors make excess EGF receptors; indeed, the much heralded small-molecule drug Gleevec, sold by Novartis, interferes with the ability of cancer cells to receive growth signals from those receptors. Anti-EGF receptor monoclonals might best be administered in combination with traditional chemotherapies. At the American Society of Clinical Oncology conference in May, researchers reported that cetuximab, an anti-EGF receptor antibody produced by ImClone Systems in New York City, helped chemotherapy to start working again in 23 percent of patients with advanced colorectal cancer who had stopped responding to chemotherapy alone.

Other companies are focusing on making monoclonal antibodies to molecules on the surfaces of the cells that line the blood vessels. Certain types of these molecules, such as $\alpha_v\beta_3$, play a role in angiogenesis, the growth of new blood vessels, which is a crucial step in the development of tumors.

A hugely successful monoclonal antibody drug now on the market, Remicade, targets tumor necrosis factor (TNF), a molecule the body uses to juice the cellular arm of the immune system but that also plays a role in inflammatory diseases. According to company reports, Remicade, which is on pharmacy shelves for Crohn's disease (an inflammatory bowel disease) and rheumatoid arthritis, made $370 million last year for its developer, Centocor. Therapies that wipe out TNF have a potential $2-billion annual market, according to Carol Werther, managing director of equity research at the investment bank Adams, Harkness and Hill. (Enbrel, an anti-TNF drug developed by Immunex in Seattle that was approved in 2000 for patients with moderate to severe rheumatoid arthritis, is not technically a monoclonal antibody, because only part of an antibody—the backbone—is used; that backbone is linked to a piece of another kind of molecule, the normal cellular receptor for TNF.)

Emerging Issues

WITH ALL THESE good opportunities facing them, biotechnology and pharmaceutical companies might be expected to be ramping up their production lines in anticipation of a big market surge. But worldwide just 10 large-scale antibody plants are now operating.

Part of the problem is financial: banks don't want to lend the hundreds of millions of dollars it takes to build a state-of-the-art monoclonal production facility unless the likelihood that the plant will generate profits is all but guaranteed.

Monoclonals might be victims of their own success: industry watchers are predicting that companies won't have sufficient production facilities to make them all.

Many of them look back on the 1980s, when drug manufacturers built facilities that operated for years at only partial capacity.

The gold standard for producing monoclonals from hybridomas relies on enormous tanks called bioreactors. V. Bryan Lawlis, chairman of Diosynth ATP in Cary, N.C., estimates that one giant, 60,000-liter bioreactor plant would be able to (hypothetically) accommodate only four products. Assuming that 100 monoclonals will be on the market by 2010, as analysts predict, Lawlis calculates that the industry will need to build at least 25 new facilities or "we can't satisfy all the needs." Those production plants would require $5 billion or more and between three and five years to be built and certified by the FDA—a prospect no one thinks is going to happen.

To fill the void, some companies are turning to transgenic animals and plants, those organisms engineered to carry genes for selected antibodies. Transgenic mammals that secrete monoclonals in their milk can generate one gram of antibody for roughly $100—one third the cost of traditional production methods, industry officials say. Centocor and Johnson & Johnson are looking into producing Remicade using transgenic goats, and Infigen in DeForest, Wis., intends to make monoclonals in cow's milk, although no such products have yet received FDA approval. Moreover, it isn't clear how many companies will be willing to turn to these transgenic

MONOCLONAL ANTIBODY DRUGS ON THE MARKET

PRODUCT	DEVELOPER/ MARKETER	APPROVAL DATE	TYPE	TARGET	DISORDER
Orthoclone OKT3 (muromonab-CD3)	Ortho Biotech/ Johnson & Johnson	1986	Murine	CD3 antigen on T lymphocytes	Acute rejection of transplanted kidneys, hearts and livers
ReoPro (abciximab)	Centocor/ Eli Lilly & Co.	1994	Chimeric	Clotting receptor (GP IIb/IIIa) on platelets	Blood clots in patients undergoing cardiac procedures such as angioplasty
Rituxan (rituximab)	IDEC Pharmaceuticals/ Genentech/Roche	1997	Chimeric	CD20 receptor on B lymphocytes	Non-Hodgkin's lymphoma (relapsed or refractory low-grade)
Zenapax (daclizumab)	Protein Design Labs/ Roche	1997	Humanized	Interleukin-2 receptor on activated T lymphocytes	Acute rejection of transplanted kidneys
Herceptin (trastuzumab)	Genentech/ Roche	1998	Humanized	HER2 growth factor receptor	Advanced breast cancers bearing HER2 receptors
Remicade (inflixibmab)	Centocor/ Schering-Plough	1998	Chimeric	Tumor necrosis factor	Rheumatoid arthritis and Crohn's disease
Simulect (basiliximab)	Novartis	1998	Chimeric	Interleukin-2 receptor on activated T lymphocytes	Acute rejection of transplanted kidneys
Synagis (palivizumab)	MedImmune	1998	Humanized	F protein of respiratory syncytial virus (RSV)	RSV infection in children
Mylotarg (gemtuzumab)	Celltech/ Wyeth-Ayerst	2000	Humanized	CD33 antigen on leukemia cells	Relapsed acute myeloid leukemia
Campath (alemtuzumab)	Millennium Pharmaceuticals/ Schering AG	2001	Humanized	CD52 antigen on B and T lymphocytes	B cell chronic lymphocytic leukemia

options over the standard bioreactors.

Newman concedes that transgenic animals are attractive alternatives, but he adds that companies must still undergo the sometimes tedious step of isolating the monoclonals from the milk proteins. "You have purification problems, but you don't have the expense of 10,000-liter bioreactors," he says. Genetically engineering and breeding the animals can also take years.

Mich B. Hein, president of Epicyte in San Diego, sees green plants as the answer to the monoclonal production shortfall. "It's pretty clear that the production facilities will not meet the demand for even the most promising molecules," he says. Plants have the advantages of being economical and easily scalable to any level of demand: they can yield metric tons of monoclonal products. But purification problems remain, and it is still unclear how the FDA will regulate pharmaceuticals produced by transgenic plants.

Epicyte has teamed up with Dow to produce corn plants able to generate monoclonal antibodies that will be formulated as creams or ointments for mucosal surfaces such as the lips and genitalia or as orally administered drugs for gastrointestinal or respiratory infections. Hein predicts that by the end of next year Epicyte will seek FDA clearance to begin clinical trials of corn-produced monoclonals to prevent the transmission of herpes simplex between adults and during childbirth. The company is also developing monoclonals that bind to sperm as possible contraceptives, as well as antibodies that could protect against human papillomavirus, which causes genital warts and cervical cancer.

Whether they come from cattle, goats, corn or bioreactors, monoclonal antibodies are set to become a major part of 21st-century medicine. SA

Carol Ezzell is a member of the board of editors.

MORE TO EXPLORE

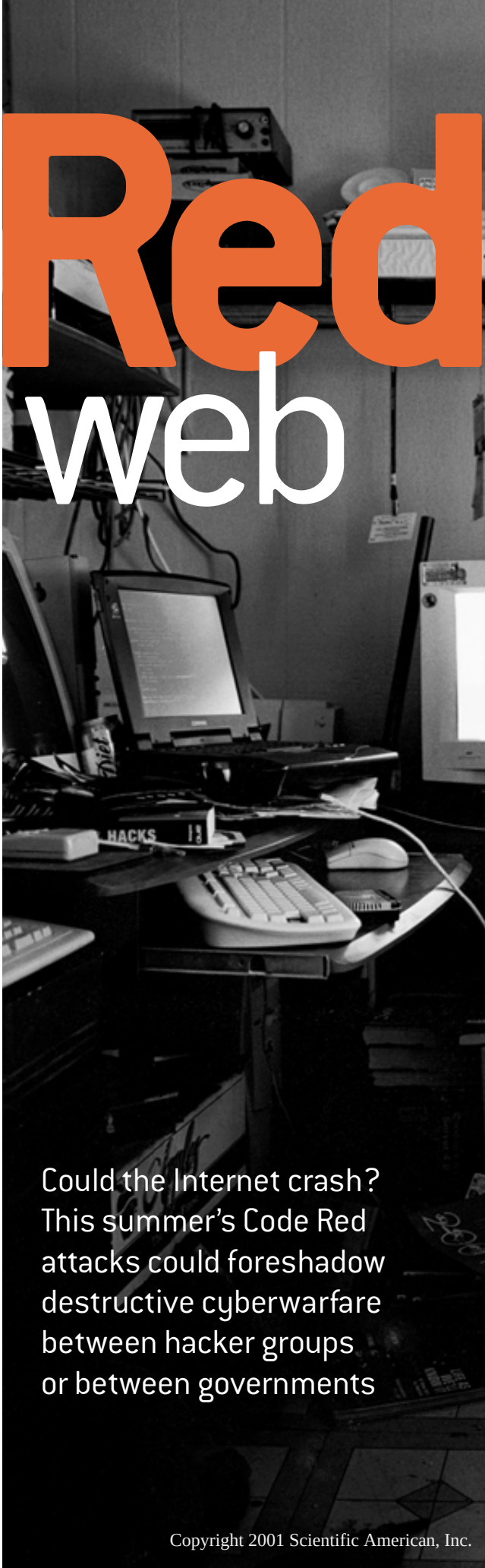
Monoclonal Antibodies: A 25-Year Roller Coaster Ride. N. S. Halim in *The Scientist,* Vol. 14, No. 4, page 16; February 21, 2000.

A Human Myeloma Cell Line Suitable for the Generation of Human Monoclonal Antibodies. A. Karpas, A. Dremucheva and B. H. Czepulkowski in *Proceedings of the National Academy of Sciences USA,* Vol. 98, No. 4, pages 1799–1804; February 13, 2001.

Biotech Industry Faces New Bottleneck. K. Garber in *Nature Biotechnology,* Vol. 19, No. 3, pages 184–185; March 2001.

Abstracts of scientific presentations at the 2001 annual meeting of the American Society of Clinical Oncology are available at **virtualmeeting.asco.org/vm2001/**

Code Red for the web



Could the Internet crash? This summer's Code Red attacks could foreshadow destructive cyberwarfare between hacker groups or between governments

"Imagine a cold that kills. It spreads rapidly and indiscriminately through droplets in the air, and you think you're absolutely healthy until you begin to sneeze. Your only protection is complete, impossible isolation."

Jane Jorgensen, principal scientist at Information Extraction & Transport in Arlington, Va., which researches Internet epidemiology for the Defense Advanced Research Projects Agency, isn't describing the latest flu outbreak but an affliction that affects the Web. One such computer disease emerged this past July and August, and it has computer security researchers more worried about the integrity of the Internet than ever before. The consternation was caused by Code Red, a Web worm, an electronic ailment akin to computerized snakebite. Code Red infects Microsoft Internet Information Servers (IIS). Whereas home computers typically use other systems, many of the most popular Web sites run on IIS. In two lightning-fast strikes, Code Red managed to infiltrate hundreds of thousands of IIS servers in only a few hours, slowing the Internet's operations. Although Code Red's effects have waned, patching the security holes in the estimated six million Microsoft IIS Web servers worldwide and repairing the damage inflicted by the worm have cost billions of dollars.

What really disturbs system administrators and other experts, however, is the idea that Code Red may be a harbinger of more virulent Internet plagues. In the past, Web defacements were perpetrated by people breaking into sites individually—the cyberwarfare equivalent of dropping propaganda leaflets on targets. But computer researchers dread the arrival of better-designed automated attack worms that could degrade or even demolish the World Wide Web.

Further, some researchers worry that Code Red was merely a test of the type of computer programs that any government could use to crash the Internet in times of war. This past spring's online skirmishes over the U.S. spy plane incident with China emphasize the dangers. Full-scale cyberwarfare could cause untold damage to the industrialized world [see "What Happens if the Internet Crashes?" on page 45]. These secret assaults could even enlist your PC as a pawn, making it a "zombie" that participates in the next round of computerized carnage.

BY CAROLYN MEINEL • Photographs by Ethan Hill

AMERICAN HACKERS are being enlisted to help fight the U.S. government's cyberwars.

Save for the scales on which these computer assaults are waged, individual hacking and governmental cyberwarfare are essentially two sides of the same electronically disruptive coin. Unfortunately, it's hard to tell the difference between them until it's too late.

Often popularly lumped in with viruses, Code Red and some similar pests such as Melissa and SirCam are more accurately called worms in the hacker lexicon. Mimicking the actions of its biological namesake, a software virus must incorporate itself into another program to run and replicate. A computer worm differs in that it is a self-replicating, self-contained program. Worms frequently are far more infectious than viruses. The Code Red worm is especially dangerous because it conducted what are called distributed denial of service (DDoS) attacks, which overwhelm Internet computers with a deluge of junk communications.

During its July peak, Code Red menaced the Web by consuming its bandwidth, or data-transmission capacity. "In cyberwarfare, bandwidth is a weapon," says Greggory Peck, a senior security engineer for FC Business Systems in Springfield, Va., which works to defend U.S. government clients against computer crime. In a DDoS attack, a control computer commands many zombies to throw garbage traffic at a victim in an attempt to use up all available bandwidth. This kind of assault first made the news last year when DDoS attacks laid low Yahoo, eBay and other dot-coms.

More than 359,000 servers were infected with the CODE RED WORM in less than 14 HOURS.

These earlier DDoS incidents mustered just hundreds to, at most, thousands of zombies. That's because attackers had to break into each prospective zombie by hand. Code Red, being a worm, spreads automatically—and exponentially. This feature provides it with hundreds of times more zombies and hence hundreds of times more power to saturate all available Internet bandwidth rapidly.

The initial outbreak of Code Red contagion was not much more than a case of the sniffles. In the five days after it appeared on July 12, it reached only about 20,000 out of the estimated half a million susceptible IIS computer servers. It wasn't until five days afterward that Ryan Permeh and Marc Maiffret of eEye Digital Security in Aliso Viejo, Calif., a supplier of security software for Microsoft servers, discovered the worm and alerted the world to its existence.

On July 19 the worm reemerged in a more venomous form. "More than 359,000 servers were infected with the Code Red worm in less than 14 hours," says David Moore, senior technical manager at the Cooperative Association for Internet Data Analysis in La Jolla, Calif., a government- and industry-supported organization that surveys and maps the Net's server population. The traffic jam

WEB WATCHER David Moore monitored the rapid spread of Code Red.

What Happens if the Internet Crashes?

WHAT WOULD BE the consequences if the Internet failed in the face of a hacking onslaught? They would be far worse than not being able to make bids on eBay—potentially affecting product manufacturing and deliveries, bank transactions, telephony and more. Should it occur five years from now, the results could be a lot more severe.

Today many businesses use the World Wide Web to order parts and arrange shipments. A collapse of the system would interrupt just-in-time manufacturing, in which components reach the production line within a day or two of being used, to save on inventory costs. Many retail stores also rely on the Web to keep their shelves stocked. Within days, they could start to empty.

By then you may not be able to use your checkbook or ATM card either, as many banks are using the Internet instead of dedicated lines to save money. Other economic institutions such as Wall Street are said to be more susceptible to hackers corrupting trading data than to a shutdown of the system. The latter eventuality would be met by closing down the market.

Whereas most phones would still work if the Web went down today, experts say that may change a few years from now. Internet telephony started as a way for geek hobbyists to get free long-distance phone calls. Now, however, many calls that originate from an ordinary phone travel part of the way over the public Internet.

Meanwhile unclassified communications of the U.S. Armed Services go through NIPRNET (Non-Secure Internet Protocol Router Network), which uses public Internet communications. The Department of Defense is now "immensely dependent" on NIPRNET, according to Greggory Peck, a senior security engineer for FC Business Systems in Springfield, Va., which provides computer services to the federal government.

Many people ask whether airliners might start falling out of the sky if the World Wide Web crashes. The Federal Aviation Administration's air-traffic control system is sufficiently antiquated that it is in no danger of being held hostage to the Internet.—*C.M.*

generated by so many computers attempting to co-opt other machines began to overload the capacity of the Internet. By midafternoon, the Internet Storm Center at incidents.org—the computer security industry's watchdog for Internet health—was reporting "orange alert" status. This is one step below its most dire condition, red alert, which signals a breakdown.

Then, at midnight, all Code Red zombies quit searching for new victims. Instead they all focused on flooding one of the servers that hosts the White House Web site with junk connections, threatening its shutdown. "The White House essentially turned off one of its two DNS servers, saying that any requests to whitehouse.gov should be rerouted to the other server," says Jimmy Kuo, a Network Associates McAfee fellow who assisted the White House in finding a solution. Basically, the system administrators dumped all communications addressed to the compromised server. As it turned out, Code Red couldn't cope with the altered Internet protocol address and waged war on the inactive site. "The public didn't notice anything, because any requests went to the other server," Kuo says.

By the close of July 20, all existing Code Red zombies went into a preprogrammed eternal sleep. As the worms lodge only in each computer's RAM memory, which is purged when the machine shuts down, all it took was a reboot to eradicate their remnants. Case closed.

Or was it? A few days later analysts at eEye revealed that if someone were to release a new copy of Code Red at any time between the first through the 19th day of any month (the trigger dates coded in by the original hacker), the infection would take off again.

Over the next 10 days computer security volunteers worked to notify Microsoft IIS users of the vulnerability of their servers. On July 29 the White House held a press conference to implore people to protect their IIS servers against Code Red's attacks. "The mass traffic associated with this worm's propagation could degrade the functioning of the Internet," warned Ronald L. Dick, director of the FBI's National Infrastructure Protection Center. By the next day Code Red was all over the news.

The second coming of Code Red was, as expected, weaker than the first. On August 1, it infected approximately 175,000 servers—nearly all those susceptible and about half the total of the previous episode. A slower infection rate and fewer vulnerable servers held Internet disruptions to a minimum. After a while, the second attack subsided.

But that was not the end. Yet another worm was unleashed on August 4 using the same break-in method as Code Red. The new worm, dubbed Code Red II, installed a backdoor allowing a master hacker to direct the activities of victim computers at will. The worm degraded intranets with "arp storms" (floods of Ethernet packets) and hunted for new victims. In short order, Code Red II disabled parts of the Web-based e-mail provider Hotmail, several cable and digital subscriber-line (DSL) Internet providers and part of the Associated Press news distribution system. As time passed, Code Red II managed to infect many corporate and college intranets. Halfway through August, Code Red II disabled some Hong Kong government internal servers. The most common victim computers were personal Web servers run by Windows 2000 Professional. This rash of disruptions prompted incidents.org to again declare an orange alert. Experts estimate that 500,000 internal servers were compromised.

In mid-August, Computer Economics, a security research company, said that Code Red had cost $2 billion in damage. By the time it is fully purged from the Internet, the computer attack will probably rank among the most expensive in histo-

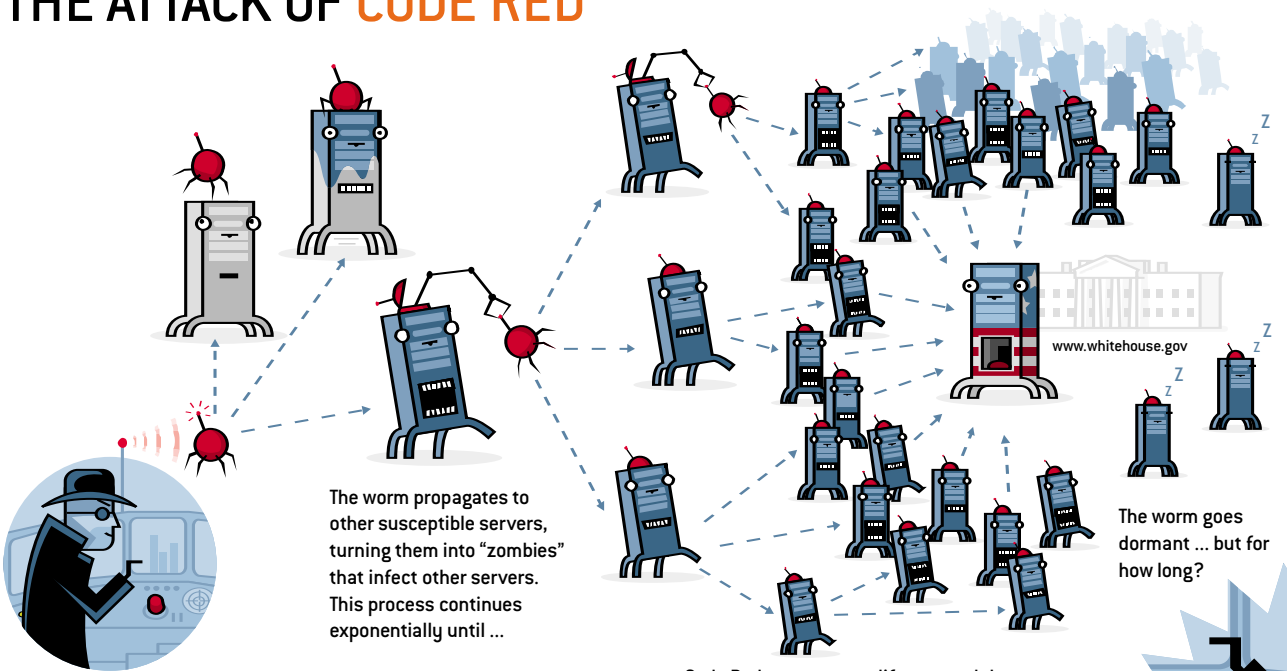
THE AUTHOR

CAROLYN MEINEL writes frequently about computer security. Based in Sandia Park, N.M., she is the author of *The Happy Hacker* and *Überhacker! How to Break into Computers*. Meinel's upcoming book, *War in Cyberspace*, examines Internet warfare. Her Web site, happyhacker.org, is a resource for home computer users.

Code Red internet worms

CODE RED is an Internet worm that infects unprotected Microsoft Internet Information Servers (IIS), on which many popular Web sites run. During the summer, the worm's secret assaults turned IIS computers into "zombies" that conducted what is called a distributed denial of service attack on the White House Web site, attempting to overwhelm it by flooding it with garbage communications. More effective worms have the potential to saturate the Web's data-transmission capacity, possibly disabling the Internet.

THE ATTACK OF CODE RED



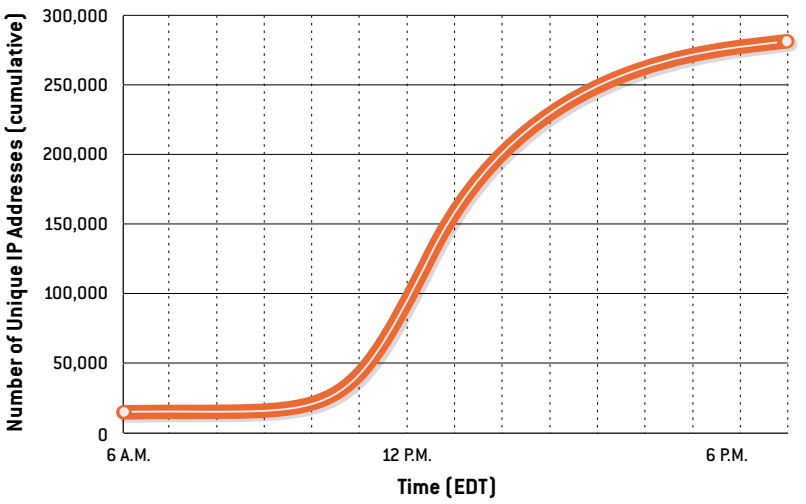
A malicious hacker sends the Code Red worm out onto the Internet to find a vulnerable host server

The worm propagates to other susceptible servers, turning them into "zombies" that infect other servers. This process continues exponentially until ...

... Code Red ceases to proliferate, and the numerous zombie servers turn to attack the White House Web site, attempting to overwhelm its server with junk communications

The worm goes dormant ... but for how long?

Day 1 | **Days 1–18** | **Days 19–27** | **Days 28–31...**



INTERNET PROTOCOL ADDRESSES INFECTED BY CODE RED

RAPID RISE—During a 12-hour period on July 19, 2001, the number of Internet protocol addresses compromised by the first large-scale assault of the Code Red worm surged from around 16,000 to about 280,000. After its initial spread, Code Red went dormant. Soon thereafter, however, a reinfection caused another, smaller outbreak. Experts estimate that the worm's attacks and the following Code Red II outburst will cost several billion dollars to rectify.

ry. Nearly $9 billion was spent to fight last year's LoveLetter virus, and 1999's Melissa worm assault cost $1 billion to repair.

Of course, Code Red isn't the only worm out there. Some of them are aimed at home computers. A worm called W32/Leaves, for example, permits a remote attacker to control infected PCs in a coordinated fashion, enabling synchronized waves of attacks. (Although Code Red II allows this possibility as well, it lacks the coding that enables remote control.) The Computer Emergency Response Team, a federally funded watchdog organization at Carnegie Mellon University, has received reports of more than 23,000 W32/Leaves zombies. The current total is unknown, but as W32/Leaves continues to propagate, the infected population will probably grow significantly. In July, Britain's Scotland Yard charged an unidentified 24-year-old man with creating W32/Leaves.

"Almost any computer, operating system or software you may buy contains weaknesses that the manufacturer knows lets hackers break in," says Larry Leibrock, a leading researcher in computer forensics and associate dean for technology of the business school of the University of Texas at Austin. Future "federal regulation could require that vendors take the initiative to contact customers and help them upgrade their products to fix security flaws," he continues. "Today, however, it is up to each consumer to hunt down and fix the many ways hackers and cyberwarriors exploit to abuse their computers."

World Cyberwars

BEYOND THE THREAT posed by malicious hacker programs is the danger of Internet attacks conducted in a concerted fashion by top computer talent spurred to act by international events. The cyberbattles that broke out over the collision of a Chinese fighter plane that collided with a U.S. Navy EP-3E spy plane this past April give a hint of how such a conflict might play out.

According to accounts in the press, the hacker exchanges began when negotiations for the release of American hostages stalled. On April 9 and 10, attackers defaced two Chinese Web sites with slurs, insults and even threats of nuclear war. During the following week, American hackers hit dozens more Chinese sites. Those supporting China responded by disfiguring one obscure U.S. Navy Web site.

China, however, held a weapon in reserve. In late March the National Infrastructure Protection Center had warned of a new worm on the loose: the 1i0n Worm. Lion, the hacker who founded the hacker group H.U.C. (Honkers Union of China), has taken credit for writing it. Unlike the initial Code Red's preprogrammed zombies, 1i0n's zombies accept new commands from a central computer. Also, 1i0n infects Linux computers, which means it can masquerade as any computer on the Net. This property makes it hard to track down infected servers.

Meanwhile pro-U.S. hack attacks escalated. The official Chinese publication, *People's Daily*, reported that "by the end of April over 600 Chinese Web sites had come under fire." In contrast, Chinese hackers had hit only three U.S. sites during the same period.

In the next few days the Chinese hacker groups H.U.C., Redcrack, China Net Force, China Tianyu and Redhackers assaulted a dozen American Web sites with slogans such as "Attack anti-Chinese arrogance!" On the first of May several DDoS strikes were initiated. Over the next week Chinese hackers took credit for wrecking about 1,000 additional American Web sites.

On May 7 China acknowledged its responsibility for the DDoS attacks and called for peace in a *People's Daily* news story. It ran: "The Chinese hackers were also urged to call off all irrational actions and turn their enthusiasm into strength to build up the country and safeguard world peace."

U.S. law-enforcement agencies, the White House and U.S. hacker organizations never objected to the American side of this cyberconflict, although the FBI's infrastructure center had warned of "the potential for increased hacker activity directed at U.S. systems."

How to Wage Covert Cyberwarfare

IN VIEW OF the spy-plane episode, some commentators have wondered whether the U.S. federal government encouraged American hackers to become agents of cyberwar. After all, the U.S. has worked with private groups to wage covert warfare before, as in the Iran/Contra scandal. And links between the two communities have been reported. It's difficult, however, to say exactly how strong the connection between hackers and the government might be. Clearly, the murky world of hacking doesn't often lend itself to certainty. And because it is the policy of the U.S. National Security Agency and various Defense Department cyberwarfare organizations not to comment on Web security matters, these relationships cannot be confirmed. Still, the indications are at least suggestive.

Consider the history of Fred Villella, now an independent computer consultant. According to numerous press reports and his own statements, Villella took part in counterterrorism activities in the 1970s. In 1996 he hired hackers of the Dis Org Crew to help him conduct training sessions on the hacker threat for federal agencies. This gang also helps to staff the world's largest annual hacker convention, Def Con.

Erik Ginorio (known to the hacker world as Bronc Buster) publicly took credit for defacing a Chinese government Web site on human rights in October

Code Red II installed a backdoor allowing a MASTER HACKER to direct victim computers at will.

1998. This act is illegal under U.S. law. Not only was Ginorio not prosecuted, he says Villella offered him a job. Villella could not be reached for comment.

In another hacker-government connection, Secure Computing in San Jose, Calif., became a sponsor of Def Con in 1996. According to its 10-K reports to the U.S. Securities and Exchange Commission, Secure Computing was created at the direction of the National Security Agency, the supersecret code-breaking and surveillance arm of the U.S. government. Two years after that, Secure Computing hired the owner of Def Con, Jeff Moss. Several former Villella instructors also staffed and managed Def Con.

Questionable things happen at Def Cons. At the 1999 Def Con, for example, the Cult of the Dead Cow, a hacker gang headquartered in Lubbock, Tex., put on a mediagenic show to promote its Back Orifice 2000 break-in program. Gang members extolled the benefits of "hacking to change the world," claiming that eight-year-olds could use this program to break into Windows servers.

Meanwhile Pieter Zatko, a Boston-area hacker-entrepreneur and a member of the gang, was onstage promoting a software plug-in for sale that increased the power of Back Orifice 2000. According to the Cult's Web site, Back Orifice 2000 was downloaded 128,776 times in the following weeks. On February 15, 2000, President Bill Clinton honored Zatko for his efforts by inviting him to the White House Meeting on Internet Security. Afterward Zatko remained with a small group to chat with the president.

Every year Def Con holds a "Meet the Feds" panel. At its 2000 meeting, Arthur L. Money, former U.S. assistant secretary of defense for command, control, communications and intelligence, told the crowd, "If you are extremely talented and you are wondering what you'd like to do with the rest of your life—join us and help us educate our people [government personnel]."

In 1997 Moss launched the Black Hat Briefings. In hacker lingo, a black hat is a computer criminal. Theoretically, these meetings are intended to train people in computer security. They bear considerable similarity to Def Con, however, only with a $1,000 price tag per attendee. Their talks often appear to be more tutorials in how to commit crime than defend against it. For example, at one session attendees

What Can Be Done to Defend the Web?

AS POGO the comic-strip character said, "We have met the enemy and he is us." One of the weakest links in protecting the Internet is the home PC user. Cybernetic worms—self-replicating hacker software that can wreak havoc on Internet operations—can turn personal computers into "zombies," or slave agents that help to destroy other computer operations. Of particular concern are worms that can conduct effectively targeted distributed denial of service (DDoS) attacks, in which zombie computers deluge a Web site with useless communications.

Computer professionals are being asked to get the word out to home users to check for zombies. "That's because our worst Internet nightmare is the grandma who uses her DSL [high-bandwidth-capacity digital subscriber line that is always connected] to shop on eBay," says Greggory Peck of FC Business Systems, which provides computer services to the federal government. High bandwidth means that a home zombie can pump lots of junk into the Internet, swamping targeted Web sites.

You may think your home computer is safe from assault because it runs automatic virus updates or because you registered your software and receive vendor e-mails about product upgrades. Guess again. Few vendors feel obligated to help users keep hackers out. That's why it's important for home users to install firewalls.

Complicating the safety issue, most new PCs will soon be running the Windows XP operating system, which enables "raw sockets." Sockets are software constructions that generate the packets (the smallest data-transmission units) that transfer information across networks. With raw sockets technology, packets can be crafted in an arbitrary manner even if that violates safeguarding protocols. Raw sockets, for example, enabled the 1i0n worm to hide on Linux servers by forging Internet addresses (*see preceding page*). They also allow hackers to create malformed packets that will crash a receiving computer.

Beyond the home PC, another approach to defending the Web is to arrest more computer criminals. Nowadays, though, dangerous attackers may operate through a chain of compromised computers, with one or more being located across national borders. To obtain evidence in these cases requires cooperation among the law-enforcement agencies of two or more countries.

International pursuit of computer criminals would be made easier by adoption of the "Convention on Cyber-crime" now under consideration by the 44 nations of the Council of Europe, which includes the U.S., Canada and Japan. Part of the treaty would also criminalize possession or creation of computer crime instructions or programs except for the authorized testing or protection of a computer system. (The text of the Cyber-crime Treaty is available at conventions.coe.int/treaty/EN/projets/cybercrime.htm)

These restraints are controversial, though. At least 35 lobby groups, including the Electronic Frontier Foundation and the Global Internet Liberty Campaign, oppose the treaty because they believe it would restrict freedom of speech and invade personal privacy. It's hard to find antidotes to viruses and worms if researchers cannot study copies of them on their computers.

Another solution is to require that Internet servers be secure. For example, the U.S. Federal Trade Commission proposed a regulation in July that requires financial service companies to guard their networks against "anticipated threats." This is only a small step in the right direction. *—C.M.*

NET VIROLOGIST Mark A. Ludwig writes about computer viruses and worms at his rural Arizona home.

learned about "Evidence-Eliminator," billed as being able to "defeat the exact same forensic software as used by the U.S. Secret Service, Customs Department and Los Angeles Police Department."

It should be noted that the U.S. government does have a formal means to wage cyberwar. On October 1, 2000, the U.S. Space Command took charge of the Computer Network Attack mission for the Department of Defense. In addition, the U.S. Air Force runs its Information Warfare Center research group, located in San Antonio.

Get enough zombies attacking enough targets, and the ENTIRE INTERNET could become unusable.

Given these resources, why would the U.S. and China encourage cybermilitias? "It's very simple. If you have an unofficial army, you can disclaim them at any time," says Mark A. Ludwig, author of *The Little Black Book of Computer Viruses* and the upcoming *The Little Black Book of Internet Viruses*. "If your military guys are doing it and you are traced back, the egg's on your face."

Wherever it came from, the Code Red assault was just a taste of what a concerted cyberwar could become. "I think we can agree that it was not an attempt at cyberwar. The worm was far too noisy and easily detected to be much more than graffiti/vandalism and a proof-of-concept," says Harlan Carvey, an independent computer security consultant based in Virginia.

Stuart Staniford, president of Silicon Defense in Eureka, Calif., notes, however, that if the zombie computers "had a long target list and a control mechanism to allow dynamic retargeting, [they] could have DDoSed [servers] used to map addresses to contact information, the ones used to distribute patches, the ones belonging to companies that analyze worms or distribute incident response information. Code Red illustrates that it's not much harder for a worm to get *all* the vulnerable systems than it is to get some of them. It just has to spread fast enough."

Code Red already offers deadly leverage for nefarious operators, according to Marc Maiffret, who bills himself as "chief hacking officer" of eEye: "The way the [Code Red] worm is written, it could allow online vandals to build a list of infected systems and later take control of them."

Get enough zombies attacking enough targets, and the entire Internet could become unusable. Even the normal mechanisms for repairing it—downloads of instructions and programs to fix zombies and the ability to shut off rogue network elements—could become unworkable. In addition, hackers constantly publicize new ways to break into computers that could be used by new worms. A determined attacker could throw one devastating worm after another into the Internet, hitting the system every time it struggled back and eventually overpowering it.

"We know how [crashing the Internet] can be done right," says Richard E. Smith, a researcher with Secure Computing and author of the newly published book *Authentication*. "What I've found particularly disquieting is how little public fuss there's been [about Code Red]. The general press has spun the story as being an unsuccessful attack on the White House as opposed to being a successful attack on several hundred thousand servers: 'Ha, ha, we dodged the bullet!' A cynic might say this demonstrates how 'intrusion tolerant' IIS is—the sites are all penetrated but aren't disrupted enough to upset the owners or generate much press comment. The rest of us are waiting for the other shoe to drop." SA

MORE TO EXPLORE

The Computer Emergency Response Team's Guide to Home Network Security: **www.cert.org/tech_tips/home_networks.htm**

The Internet Storm Center: **www.incidents.org**

The National Infrastructure Protection Center: **www.nipc.gov**

The Cooperative Association for Internet Data Analysis: **www.caida.org**

Microsoft Windows NT, 2000 and XP security information: **www.ntbugtraq.org**

Free security test for home computers: **grc.com** and **security2.norton.com/us/home.asp**

Microsoft Windows NT, 2000 and XP information: **www.microsoft.com/technet/treeview/default.asp?url=/technet/itsolutions/security/current.asp**

Driving THE Info HIGHWAY

The Internet has hit the road.

Drivers can now access anything from custom traffic reports to spoken e-mail messages to video games. But is it safe?

By Steven Ashley

The needle points to "E." The big rental van and its trailer have guzzled down yet another tank of gas. This time, however, it's late and nothing but a dark, lonesome highway stretches out ahead. Every several miles there's a turnoff to some small town, but the signs don't always say how far these burgs lie off your route or whether there are gas stations in them. You've just started hunting down the road map when you remember that the van comes equipped with a voice-activated telematics system, a two-way wireless communications unit connected to both the Internet and a Global Positioning System (GPS) locator. Punching a button on the dash, you say, "Gas." After a pause, a mechanized voice reads aloud a roster of nearby service stations, including the brand of gas, the distance to each station, even the price per gallon of unleaded regular. Although it's a bit farther away, you choose the third entry on the machine-verbalized "text-to-speech" list because you have that brand's credit card. The electronic voice responds with step-by-step driving directions to your next petroleum oasis.

Sooner or later this kind of scenario will become commonplace as more sophisticated automotive telematics technology heads out onto the road. Just as microprocessors colonized motor vehicles during the past decade, a similarly steady transition to telematics will occur as the necessary equipment is installed in new cars and trucks over the next few years, auto industry analysts say. A wireless transmitter and receiver, an antenna, elementary voice-recognition and text-to-speech capabilities, and typically a GPS unit are all that's needed on board to support what the industry calls the "thin-client" telematics service—the most fundamental set of mobile communications features. Although the basic service package is relatively simple and the changeover seems inevitable, the industry will soon have to address the complex potential safety and privacy issues that the technology raises.

Anytime, Anywhere

AUTOMOTIVE TELEMATICS is based on the notion that today's motorists are demanding instant access to safety, navigation and convenience services, as well as entertainment programming, anytime, anywhere. Already being spoken about in the eager tones that financial analysts used to describe e-commerce half a dozen years ago, the nascent telematics technologies are expected to fundamentally change the way people interact with cars, where the average American driver spends nearly 10 percent of his or her waking day. "Motor vehicles deserve to be connected to the outside world," says Chet Huber, president of OnStar, the largest telematics service provider in the U.S. "Today we're beginning with services that offer safety, security and peace of mind. Ultimately we'll expand into a lot more interactive services."

In-vehicle wireless safety and security services—such as emergency roadside as-

NHTSA (*right* and *opposite page*)

VIRTUAL TEST DRIVING of onboard automotive telematics technology is one of the functions of the National Advanced Driving Simulator (*above* and *opposite page*), which the National Highway Traffic Safety Administration recently opened at the University of Iowa.

sistance, automatic collision notification and remote door unlocking—are already becoming more familiar to the motoring public. These features are offered by Mercedes-Benz's TeleAid, BMW's Assist and Hertz's NeverLost, in addition to OnStar. Subscribers to premium telematics services are meanwhile starting to take advantage of more sophisticated features, such as verbal e-mail messages, digital music, and tailored traffic and weather updates, as well as on-demand news, sports and stock-market reports. And drivers of luxury cars have become accustomed to instrument panels outfitted with color LCD screens that display navigation maps or with other useful driver aids.

"In the five years we've been operating, OnStar has delivered 10 million customer interactions," Huber says. "One out of four General Motors cars has OnStar—that's 5,000 new subscribers every day. And now many other car brands, including Acura, Audi, Honda, Lexus, Saab and Subaru, will offer OnStar services as well." Free for the first 12 months, basic service costs $199 a year, which Huber says is about what it costs annually to keep a cell phone in the car. "To remain competitive, every vehicle in the country will have to be able to deliver at least the basic telematics services," he predicts.

Looking ahead, engineers are working on ways to avoid built-in dashboard displays, which tend to become obsolete relatively quickly, with new technology that integrates a driver's personal digital assistant (PDA) into the vehicle system via a center-mounted docking cradle. The PDA would serve as the visual interface. It would even automatically transfer to the vehicle the motorist's personal information, such as fuel or restaurant brand preference, seat position settings, regular commuting routes and daily work schedule.

Rosy Predictions

ONE OF THE BIGGEST players in the area, auto components supplier Delphi Automotive Systems in Troy, Mich., suggests that half of all new cars could have telematics devices fitted as standard equipment by 2005. Indeed, some observers are forecasting exponential growth for the telematics business. For example, UBS Warburg, a financial services company, expects the market to grow 10-fold, to $47.2 billion, within a decade. Frost & Sullivan, a marketing consulting company, is much more conservative in its prognosis, predicting the North American market to hit $7 billion by 2007. Philip Rowland, principal at the management consulting firm McKinsey & Co., is similarly circumspect, noting that by 2010 the worldwide telematics market could range from $13 billion to $100 billion, depending on customer demand and regulatory decisions made in the U.S., Japan and western Europe.

Whereas telematics in its simplest forms is not new—AM/FM radios, citizen-band radios and cell phones have been around for a while—the future points to much greater integration of the automobile and society than ever before. Once a vehicle is "wired" to transmit and receive information, the potential to piggyback other products and services on those signals explodes. Consumers might buy or lease a new vehicle once every few years at best, but suppliers of telematics services are expecting the gadgets to be cash cows that can be milked on a daily basis.

Facing ever stiffer market competition and low margins on increasingly basic commodity-like products, automakers—GM, Toyota, DaimlerChrysler, Ford and PSA Peugeot Citroën among them—are reportedly spending huge (as yet undisclosed) sums to establish a telematics infrastructure. Telematics equipment suppliers such as Delphi, Siemens, Bosch, Visteon and Johnson Controls are also working hard to make that vision successful. In the meantime, other entrants, including Microsoft, Motorola, Clarion, Westwood One and ATX Technologies, are getting involved. Scott McNealy, the outspoken CEO of Sun Microsystems, has made it clear that his company views the automobile as just another Internet portal, referring to the car as little more than "a Java browser with wheels."

At the same time, a range of difficult safety, regulatory, privacy and liability is-

TELEMATICS SERVICES

SERVICES	PAYMENT TYPE	KEY TECHNOLOGIES
SAFETY AND SECURITY		
Roadside assistance	Subscription	GPS
Stolen vehicle tracking	Subscription	GPS
Remote door unlocking	Subscription	GPS
Air bag deployment call (911)	Subscription	GPS
ENTERTAINMENT		
Video games	Pay per use	Digital video
DVD playback		Digital video
Satellite radio	Subscription	Satellite radio
Music and movie downloads	Pay per use	High-bandwidth wireless
Internet radio	Subscription	High-bandwidth wireless
NAVIGATION		
Turn-by-turn directions	Subscription	GPS, wireless data, speech*
Tourist/recreational info	Ad supported	Wireless data
News, stocks, weather	Subs, ad supported	Wireless data, speech*
Tickets, reservations	Ad supported	Wireless data, speech*
Calendar, address book	Subs, ad supported	Wireless data
Real-time traffic, rerouting	Subs, pay per use	GPS, wireless data
Location-based advertising	Ad supported	GPS, wireless data

SOURCE: Forrester Research, Inc.

* Voice recognition and text-to-speech

DOCKING STATION for personal digital assistants and cell phones.

Telematics is based on the notion that motorists are demanding access to safety and other services **anytime, anywhere.**

sues related to telematics remains unresolved. According to some, that's not necessarily bad. "Because it's still early in its development," McKinsey's Rowland says, "the telematics industry now has a classic opportunity to lobby and confer with governments to ensure that the vast economic and social benefits telematics could make available are not impeded by the need to maintain safety, privacy and so forth." Technical standardization of telematics systems also has time to be implemented, he adds. Cooperative projects such as the Automotive Multimedia Interface Collaboration, an industry-wide standard-setting organization, could foster the development of open architecture specifications for these information systems.

Rowland and his colleagues say that three distinct telematics submarkets are emerging. The first, a "front-seat" market, will revolve around safety, security and convenience features that make driving easier by providing tailored assistance when it is needed. An example of a front-seat service is customized traffic reporting: when a driver sees a traffic jam up ahead, the telematics system can instantly provide alternative, open routes. Because of safety considerations, it is as yet unclear to what degree other so-called productivity services, such as e-banking, stock quotes and audible e-mail, should be provided to front-seat occupants.

The second, "rear-seat" market will consist mainly of entertainment offerings, including on-demand interactive games, digital music, movies and videos. Rear-seat services will allow drivers to download entertainment products that can keep the kids busy on long trips, for instance.

The third market, for engine and other mechanical applications, will use data collected by onboard computers to provide such tools as remote diagnostics, software upgrades and "smart" ordering of replacement parts. This technology would permit carmakers or dealers to alert a motorist when his or her engine malfunctions and could even retune the engine when the vehicle is parked late at night.

Hands on the Road, Eyes on the Wheel

DESPITE THE TECHNOLOGY'S potential, safety and other issues related to its use are yet to be determined. The current debate over the use of handheld cell phones in cars suggests that the telematics human-machine interfaces, and how drivers use them, will be critical. "For many—mostly societal—reasons, consumers are importing a whole series of portable devices into their vehicles for use when they're driving: cell phones, laptops, personal digital assistants," says Bob Lange, executive director of safety integration at GM's Safety Center in Warren, Mich. "First of all, people are spending more of their time commuting. And since everyone's being subjected to a major time squeeze as well as increasing pressure to be more productive, more and more of these devices are going to be used in the car. Automakers have to be cognizant of these trends and [work] to make it possible for consumers to use these devices safely."

Automotive safety expert Paul Green agrees: "There is great excitement about the possibility of how these systems might enhance the driving experience. Yet relatively little emphasis has been given to the potential risks associated with the overload these systems might pose to drivers." Green is a senior research scientist at the University of Michigan Transportation Research Institute in Ann Arbor, which conducts inquiries into transportation topics. "If action is not taken, a significant number of information-system-related deaths and injuries will result," he warns. "At this point, safety and human-factors efforts lag far behind electronics development." This could cause a consumer backlash or prompt the federal government to step in and curtail the use of telematics products in moving vehicles.

The key unresolved point is how to avoid unduly distracting the driver from the primary mission—driving—while he or she is answering e-mails or finding a restaurant. Says GM's Lange: "We know that under most driving circumstances the cognitive demand of the driving process is very modest. That's why we all find ourselves doing other, nondriving-related tasks while we're driving."

Driver Distraction

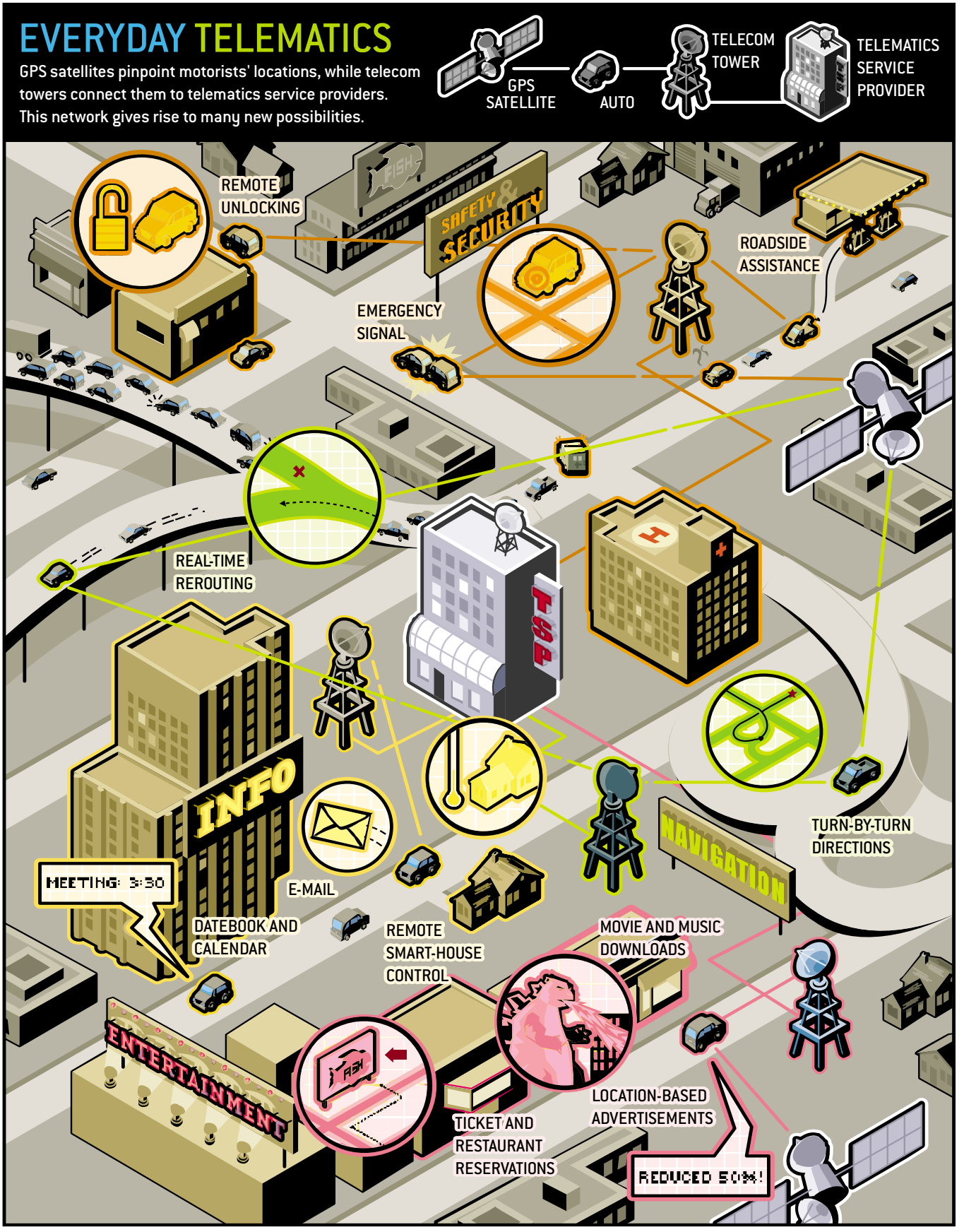
BUT HOW MUCH is too much? "Unfortunately, driver-distraction data are so sparse that we can't determine the real magnitude of the problem," says Michael Goodman, chief of driver research and simulation at the National Highway Traffic Safety Administration (NHTSA) in Washington, D.C. "We believe that a minimum of 25 percent of fatal crashes are distraction-related. Other researchers argue that the number is more like 30 to 50 percent. In any case, distraction-related fatal crashes are very underreported, as the deceased driver is not there to ask and drivers are unwilling to describe the causes because of potential liability. What we do know is that just about any activity people do in cars—eating, adjusting the mirror, changing radio stations—is associated with crashes. When that action coincides with a random event like a dog running out into the street or the onset of a dangerous curve, you've got an accident."

Cellular telephone technology is serving as the model for the adoption of auto-

DELPHI AUTOMOTIVE SYSTEMS

EVERYDAY TELEMATICS

GPS satellites pinpoint motorists' locations, while telecom towers connect them to telematics service providers. This network gives rise to many new possibilities.



XPLANE.COM

BACKSEAT video screens for passengers.

What we do know is that just about any activity that people do in cars—eating, changing radio stations—is associated with crashes.

motive telematics. As with the cell phone, telematics keeps the driver in touch with the rest of the world. Likewise, the potential for telematics to induce driver overload is ever present. Despite continuing controversy about the use of handheld cell phones while driving and the recent bans imposed in New York State and elsewhere, however, conclusive research on the safety implications of in-vehicle electronics use is still relatively meager. Human-factors researchers do say, though, that even hands-free, voice-activated cell phones cause sufficient cognitive distraction to produce driver error.

According to industry figures, there are currently about 105 million cell phones in the U.S., with the total expected to nearly double to 200 million by 2005. Some 70 to 80 percent of cell phone owners use them in vehicles. At the same time, phones are getting cheaper and easier to operate, helping to boost the rise in usage. With more users making more calls, the exposure to potential distraction is increasing and, along with it, the risk of accidents. As Goodman says, "different kinds of distractions are associated with different levels of risk. People do a lot of eating and drinking in cars, but there's only so much they can eat and drink. The same cannot be said of wireless phone use."

Interestingly, a conversation using a hands-free cell phone is not quite the same as talking to a passenger. "The phone is just as compelling as talking to a passenger," Goodman says. "There's a strong desire to respond and complete the conversation, but the other person is not aware of the driving situation—whereas the passenger, being just as concerned about safety as the driver, tends to keep quiet during challenging driving conditions."

Concern about on-the-road cell phone use is supported by a new study conducted at the University of Utah and issued by the National Safety Council (NSC). It indicates that conversing on cell phones while driving can lead to significant decreases in driving performance regardless of whether the phone units are handheld or hands-free. The investigation says that cell phone use on the road creates much higher levels of driver distraction than listening to the radio or audio books.

According to the authors, the study's findings suggest that legislative initiatives that restrict handheld devices but permit hands-free devices in motor vehicles are not likely to reduce driver distractions associated with cell phone conversations significantly (see www.nsc.org/news/nr081501a.htm). "This study adds new data to the ongoing national debate on driver distractions and their causes," notes Alan C. McMillan, NSC president. "A great deal more research like this is needed, to help us fully understand the public policy implications of the growing use of cell phones and other electronic devices—such as global positioning systems, faxes and computers—in moving vehicles."

Because of the potential for disastrous driver distraction, more than a dozen countries now restrict or prohibit cell phones and wireless technology in motor vehicles, including Australia, Brazil, Chile, Germany, Israel, Italy, Japan, Philippines, Portugal, Singapore, South Africa, Spain, Switzerland and the U.K. The European Commission 1999 design guidelines for automotive human-machine interfaces state: "Information and communications intended for use by the driver while driving must not distract, disturb, or overload drivers." Currently in the U.S., there are no accepted industry guidelines or government regulations governing in-car telematics devices.

To ward off a regulatory backlash and avoid product-liability lawsuits, telematics providers are focusing on crucial, but still relatively immature and otherwise potentially problematic technologies, such as voice-recognition/voice-activation systems and head-up displays. This equipment will allow drivers to use wireless technology without taking their eyes off the road or their hands off the wheel. But how about ensuring that the driver's mind stays on the task of driving? How much interaction, or cognitive distraction, can a driver handle before he or she loses focus on the road ahead?

TELEMATICS PLAYERS LIST

TELEMATICS SERVICES

Assist, BMW *Munich, Germany*
ATX Technologies *Dallas*
OnStar *Troy, Mich.*
TeleAid, Mercedes-Benz *Stuttgart, Germany*
Wingcast, Ford/Qualcomm *San Diego*

TELEMATICS EQUIPMENT

Robert Bosch *Stuttgart, Germany*
Delphi Automotive Systems *Troy, Mich.*
IBM *White Plains, N.Y.*
Johnson Controls *Plymouth, Mich.*
Microsoft *Redmond, Wash.*
Motorola *Schaumberg, Ill.*
Philips Electronics *Eindhoven, Netherlands*
Siemens Automotive *Regensburg, Germany*
Sun Microsystems *Palo Alto, Calif.*
Visteon *Dearborn, Mich.*

NAVIGATION SYSTEMS

ComROAD *Unterschleissheim, Germany*
Webraska *Poissy, France*

TRAFFIC INFORMATION

Mobility Technologies *Wayne, Pa.*
Westwood One *New York City*

FORD MOTOR COMPANY

GAME PLAYERS in the rear seat to keep the kids occupied.

The all-encompassing nature of telematics systems evokes George Orwell's Big Brother.

According to safety specialists, cognitive distraction is one of four general types of driver distraction. The others are visual, auditory and biomechanical. But cognitive distraction, which can occur while contemplating business or personal matters, remembering a list of spoken instructions or even listening to a synthesized voice, is much more elusive and difficult to measure than the other types. What is known is that it diminishes the operator's awareness of the driving situation.

The question comes down to how and when to give information to the driver. NHTSA has begun a series of studies on the topic. The investigations will make major use of the new National Advanced Driving Simulator, a $50-million high-fidelity system that is just coming online in Iowa City. The simulator will allow scientists to duplicate highway driving in a safe and controlled laboratory setting. NHTSA researchers are also conducting in-vehicle research on test tracks.

Automakers are following suit with their own investigations. Ford, for example, has built a $10-million driving simulator dubbed VIRTTEX, for VIRtual Test Track EXperiment, to study driver workload and distraction issues related to in-vehicle electronic devices. "The industry needs good, scientifically accepted design guidelines and testing," says Jeff Greenberg, chief of VIRTTEX at Ford's Research Laboratory in Dearborn, Mich. "It is important that all of these systems be safe and that the scientific community agrees on what is acceptable."

Driver Workload Managers

MEANWHILE GM is building a driver-workload-assessment laboratory to evaluate specific telematics devices on a test track. "Until we have good science that tells us how much is too much," says GM's Bob Lange, "we will err on the side of limiting driver involvement with high-level tasks. For example, GM has decided to disable destination entry input [driver queries regarding trip routes] for navigation systems while the vehicle is moving. In general, we want to minimize the number of steps to complete a task, by using voice recognition in conjunction with a click or two of a button."

NHTSA researchers expect the problem to be partially ameliorated through the development of a series of increasingly sophisticated "workload managers." Now under development at many car companies, such managers would regulate the information flow presented to the driver by monitoring moment-to-moment driving demands. In heavy traffic, for example, an incoming call might be diverted to an answering machine.

"If we were sophisticated enough to truly understand how drivers interact with the environment and the vehicle," Lange says, "we could conceive of a rather elaborate algorithm that would enable and disable telematics systems."

"Soon we'll see the beginnings of a dialogue manager," he predicts. "At first, it would work by capturing and analyzing currently available vehicle data—throttle position, brake position, steering angle. Then, as we add sensors that can monitor ambient conditions, the dialogue manager can become more effective."

These sensors, many of which now exist but are not yet installed on vehicles, could observe visual conditions (light, dark, foggy), road-surface conditions (wet, dry, icy), and traffic flow and density as registered by radar- or infrared-based adaptive cruise control or collision-avoidance systems. After that, a head-position-monitoring system similar to those used by military helicopter pilots could be developed to follow a driver's head movements to determine if he or she is paying attention. If a hazard is detected while the driver's eyes are not on the road, it would send out a warning.

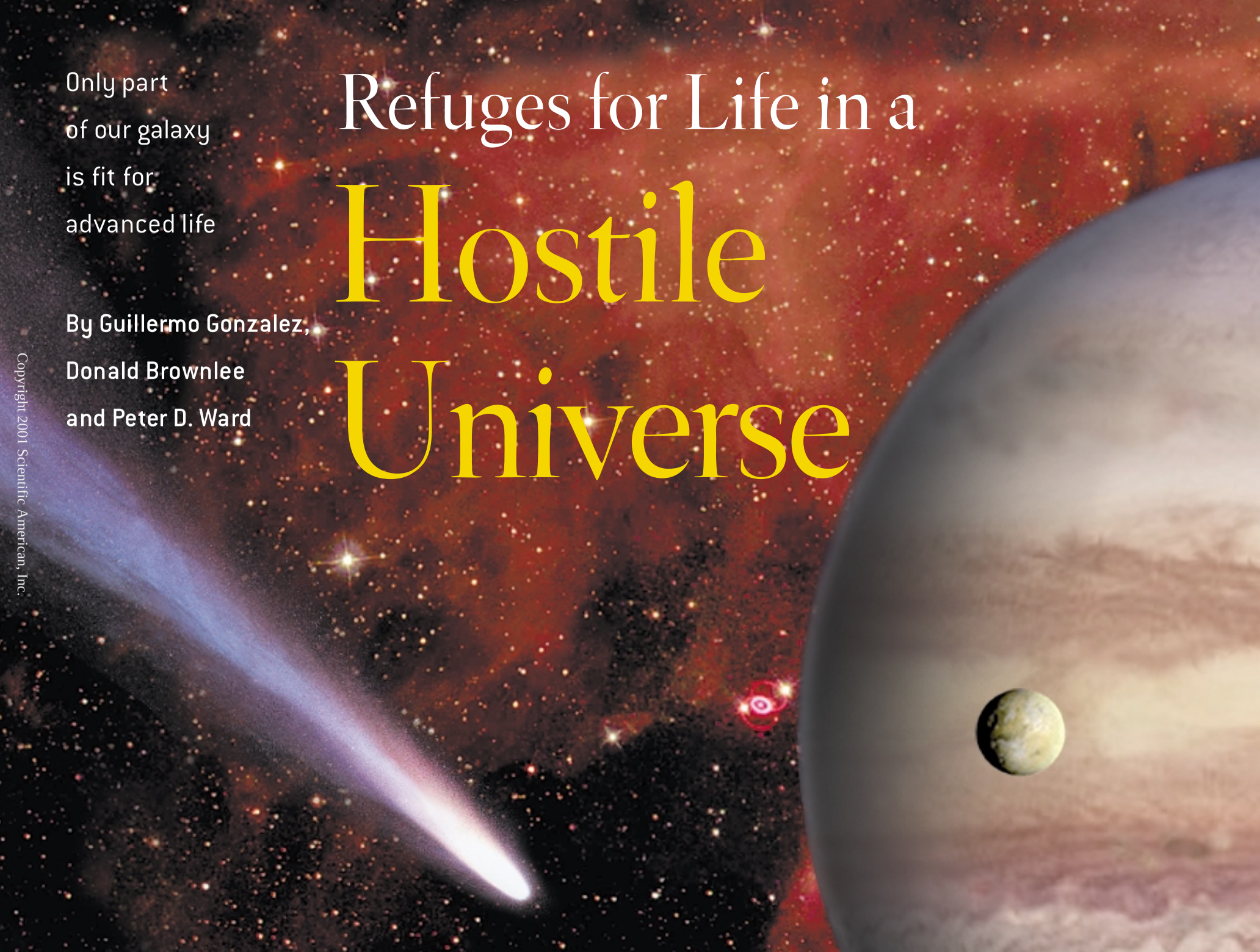
Never Out of Touch

BEYOND SAFETY concerns, the all-encompassing nature of telematics systems evokes George Orwell's Big Brother. Telematics technology was certainly anything but a benefit to James Turner, who rented a van from Acme Rent-A-Car in New Haven, Conn., early last October. After Turner had completed a drive to Virginia, Acme informed him that tracking data from the van's onboard GPS locator indicated that he had exceeded the speed limit three times during his travels. As noted in the rental contract, the company charged Turner $150 for each alleged infraction. First, Turner was incredulous at getting such an unexpected notice from his rental company rather than from the police. Now he's challenging the fines in court. Meanwhile the Connecticut Department of Consumer Protection has requested that the company sign a cease-and-desist order, which would stop it from issuing speeding fines and compel it to provide restitution to the dozens of customers whom it has charged.

Until safety and privacy concerns are addressed in a comprehensive way, it will remain the responsibility of drivers to keep their minds on driving despite the inevitable distractions caused by telematics features. One thing is certain: America's celebrated love affair with the automobile will never be the same. It is going become a lot tougher to get away from the rest of the world by driving away in your car. SA

Steven Ashley is a member of the board of editors.

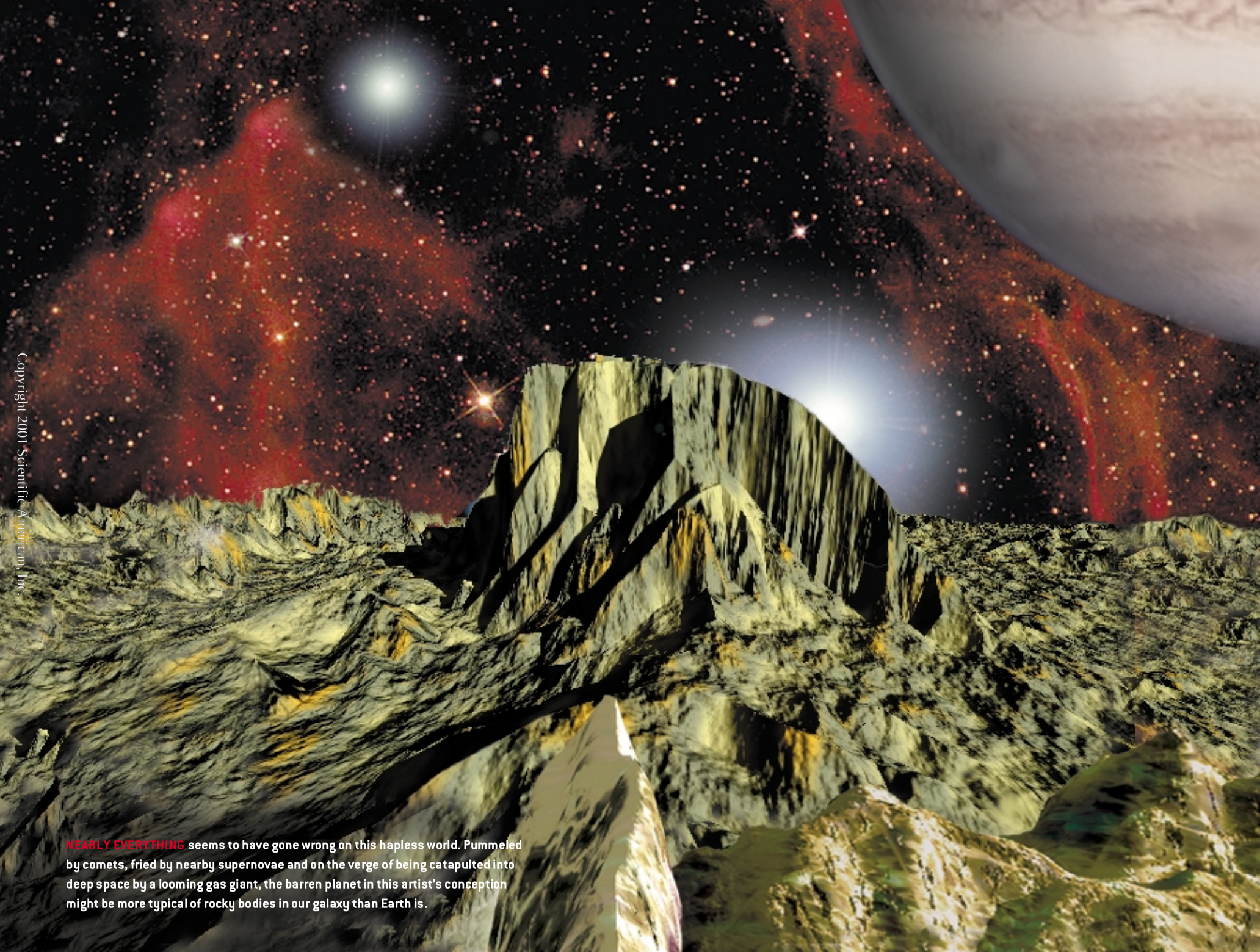
VISTEON



Only part of our galaxy is fit for advanced life

Refuges for Life in a Hostile Universe

By Guillermo Gonzalez, Donald Brownlee and Peter D. Ward



NEARLY EVERYTHING seems to have gone wrong on this hapless world. Pummeled by comets, fried by nearby supernovae and on the verge of being catapulted into deep space by a looming gas giant, the barren planet in this artist's conception might be more typical of rocky bodies in our galaxy than Earth is.

In science-fiction stories, interstellar travelers visit exotic locales in the Milky Way and meet with interesting aliens. You name the place, and someone has put a civilization there: the galactic center, a globular cluster, a star-forming region, a binary star system, a red dwarf star. Part of the reason that sci-fi writers have to be so inventive is that scientists keep spoiling the fun. It used to be quite respectable to speculate about intelligent beings on the moon, Mars, Venus, Jupiter or even the sun, but nowadays canal-building Martians and cool oases inside the sun are merely quaint notions. As writers go ever farther afield to situate their characters, scientists are not far behind. Researchers are now casting a skeptical eye on musings about the prevalence of intelligent life throughout the Milky Way. Just as most of the solar system is hostile to multicellular organisms, the same may be true of much of the galaxy.

Within a given planetary system, astronomers describe the optimal locations for life in terms of the circumstellar habitable zone (CHZ). Although its definition has varied, the CHZ is generally considered to be the region around a star where liquid water can persist on the surface of a terrestrial, or Earth-like, planet for at least a few billion years. The zone is ring-shaped [*see illustration on opposite page*]. Its inner boundary is the closest that a planet can orbit its host star without losing its oceans to space. In the most extreme case, a runaway greenhouse effect might take hold and boil off the oceans (as happened on Venus). The outer boundary is the farthest a planet can roam before its oceans freeze over. From basic stellar theory, astronomers can estimate the size of the CHZ for a star of any mass [see "How Climate Evolved on the Terrestrial Planets," by James F. Kasting, Owen B. Toon and James B. Pollack; SCIENTIFIC AMERICAN, February 1988].

Obviously, many other factors also contribute to the habitability of a planet, including the ellipticity of its orbit, the company of a large moon and the presence of giant planets, let alone the details of its biology. But if a planet orbits outside the zone, none of these minutiae is likely to matter. Similarly, it doesn't make much difference where the CHZ is located if the planetary system as a whole resides in a hostile part of the galaxy.

Thus, in 1999 we proposed the concept of a galactic equivalent to the CHZ: the galactic habitable zone (GHZ). The GHZ defines the most hospitable places in the Milky Way—those that are neither too close nor too far from the galactic center. We are not the first to consider habitability in this broader context. For the past decade Virginia Trimble of the University of Maryland and the University of California at Irvine has been writing about the connection between galactic chemical composition and the conditions required for life. But in recent years, there has been a huge breakthrough: the discovery of giant, Jupiter-size planets around sunlike stars. Not every sunlike star has such a planet. In fact, the giant planets discovered to date are primarily found around stars that are rich in chemical elements heavier than helium—what astronomers call "metals." This correlation suggests that metal content is an important factor in forming giant planets. (At present, the leading search technique cannot detect Earth-size planets.) At the same time, astronomers have gained a new and sobering appreciation of how deadly our galaxy can be, filled as it is with exploding stars and stellar close encounters. Even where planets do exist, they may not be fit for complex life-forms.

Overview/*Habitable Zone*

- What does a planet need to support complex life-forms? Astronomers have generally focused on the stability of surface water—which is possible only within a certain range of distances from the planet's star, a region known as the circumstellar habitable zone. But in discovering extrasolar planets over the past five years or so, researchers have come to appreciate a broader set of conditions.
- Ideally, the star and its planetary retinue should orbit within a certain range of distances from the center of the galaxy. Too far, and the nebula from which the star emerged will lack the heavy elements out of which planets are made. Too close, and hazards such as orbital instabilities, cometary collisions and exploding stars will nip ecosystems in the bud. The sun's position is just right.
- All this suggests that complex life is rare in the galaxy.

Where's the Wherewithal?

THE BOUNDARIES of the galactic habitable zone are set by two requirements: the availability of material to build a habitable planet and adequate seclusion from cosmic threats. The story of how chemical elements came to be assembled into Earth is one told by modern cosmology, stellar astrophysics and planetary science. The big bang produced hydrogen and helium and little else. Over the next 10 billion years or so, stars cooked this raw mix into a rich stew of elements. Within the interstellar medium, the ratio of the number of metal atoms to the number of hydrogen atoms—that is, the "metallicity"—gradually increased to its present value.

These metals are the building blocks of Earth-like planets, and their abundance affects the size of the planets that can form. Size, in turn, determines whether a planet can retain an atmosphere and sustain geologic activity. Moreover, without enough metals, no giant planets can form at all, because they coalesce around a rocky core of a certain minimum size. Ob-

EDWARD BELL AND NASA [*preceding pages*]; DON DIXON [*opposite page*]

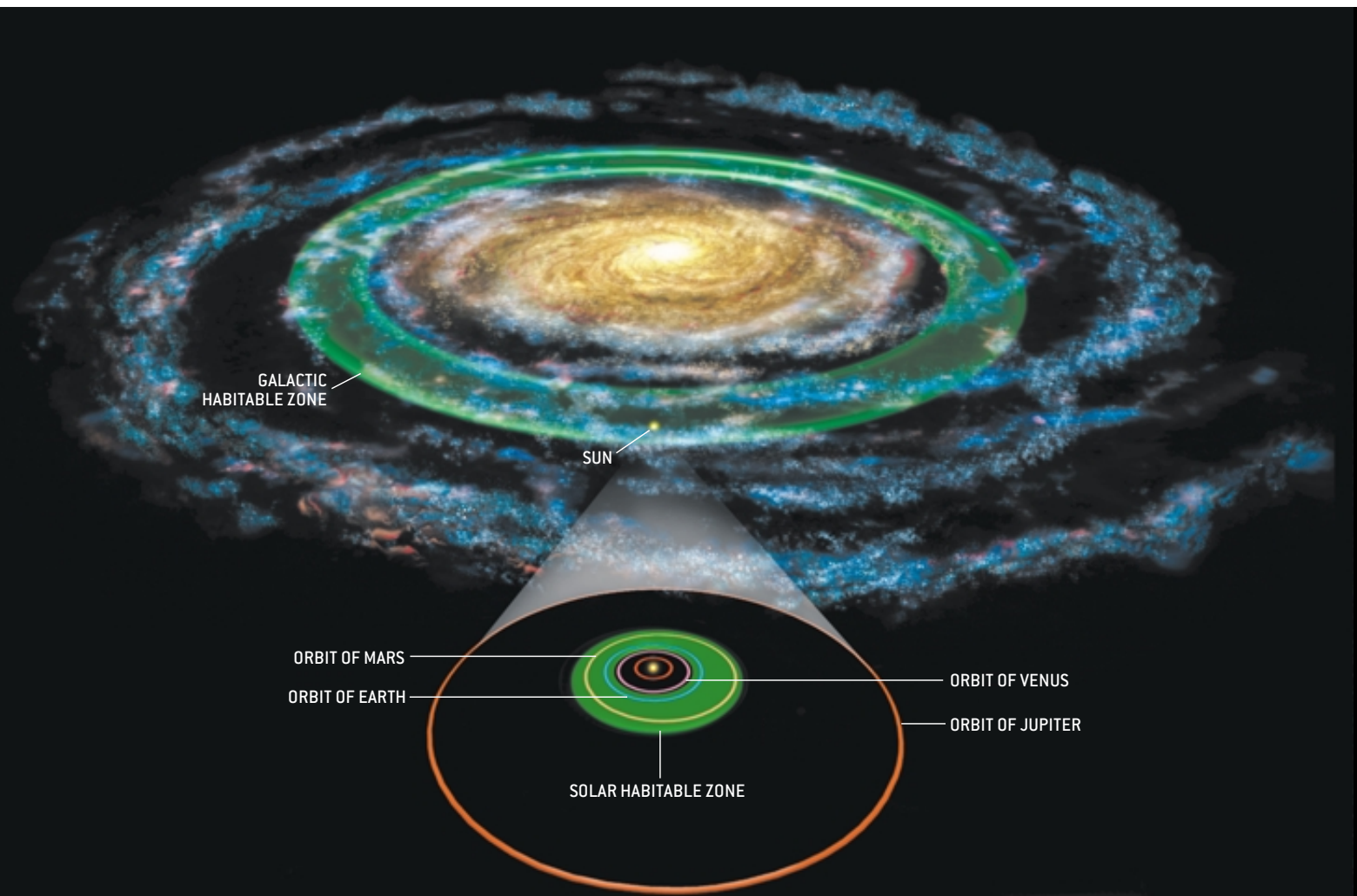
Astronomers have gained a new and sobering appreciation of HOW DEADLY OUR GALAXY CAN BE.

servations of extrasolar planets are beginning to define the required metallicity for building giant planets. No such planet has been found around any star with a metallicity of less than 40 percent of the sun's. In a study reported last year, the Hubble Space Telescope failed to detect any planets in the globular cluster 47 Tucanae, whose stars have metallicities of 25 percent of the solar value [see "Searching for Shadows of Other Earths," by Laurance R. Doyle, Hans-Jörg Deeg and Timothy M. Brown; SCIENTIFIC AMERICAN, September 2000].

Conversely, too high a metallicity can also be a problem. Terrestrial planets will be larger and, because of their stronger gravity, richer in volatile compounds and poorer in topographic relief. That combination will make them more likely to be completely covered with water, to the detriment of life. On Earth, the mix of land and sea is important for atmospheric temperature control and other processes. High metallicity also increases the density of the protoplanetary disk and thereby induces the giant planets to shift position [see "Migrating Planets," by Renu Malhotra; SCIENTIFIC AMERICAN, September 1999]. A by-product of this orbital migration is that it will fling any smaller, Earth-like bodies out of the system altogether or shove them into the sun. As the elephants move around, the ants get crushed.

In a recent study, Charles H. Lineweaver of the University of New South Wales in Australia explored the dependence of planet formation and migration on metallicity. He assumed that the probability of forming a terrestrial planet is proportional to the metallicity of the parent star, because both the star and the planet arose from the same cloud of dust and gas. From the extrasolar planet statistics, he inferred that the probability of giant-planet migration rises steeply with increasing metal-

HABITABLE ZONE of the Milky Way (*green*) excludes the dangerous inner regions and the metal-poor outer regions of our galaxy. It is analogous to the habitable zone on the much smaller scale of our solar system (*inset*). Neither zone has sharp boundaries. The bulge is shown as yellow and the active star-forming regions in the spiral arms as blue and pink.



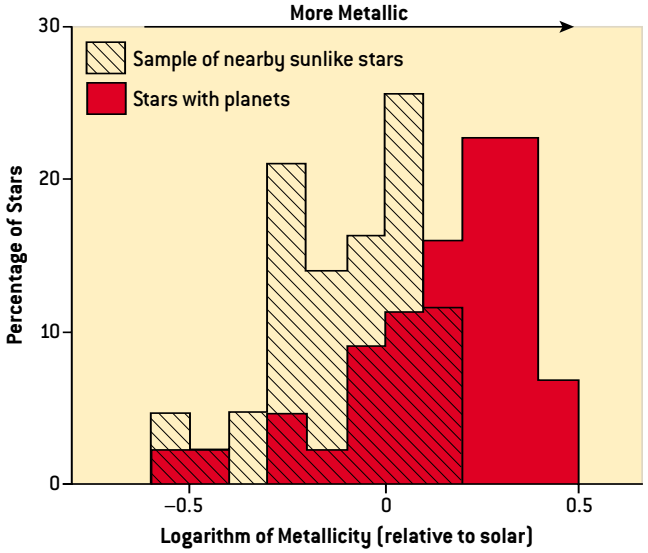
licity, with migration inevitable if the metallicity is 300 percent of the solar value. Although Lineweaver's calculations are tentative, they suggest that a metallicity near the sun's may be optimal for the production of Earth-mass planets in stable orbits.

Through Thick and Thin

ONLY PART OF THE MILKY WAY satisfies this requirement. Astronomers usually subdivide the Milky Way into four overlapping regions: halo, bulge, thick disk and thin disk. Stars in each region orbit the galactic center much as planets in our solar system orbit the sun. The halo and thick disk tend to contain older, metal-poor stars; it is unlikely that terrestrial planets as large as Earth have formed around them. Stars in the bulge have a wide range of metallicities, but cosmic radiation levels are higher there.

The thin disk is the sun's home. The metallicity of its gas declines with distance from the galactic center. At the sun's location, about 8.5 kiloparsecs (28,000 light-years) out, it is decreasing at 17 percent per kiloparsec. The logarithm of the metallicity (which astronomers give in units called "dex," the sun having a value of 0 dex, by definition) falls off linearly with distance, with a slope of –0.07 dex per kiloparsec. Observers measure the metallicity gradient using spectral features in various classes of stars and nebulae. The different indicators have converged onto the same answer only within the past three or four years, and galaxies similar to the Milky Way are now known to have similar disk metallicity gradients.

The gradient is an outcome of variations in the star-formation rate. Farther from the center of the galaxy there is proportionately less gas and therefore less star formation. Consequently, the outer reaches of the galaxy have built up less metal than the inner parts. In the galaxy as a whole, the star-formation rate peaked about eight billion to 10 billion years ago and has been declining ever since. Today the metallicity in the solar neighborhood is increasing by about 8 percent every billion years. As the gas supply dwindles, the metallicity will grow at an ever slower rate.



Taking into account the disk metallicity gradient and its evolution, we can place rough limits on the GHZ both in space and in time [*see illustrations on page 66*]. Stars forming today with a metallicity of between 60 and 200 percent of the sun's value generally reside between 4.5 and 11.5 kiloparsecs from the galactic center—a region that contains only about 20 percent of the stars in the galaxy. Moreover, the typical star in the solar neighborhood did not reach the 60 percent threshold until five billion to six billion years ago. The sun itself is about 40 percent richer in metal than other stars formed at the same time and location in the disk. This increased metal content may have given life on Earth a head start.

Iron Curtains

ONE POTENTIAL COUNTERARGUMENT is that the correlation of metallicity and detected planets is not the same as causation. Perhaps the causation goes in the opposite direction: instead of high stellar metallicity explaining the presence of giant planets, the presence of giant planets might explain the high stellar metallicity. This would happen if they tended to fall into the stars, enriching their metal content. Most astronomers now think that stars do gobble up planets and smaller bodies. But the outer convective layers of sunlike stars are so massive and so well mixed that they would need to devour an unreasonable amount of planetary material to fully account for the high metallicities seen among stars with planets.

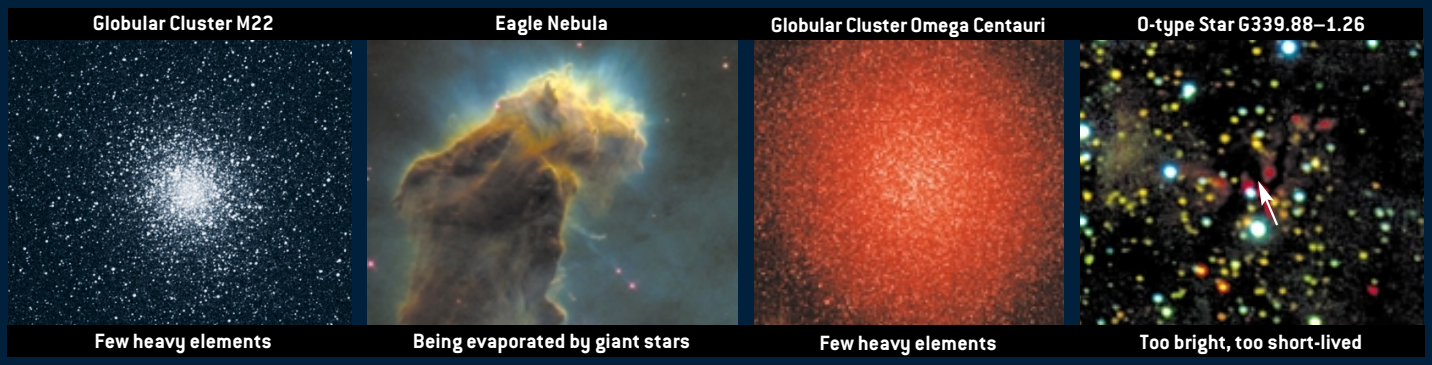
Another rejoinder is that the correlation might be an observational bias. It is harder to spot planets around metal-poor stars; the leading planet search method relies on stellar spectral lines, which are weaker when a star has less metal. But the detection efficiency does not suffer appreciably until a star's metallicity drops below about 10 percent of the sun's value—which is well below the 40 percent threshold needed for giant planets. The observed correlation with planets is quite real.

Metallicity is not the only compositional prerequisite for habitable planets; the relative abundances of different elements matter, too. The most abundant elements on Earth were produced primarily in supernova explosions, of which there are two basic types. Type I events, most of which result from the detonation of a white dwarf star, produce mainly iron, nickel and cobalt. Type II supernovae, which entail the implosion of a massive star, mostly synthesize oxygen, silicon, magnesium, calcium and titanium. Crucially, type II events are also the sole natural source of the very heaviest elements, such as thorium and uranium.

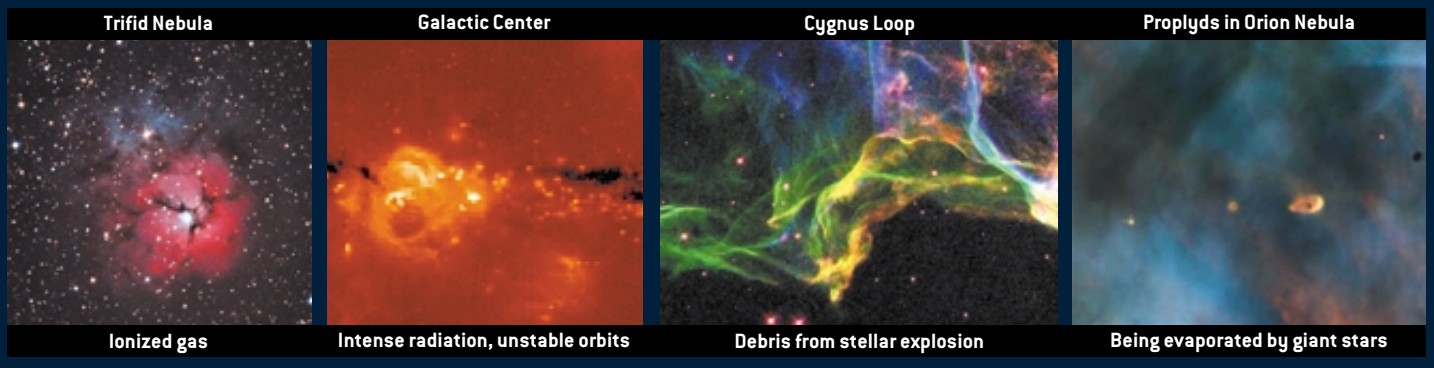
Because star formation in our galaxy is tapering off, the overall rate of supernova explosions is declining—as is the ratio of type II to type I events. Type II supernovae involve short-lived massive stars, so their rate closely tracks the star-formation rate. The rate of type I supernovae, on the other hand, depends on the

SURVEYS OF EXTRASOLAR PLANETS conducted by astronomers have revealed how important the supply of planet-building material is. As this histogram shows, the stars that are parents to giant planets (*red area*) tend to have a greater abundance of heavy elements ("metals") than the average nearby sunlike star does (*black*).

SARA CHEN; SOURCE: NUNO C. SANTOS *Geneva Observatory*



WHAT IS BEAUTIFUL is often dangerous, in space as on Earth. Some of the most renowned sites in the galaxy are hostile to planets, let alone living things. The safest places in the galaxy tend to be the most boring ones.



production of longer-lived intermediate-mass stars, so it responds more slowly to changes in the star-formation rate.

As a result of the shifting supernova ratio, new sunlike stars are richer in iron than those that formed five billion years ago. All else being equal, this implies that a terrestrial planet forming today will have a proportionately larger iron core than Earth does. It will also have, in 4.5 billion years, about 40 percent less heat from the decay of potassium, thorium and uranium. The heat generated by these radioactive isotopes is what drives plate tectonics, which plays an essential role in the geochemical cycle that regulates the amount of carbon dioxide in our atmosphere. Perhaps terrestrial planets forming today would be single-plate planets like Venus and Mars. The lack of plate tectonics on Venus contributes to its hellish conditions [see "Global Climate Change on Venus," by Mark A. Bullock and David H. Grinspoon; SCIENTIFIC AMERICAN, March 1999]. But we do not yet understand all the ways a planet's geology depends on its internal heat flow.

Danger, Danger

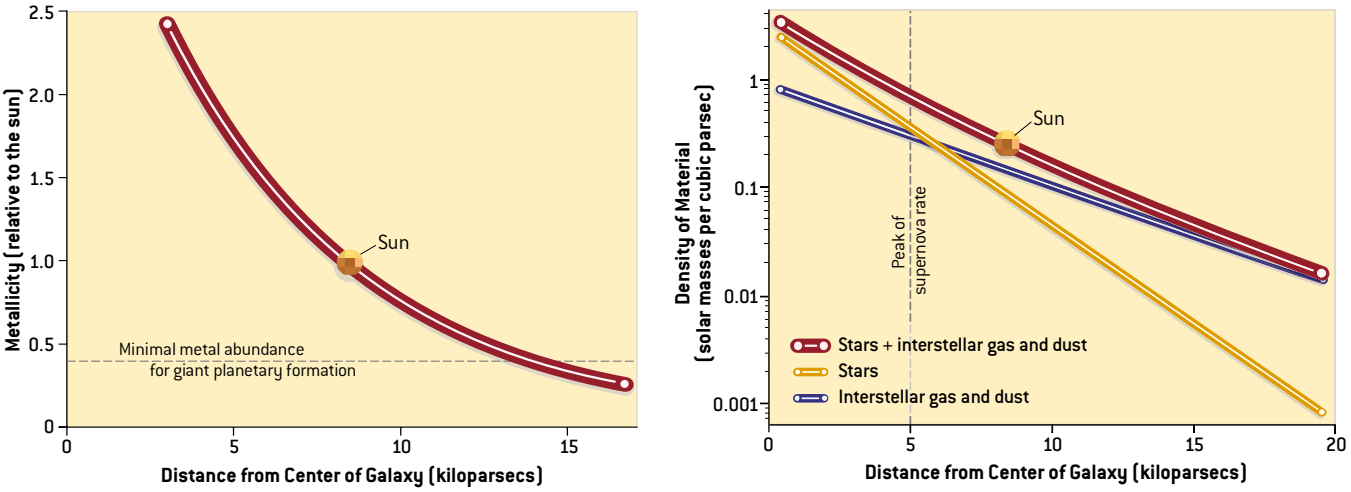
EVEN IF YOU MANAGE to get all the necessary atoms in the right place at the right time to build an Earth, you may not be justified in sticking a "habitable" label on it. A planet must also be kept reasonably safe from threats. These threats can be put into one of two categories: impacts by asteroids and comets, and blasts of radiation.

In our solar system the frequency of asteroid impacts depends on the details of Jupiter's orbit and formation; the rest of the galaxy has no direct effect. The cometary threat, on the other hand, is quite sensitive to the galactic environment. Comets are thought to reside in two long-term reservoirs, the Kuiper belt (which starts just beyond Neptune) and the Oort cloud (which extends halfway to the nearest star). Other stars probably have similar retinues. Infrared observations of young nearby stars indicate that most are surrounded by excess dust, consistent with the presence of Kuiper-belt objects. More recently, detection of water vapor around the highly evolved luminous

THE AUTHORS

GUILLERMO GONZALEZ, DONALD BROWNLEE and *PETER D. WARD* share an interest in the habitability of planets—both because they happen to live on one and because habitability is an intellectual challenge that draws on nearly every field of astrophysics and geophysics. The three are members of the astrobiology program at the University of Washington, which NASA recently awarded an astrobiology grant. Gonzalez, currently at Iowa State University, earned his doctorate at Washington studying the compositions of highly evolved stars in globular clusters. Brownlee specializes in the study of comet dust and meteorites and is the principal investigator for the Stardust mission, which plans to return comet dust samples to Earth in January 2006. Ward, a paleontologist, studies global mass extinctions.

NASA



LOCATION OF HABITABLE ZONE is determined by a balance between the supply of planet-building material and the prevalence of threats. The supply falls off with distance from the galactic center (*left*), while the density of stars—a proxy for perils such as stellar explosions and close encounters—also decreases with distance (*right*). An acceptable compromise is reached somewhere in the middle, although astronomers cannot yet pin down the precise location.

star IRC+10216 has been interpreted as evidence of evaporating comets. Changes in the shapes of certain spectral lines in Beta Pictoris, a young star with a dust disk, could be caused by infalling comets.

Because Oort-cloud comets are only weakly bound to the sun, it doesn't take much to deflect them toward the inner planets. A tug from galactic tides, giant molecular clouds or passing stars can do the trick [see "The Oort Cloud," by Paul R. Weissman; SCIENTIFIC AMERICAN, September 1998]. The frequency of such perturbations depends on our position in the Milky Way. As one goes toward the galactic center, the density of stars increases, so there are more close encounters. Moreover, a planetary system forming out of a metal-rich cloud will probably contain more comets than one forming out of a cloud with less metal. Thus, planetary systems in the inner galaxy should suffer higher comet influxes than the solar system does. Although the outer Oort cloud in such a system will become depleted more rapidly, it will also be replenished more rapidly from the inner cometary reservoirs.

High-energy radiation, too, is a bigger problem in the inner regions of the galaxy. Up to a point, a planet's magnetic field can fend off most particle radiation and its ozone layer can screen out dangerous electromagnetic radiation. But sufficiently energetic radiation can ionize the atmosphere and generate nitrogen oxides in amounts capable of wiping out the ozone layer. Energetic radiation hitting the atmosphere can also let loose a deadly rain of secondary particles.

The nastiest radiation events are, in order of decreasing duration, active galactic nucleus outbursts, supernovae and gamma-ray bursts. The nucleus of the Milky Way is currently relatively inactive; the supermassive black hole at the heart of our galaxy appears to be dormant. But observations of other galaxies suggest that central black holes occasionally turn on when a star or cluster wanders too close and is pulled to its death. The result is a burst of high-energy electromagnetic and particle radiation. Most of the radiation is emitted in a jet along the rotation axis of the galaxy, but many of the charged particles will spiral along the galaxy's magnetic field lines and fill its volume. The worst place to be during such an outburst is in the bulge. Not only would the overall radiation levels be high, the stars there would tend to have highly inclined and elliptical orbits that could bring them close to the nucleus or jet.

Supernovae and gamma-ray bursts are also more threatening in the inner galaxy, simply because of the higher concentration of stars there. Observations of supernova remnants indicate that supernovae peak at about 60 percent of the sun's distance from the galactic center, where they are about 1.6 times more frequent than at our location. The threat from gamma-ray bursts remains uncertain; astronomers do not know what triggers these gargantuan explosions or how tightly they beam their radiation. We could just be lucky to have avoided such a death ray so far.

Radiation can also steal life from the crib. Sunlike stars are not born in isolation but rather are often surrounded by both low- and high-mass stars. The high levels of ultraviolet radiation emitted by the latter erode circumstellar disks around nearby stars, reducing their chances of forming giant planets. John Bally of the University of Colorado at Boulder and his colleagues have estimated that only about 10 percent of stars avoid this kind of harassment. This could explain why a mere 3 percent of nearby sunlike stars are found to have giant planets.

All these threats imply a fairly broad habitable zone with fuzzy boundaries. But if we include proximity to the corotation circle as another requirement, then the GHZ could be very narrow. The corotation circle is where the orbital period of a star equals the rotation period of the galaxy's spiral arm pattern.

SARA CHEN

When a star orbits at or very near the corotation circle, spiral arm crossings are less frequent. It will take longer to cross a spiral arm, but what is important is the relatively long period between crossings. Recent measurements of the dynamics of stars near the sun indicate that the sun orbits very near the corotation circle. The spiral arms may look pretty, but they are best appreciated from afar, because the intense star formation and giant molecular clouds within the arms multiply the risks to complex life-forms.

Paradox Lost

AT THIS STAGE of our research, we are still some way from filling in the details of the GHZ. Continuing studies of comets, galactic nuclei, supernovae, gamma-ray bursts and stellar dynamics will help pinpoint the threats to life. Even now, however, we have a broad picture of the GHZ. The inner regions of the galaxy suffer from orbital instabilities, radiation bursts and cometary perturbations. The outer regions are safer, but because of the lower metallicity, terrestrial planets are typically smaller there. The GHZ appears to be an annulus in the disk at roughly the sun's location [*see illustration on page 63*]. The GHZ is a probabilistic concept: not every planet inside the zone is habitable (and not every planet outside is sterile). But the probability is much greater inside. The GHZ has been slowly creeping outward, as interstellar gas reaches solar metallicity.

The GHZ concept has important implications for searches for extraterrestrial intelligence. It can, for example, identify the most probable places for complex life to form, so that researchers can direct their searches accordingly. We can already say with some confidence that globular clusters, the outer disk and the galactic center make poor targets.

The GHZ concept also has implications for the debate swirling around the Fermi Paradox: If our galaxy is teeming with other civilizations, we should see some evidence of their existence; we do not, so perhaps we are alone [see "Where Are They?" by Ian Crawford; SCIENTIFIC AMERICAN, July 2000]. One of the arguments proposed to avoid that conclusion is that ETs may have no motivation to leave their home world and scatter signs of their presence through space. But if our ideas about the GHZ are correct, we live within an especially comfortable region of the Milky Way. Any civilization seeking a new world would, no doubt, place our solar system on their home-shopping list. The GHZ theory also weakens the argument that the galaxy is so big that interstellar explorers or colonizers have passed us by. The GHZ may be large, but it is just a part of the entire galaxy, and any galactic travelers would tend to roam around the annulus rather than haphazardly through the galaxy.

Furthermore, the GHZ concept constrains habitability not just in space but also in time. The Milky Way used to be pummeled by supernovae and an active nucleus. Only in the past five billion years or so could civilizations have safely arisen. The sun's relatively high metallicity probably gave us a head start. Therefore, the GHZ concept may provide at least a partial solution to the Fermi Paradox: complex life is so rare and isolated that we are effectively alone. To be sure, these implications apply only to complex life; simple organisms such as microbes could endure a much wider range of environments.

The broader universe looks even less inviting than our galaxy. About 80 percent of stars in the local universe reside in galaxies that are less luminous than the Milky Way. Because the average metallicity of a galaxy correlates with its luminosity, entire galaxies could be deficient in Earth-size planets. Another effect concerns the dynamics of stars in a galaxy. Like bees flying around a hive, stars in elliptical galaxies have randomized orbits and are therefore more likely to frequent their more dangerous central regions. In many ways, the Milky Way is unusually hospitable: a disk galaxy with orderly orbits, comparatively little dangerous activity and plenty of metals. It may not remain so for long. The Andromeda galaxy is predicted to have a close encounter with the Milky Way in about three billion years. That event will dislodge most stars in the disk from their regular orbits. It may also pour fresh fuel onto the Milky Way's central black hole and cause it to flare up, with possibly unhappy consequences for the inhabitants of Earth.

Douglas Adams, that great expositor of simple truths, famously summed up what he took to be the product of the past few centuries of progress in astronomy: "Far out in the uncharted backwaters of the unfashionable end of the western spiral arm of the Galaxy lies a small unregarded yellow sun." But as is often the case, fashionable is not the same as comfortable. We live in prime real estate. SA

Any extraterrestrial civilization SEEKING A NEW WORLD would place our solar system on their home-shopping list.

MORE TO EXPLORE

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The Galactic Habitable Zone: Galactic Chemical Evolution. Guillermo Gonzalez, Donald Brownlee and Peter D. Ward in *Icarus,* Vol. 152, No. 1, pages 185–200; July 1, 2001. Preprint available at **astro-ph/0103165**

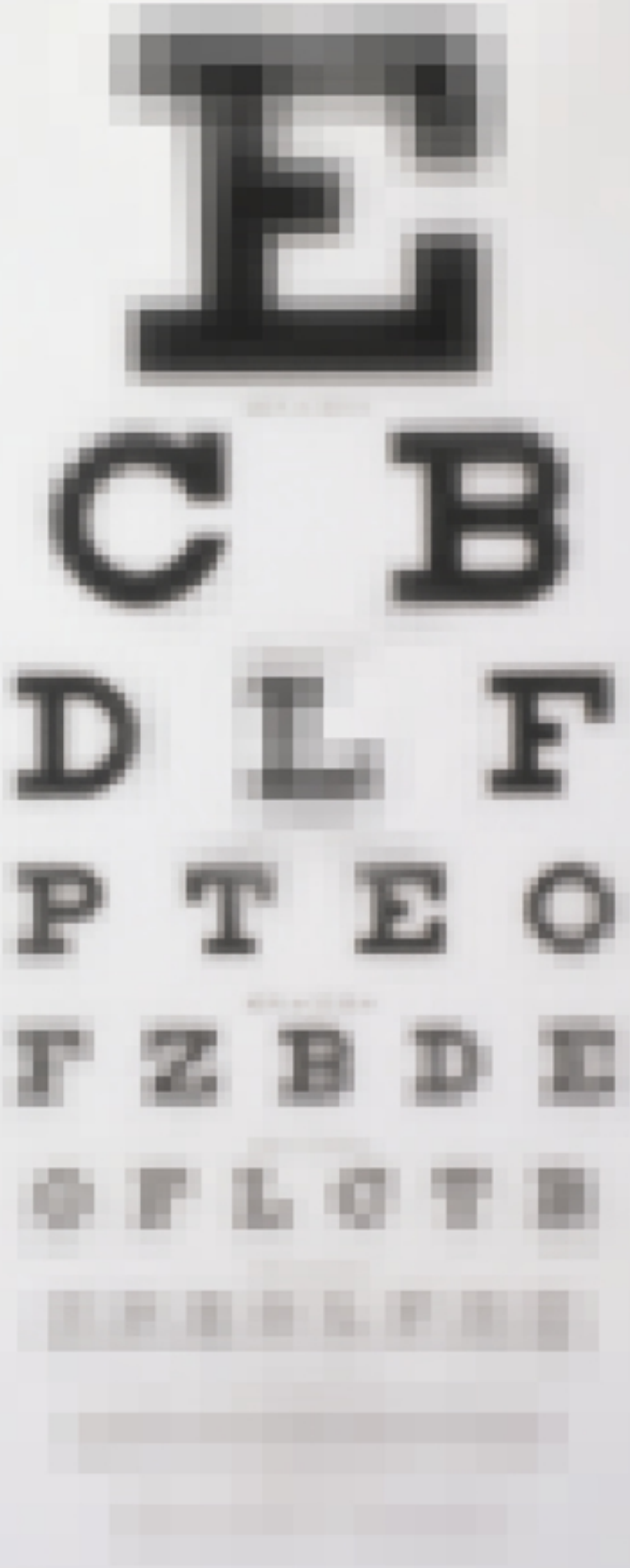


IMAGE ALTERED BY SARA CHEN

the challenge of macular degeneration

Researchers have begun to identify the causes of this dreaded eye disease that targets the elderly

By Hui Sun and Jeremy Nathans

CAREFULLY OBSERVE THE EYES of a friend while he or she is reading a book, and you will see the two eyes rotating from side to side with each line of text. Your eyes are moving in the same way as you read this article. To understand how important this eye movement is, try reading this sentence at a normal distance while keeping your gaze fixed on one word. You will be able to read the words within about two centimeters of the center of your gaze but not the words farther away. If your vision is normal, you will be aware that the more distant text is present, but you won't be able to see it at the high spatial resolution required for reading.

VISION LOSS caused by macular degeneration is simulated in this image, which shows what a viewer with the disease would see if his or her gaze were focused on the "L" in the third line of the eye chart. The "L" is blurred because macular degeneration damages the central part of the retina, which is responsible for high-resolution vision. The "E" at the top of the chart and the bottom lines are also blurred, because peripheral vision always has low resolution, even in healthy eyes.

It is a remarkable fact that we go about our daily lives generally unaware that less than 1 percent of each image is received and processed at high resolution. We are largely oblivious to this design feature because rapid eye movements allow us to fixate on the part of the image that is of immediate interest. When we fixate, we rotate our eyes so that the point of interest is imaged on the central region of the retina, the paper-thin sheet of neurons that lines the back wall of the eyeball. This central region, which is the only part of the retina that facilitates high-resolution vision, is called the fovea; a somewhat larger zone centered on the fovea is called the macula.

Scientists hope to develop new treatments that can slow or halt the progress of macular degeneration.

By consigning more than 99 percent of the retina to the task of low-resolution vision, the human visual system makes efficient use of a finite number of retinal neurons. This design, however, carries a significant risk: if a person's central retina is damaged by disease, he or she will suffer a significant loss of acuity in the central field of vision [*see illustration on page 68*]. This is what happens in macular degeneration, a disease that affects nearly two million Americans, most of them elderly. There are few places in the human body where loss or dysfunction of such a tiny piece of tissue—it is about two millimeters in diameter—can have such dire consequences.

Ophthalmologists have long been able to diagnose macular degeneration accurately, but the difficult task of determining the causes of the disease has only just begun. By identifying the processes that lead to damage of the central retina, scientists hope to develop new treatments that can slow or halt the progress of macular degeneration. And perhaps in time researchers will discover effective techniques for repairing the retinal damage.

The Workings of the Retina

LET US BEGIN with a look at the normal human retina. Light enters the eye through the pupil and is focused by the lens to form a sharp image on the retina, where it is captured by specialized photoreceptor neurons called rods and cones [*see illustration on opposite page*]. Rods are responsible for vision in dim light, whereas cones handle vision in bright light, as well as color vision. Each photoreceptor cell has a long appendage, called the outer segment, filled with specialized proteins that absorb light and amplify and convey information about the intensity and duration of the stimulus. The shape of the outer segment gives the different photoreceptor cells their names: the outer segment of a cone tapers to a point, but the outer segment of a rod is cylindrical throughout its length.

Each photoreceptor outer segment is filled with hundreds of flattened membrane sacs (called discs) arranged like a stack of pancakes. The discs and the specialized proteins are synthesized in the photoreceptor's cell body and are assembled at the base of the outer segment. Each photoreceptor synthesizes about 10 percent of the outer segment every day. As this material is added to the outer segment's base, the tip of the outer segment is clipped off and degraded by a specialized sheet of cells called the retinal pigment epithelium (RPE), which lies immediately behind the retina. This system most likely exists as a way of replacing protein and lipid components in the outer segment that have suffered chemical damage from exposure to light and oxygen, a process known as photo-oxidation.

The RPE services photoreceptor cells in other ways as well: it maintains the correct ionic composition of the fluid surrounding the photoreceptors; processes and recycles the vitamin A derivative that the photoreceptors use for light detection; and transports and filters nutrients from the choroidal blood vessels, which lie immediately behind the RPE. Finally, as its name suggests, the RPE is deeply pigmented. Melanin granules in the RPE absorb light that passes through the photoreceptors, minimizing the loss in image quality that would be caused by stray light inside the eye.

The distinguishing feature of macular degeneration is a loss of central vision, but the appearance of the retina differs greatly from patient to patient. Macular disease in older people—which is called age-related maculopathy, or ARM—is often associated with the loss of RPE cells. When the retina is viewed through an ophthalmoscope, this cell loss appears as unpigmented or irregularly pigmented areas. RPE cell loss can be more precisely analyzed by fluorescein angiography, a technique that enables ophthalmologists to see the blood vessels of the eye by injecting a fluorescent compound into the bloodstream. In a normal eye the fluorescent dye is readily seen in the fine blood vessels within the retina. But the dye is not seen, or is seen at a much reduced intensity, in the far more extensive choroidal vessels, because these vessels lie behind the heavy pigmentation of the RPE. In an eye with ARM, however, any area where the RPE cells are missing will reveal the dye within the choroidal circulation.

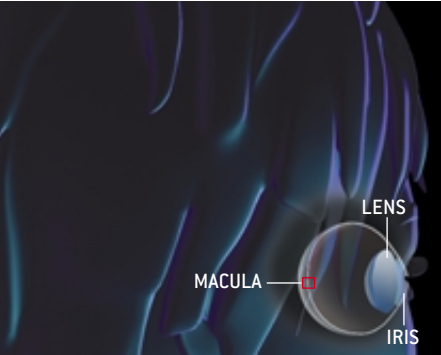
In about 10 percent of individuals with ARM, fluorescein angiography may also uncover a more ominous problem: new blood vessels growing from the choroid into or just beneath the retina, a process called neovascularization. Under normal conditions, a thin sheet of extracellular proteins and polysaccharide chains known as Bruch's membrane separates the choroidal blood vessels and the RPE. Any growth of choroidal vessels

Overview/*Macular Disease*

- To see an object at high resolution, an observer must rotate his or her eyes so that the object is imaged on the central region of the retina. Macular degeneration can severely damage this region, causing a significant loss of visual acuity.
- Macular disease in older people is called age-related maculopathy, or ARM. The disorder leads to the loss of specialized cells in the retina that assist the photoreceptor neurons (rods and cones).
- Because a risk factor for ARM is a family history of the disease, researchers are trying to identify genes that are associated with the disorder. By analyzing these genes and the proteins they produce, scientists hope to learn how to slow or halt the progress of the disease.

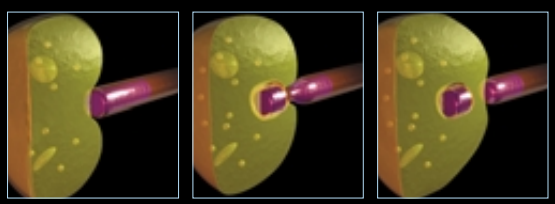
PEERING INSIDE THE EYE

The macula is at the center of the retina, the thin sheet of neurons that lines the back wall of the eyeball. Though only two millimeters wide, the macula contains hundreds of thousands of photoreceptors—the rods and cones that absorb light and send visual information to the brain.



HEALTHY MACULA

Light passes through layers of ganglion and bipolar cells, which are nearly transparent, before reaching the rods and cones (*left*). The outer segments of the photoreceptors abut a sheet of cells called the retinal pigment epithelium (RPE). These cells recycle the contents of the outer segments: as each segment grows, its tip is clipped off and digested by an RPE cell (*below*).



EFFECTS OF MACULAR DEGENERATION

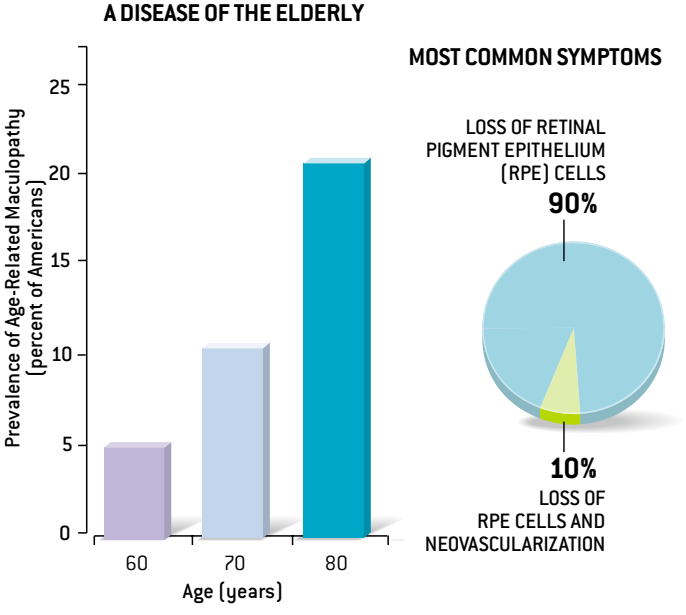
Macular degeneration may interfere with the recycling of the photoreceptors' outer segments. Deposits of indigestible material accumulate in the RPE cells, slowly killing them. The neighboring photoreceptors then die. In some cases, the choroidal blood vessels break through Bruch's membrane and enter the retina, where they can cause irreversible scarring.

BRYAN CHRISTIE

through Bruch's membrane is cause for concern because the new vessels are prone to bleeding, which ultimately results in irreversible scarring of the retina. Moreover, defects in Bruch's membrane permit fluid to accumulate underneath the RPE or between the retina and the RPE, a condition that impairs gas and nutrient exchange between the retina and the choroidal blood supply.

In the adult eye, any gaps that form within the RPE layer as a result of cell death appear to be imperfectly filled by new RPE cells, perhaps because of a limitation on cell division or differentiation. Why do RPE cells malfunction or die as we get older? The Achilles' heel of the RPE may come from its role in recycling the outer segments of photoreceptors. RPE cells are large and flat, and each one services about 50 photoreceptors. Thus, each RPE cell must engulf and degrade 10 percent of 50 outer segments every day throughout the life of an individual. This daily diet is equivalent in mass to five red blood cells, making the RPE cell by far the most active phagocytic cell in the body. (Phagocytosis is the process by which a cell engulfs and digests material.)

As humans age, subcellular material called lipofuscin accumulates inside the RPE cells, and small deposits called drusen can accumulate immediately underneath the RPE. Although the exact chemical composition of this material is not fully known, both lipofuscin and drusen are likely to consist, at least in part, of indigestible debris left over from the engulfment of thousands of outer segments. Drusen are large enough to be seen through an ophthalmoscope, and their abundance is roughly correlated with the risk of vision loss in ARM.



MACULAR DEGENERATION affects nearly two million Americans. About one fifth of all 80-year-olds suffer from age-related maculopathy (ARM), the most common form of the disease. ARM is associated with the loss of RPE cells. About 10 percent of those with the disease also have neovascularization, which can cause severe vision loss.

According to epidemiological studies, the only factors that have a consistent correlation with the risk of developing ARM are age, a history of cigarette smoking and a family history of the disease. Among Americans, ARM is found in approximately 5, 10 and 20 percent of people at ages 60, 70 and 80, respectively. Although most of these individuals have early-stage ARM with minimal loss of visual function, they are at significant risk for progressing to more severe loss.

The Genetic Connection

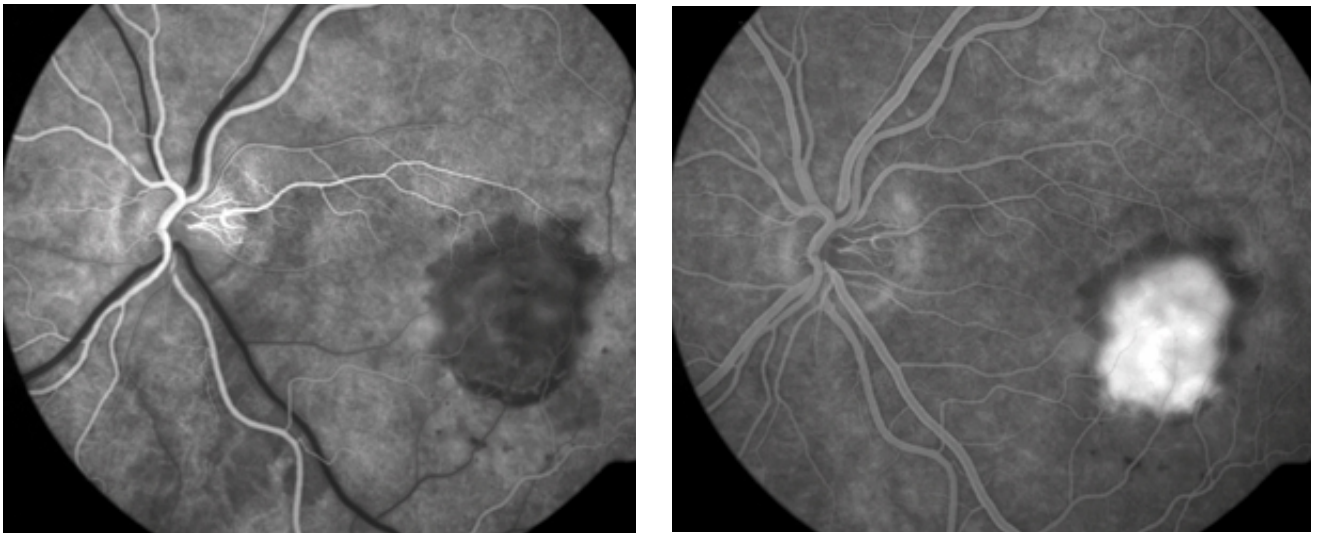
THE FINDING that a family history of ARM is a risk factor suggests that the disease may have a genetic component. Of course, familial clustering might reflect a shared environmental factor rather than shared genes. But studies of identical and fraternal twins have shown that identical twins exhibit close to 100 percent concordance for ARM—that is, if one member of an identical-twin pair has ARM, the other twin is almost certain to have it as well. For fraternal twins or nontwin siblings, the concordance is less than 50 percent. The simplest interpretation of these data is that identical twins have a greater degree of concordance because they are genetically identical. (On average, fraternal twins share half their genes.)

The twin data offer compelling evidence for a genetic component to ARM, but they do not indicate whether this reflects the action of one, 10 or 100 genes, nor do they provide us with any simple method of identifying the relevant genes. Furthermore, ARM presents a special challenge to the standard method of identifying disease genes, which involves studying families with large numbers of affected individuals. A disease that occurs late in life will typically be found in only a small fraction of family members because many individuals will be too young to show evidence of the disease and others will have died before showing any symptoms.

To circumvent these difficulties, researchers have focused on a group of less common macular diseases that occur earlier in life and show clear patterns of inheritance. Of these, the most intensively studied disorders are dominant familial drusen, vitelliform macular dystrophy, Sorsby's fundus dystrophy and Stargardt disease. Each of these disorders typically affects the central retina and is associated with an accumulation of material within or under the RPE. Stargardt disease is the most common of the four, occurring in one in every 10,000 people. Although these early-onset diseases are worthy of study in their own right, their similarity to ARM holds out the additional possibility that they may provide critical clues to understanding the causes of the age-related disorder.

Over the past several years, the genes responsible for these early-onset diseases have been identified by meticulous studies of affected families. In each case, researchers determined the chromosomal location of the disease gene by comparing the patterns of inheritance, then identified the gene itself by finding DNA sequence changes—mutations of the gene—that distinguish affected and unaffected individuals. For three of the diseases, they observed that any of a variety of mutations in the

JESSIE NATHANS



FLUORESCEIN ANGIOGRAPHY is a technique that allows ophthalmologists to observe the effects of macular degeneration by injecting a fluorescent dye into the bloodstream. Just 12 seconds after injection, the dye lights up the arteries of the retina, whereas the veins remain dark (*left*). The macula appears as a dark zone because of previous bleeding from new vessels that have broken into the central region of the retina. Half a minute later the macula turns bright from the dyed blood that has leaked out of the new vessels and into the retina (*right*).

relevant genes can give rise to the disorder. Dominant familial drusen, however, is unusual: every person with this disorder appears to carry exactly the same mutation. The data suggest that the affected individuals scattered throughout Europe and the U.S. share a common ancestor who carried this mutation.

Investigators next turned their attention to the proteins produced by the disease genes. The mechanism of Stargardt disease is currently the best understood. Although the disorder is characterized by a massive accumulation of lipofuscin in the RPE, we now know that the primary defect lies in the outer segments of the photoreceptors. The Stargardt disease gene encodes a transport protein called ABCR that resides in the membranes of the discs in the outer segment. Experiments indicate that ABCR uses ATP, the cell's chemical energy source, to transport a vitamin A derivative inside the photoreceptor cell.

This transport reaction is part of a larger cycle that replenishes the supply of the critical light-sensing form of vitamin A—called 11-cis retinal—in the photoreceptor outer segment. The process of light absorption in the photoreceptor converts 11-cis retinal to a related derivative called all-trans retinal, which is released into the disc membrane and then chemically modified and transported to an RPE cell. Defects in the ABCR protein, however, slow the chemical modification of all-trans retinal, resulting in a buildup of this compound. Unfortunately, all-trans retinal spontaneously reacts at a low rate with membrane lipids to form a substance known as A2E—a stable derivative that resists degradation. As the RPE cells engulf the outer segments, A2E accumulates in the cells in the form of lipofuscin. Recent evidence indicates that A2E impairs RPE viability by sensitizing the cells to light damage.

Is the mechanism of Stargardt disease related to that of ARM? One potential connection comes from the finding that A2E also accumulates in the RPE of the normal human eye as it ages, albeit at lower levels than in eyes affected by Stargardt disease. In fact, A2E was first identified as one of the major components of lipofuscin in the eyes of older people. This discovery suggests that A2E's effects in normal eyes may be similar to its effects in eyes with Stargardt disease. A second connection is indicated by recent genetic studies: two DNA sequence changes in the ABCR gene have been found to occur more frequently in individuals with ARM than in the general population. This result suggests that at least some cases of ARM may be influenced by sequence changes in the ABCR gene.

Similar studies of the genes responsible for the other early-onset diseases have not revealed any mutations of those genes in individuals with ARM. It is important, however, to explore these disorders thoroughly; functionally similar defects in biochemistry and cell biology might also play a role in ARM. For example, research indicates that the genetic mutations that cause Sorsby's fundus dystrophy may impair the eye's ability to degrade extracellular material such as Bruch's membrane. In patients with this disorder, Bruch's membrane is greatly thickened, which reduces the diffusion of essential nutrients to the RPE and retina. The mechanisms of dominant familial drusen and vitelliform macular dystrophy are not as well understood, but initial evidence suggests that these diseases may also interfere

THE AUTHORS

HUI SUN and *JEREMY NATHANS* have been working together on the retina for eight years at the Johns Hopkins University School of Medicine. Sun, a postdoctoral fellow, received his Ph.D. in molecular biology and genetics from Johns Hopkins in 1998. Nathans, a professor, received a Ph.D. in biochemistry and an M.D. from the Stanford University School of Medicine in 1987. Both Sun and Nathans are members of the Howard Hughes Medical Institute. Although they grew up at opposite ends of the globe (Tianjin, China, and Baltimore, respectively), their professional interests are quite similar.

KEVIN LANGTON *Department of Ophthalmology, Columbia University*

We should keep in mind that for a disease that develops over decades, any treatment that slows its progress by even 10 or 20 percent will have an enormous impact.

with the normal functioning of Bruch's membrane and the RPE.

Another line of inquiry has focused on the retinal degeneration caused by the process of vision itself. Light absorption by vitamin A and its derivatives in the retina produces chemically reactive free radicals—oxygen-containing compounds with unpaired electrons. Research on organisms as diverse as humans and bacteria has shown that free radicals are a major source of damage for most, if not all, life-forms. Studies of retinal degeneration in laboratory animals further suggest that this type of damage occurs in both the photoreceptors and the RPE. It is an irony of nature that the same light-absorbing properties that make vitamin A and its derivatives so useful as visual sensors also make them efficient producers of free radicals.

A number of epidemiological studies have examined lifetime light exposure as a possible risk factor for ARM. Evidence from some of these studies shows that high levels of light exposure may indeed increase the risk of developing the disorder. Furthermore, the photo-oxidative damage may be worsened by chemicals such as A2E, which is presumed to augment the production of free radicals in the RPE.

How do the retina and the RPE minimize photo-oxidative damage? The retina contains high concentrations of several antioxidant chemicals that efficiently "soak up" free radicals. Two of the antioxidants, zeaxanthin and lutein, are highly concentrated in the macula; a third, vitamin E, is present at high concentrations in photoreceptor outer segments and also in the RPE. All three antioxidants come from plants; dark-green leafy vegetables such as spinach, collard greens and kale are particularly rich in zeaxanthin and lutein.

Other defenses employed by the body's cells include the zinc-containing enzyme superoxide dismutase and a second enzyme, catalase, both of which inactivate various free radicals. These observations have led some researchers to hypothesize that increasing the amount of zeaxanthin, lutein and zinc in one's diet might lower the risk of developing ARM or delay its onset. Unfortunately, epidemiological studies designed to assess the correlation have yielded conflicting results. There is no clear consensus yet on the effectiveness of any dietary supplements in decreasing the risk of macular disease.

Prospects for Treatment

AT PRESENT, the only accepted treatments for macular degeneration are those aimed at destroying the new blood vessels that have grown through Bruch's membrane. Photocoagulation, the mainstay of current therapy, consists of cauterizing the blood vessels with a highly focused laser beam directed at the subretinal target through the cornea and lens. Unfortunately, the localized heating also irreversibly damages the retina at the site of irradiation. A promising new laser treatment

IMPORTANCE OF MACULA is demonstrated in this pair of altered photographs. A person with healthy eyes sees objects much more clearly if they are in the central field of vision rather than at the periphery (*left*), because the central part of the retina is the only region that facilitates high-resolution vision. Macular degeneration damages this part of the retina, blurring the central field (*right*).

IMAGES ALTERED BY SARA CHEN

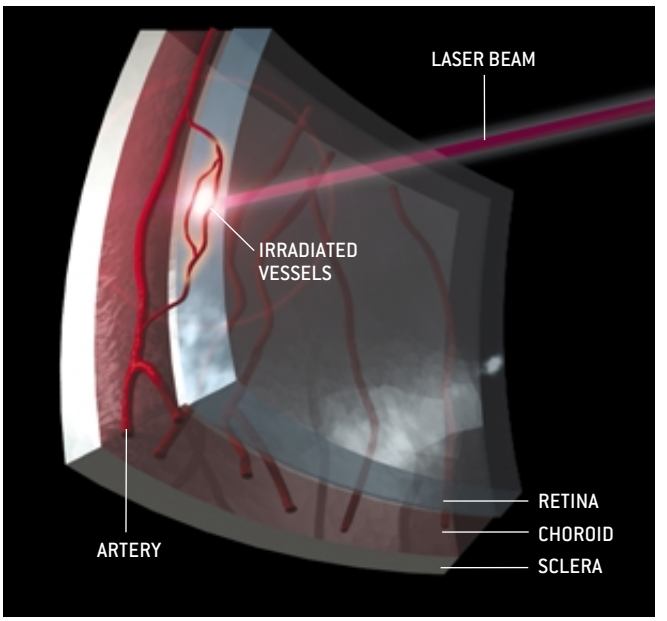
called photodynamic therapy may, for the most part, avoid this problem by more precisely targeting the new blood vessels for destruction. In this therapy, a light-absorbing dye called a photosensitizer is injected intravenously into the patient. A low-energy laser beam is then focused on the new blood vessels. When the photosensitizer absorbs the laser light, it produces a high concentration of free radicals that destroy the blood vessels but largely spare the adjacent retina. Photodynamic therapy is now in advanced clinical trials and is likely to be widely available in one or two years.

Although neovascularization is the most significant threat to vision posed by ARM, 90 percent of those with the disease do not have this symptom and are therefore not candidates for treatment. Moreover, photocoagulation and photodynamic therapy do not correct or slow the underlying disease process, so individuals who have received these treatments continue to suffer from the growth of new blood vessels.

What shape might future therapies take? Researchers are exploring several alternative methods for removing new blood vessels or slowing their growth. These methods include microsurgical removal of blood vessels through a small incision in the retina and high-energy irradiation of the back of the eye using techniques borrowed from cancer radiation therapy. Another interesting approach is an experimental surgical technique called retinal rotation. In this method the retina is gently lifted from the underlying RPE, rotated a few degrees around the optic nerve, and then allowed to settle back onto the RPE in its new location. If, prior to surgery, RPE cell loss or new blood vessel growth is localized to the region underneath the fovea, the fovea can be rotated so that it comes to rest over a healthier region of the RPE. As might be expected, rotating one of the retinas causes the brain to receive conflicting signals from the two eyes. Fortunately, this problem can be solved by surgically lengthening or shortening various muscles around the eyeball to produce a compensatory rotation of the entire eye in the opposite direction.

Another intriguing possibility is RPE cell transplantation. In studies with laboratory animals, scientists have been able to grow RPE cells outside the body and transplant them under the retina with high rates of success. Among the open questions are whether this technique can delay or halt the loss of visual function in humans and whether microsurgical techniques can be developed to place the cells under the fovea reliably without causing additional damage. As in all transplant procedures, immunological rejection may limit the long-term survival of donor cells if they are derived from another individual. This problem might be sidestepped by using donor RPE cells from the patient's own peripheral retina.

Some have even envisioned the repair or regrowth of the retina itself. This goal has long been considered virtually impossible because the adult mammalian retina shows no evidence that it can undergo further cell divisions. But retinal growth occurs throughout adult life in various species of fish that have retinas just as complex as our own. In these animals, stem cells—which can divide and differentiate into all the retinal cell types—reside at the outer margins of the retina and direct its continued growth. Recent work indicates that similar stem cells may exist in a dormant state at the edges of the mammalian retina. Perhaps these cells could be activated or transplanted to repair damage to the retina or the RPE.



PHOTODYNAMIC THERAPY is a promising new treatment for some cases of macular degeneration. A light-absorbing dye called a photosensitizer is injected into the patient. Then a low-energy laser beam is focused on the new blood vessels that have grown into the retina. When the photosensitizer absorbs the laser light, it produces free radicals that destroy the blood vessels but for the most part spare the adjacent retina.

The expense and risk of these therapies for macular disease will probably limit their use to patients who face imminent and severe vision loss. Therefore, it would be highly desirable to develop a less invasive treatment that could slow or halt the disorder at an earlier stage. Basic research into the biochemical and cellular defects responsible for macular degeneration will lay the groundwork for achieving this goal. It is not unreasonable to suppose that scientists could find a naturally occurring or synthetic compound that improves the function or extends the viability of RPE cells. Such a compound could protect the RPE from photo-oxidative damage, for example, or improve its efficiency in degrading photoreceptor outer segments. Although identifying such interventions for macular degeneration may seem like a tall order, we should keep in mind that for a disease that develops over decades, any treatment that slows its progress by even 10 or 20 percent will have an enormous impact. SA

MORE TO EXPLORE

Age-Related Macular Degeneration. Edited by Jeffrey W. Berger, Stuart L. Fine and Maureen G. Maguire. Mosby, 1999.

The National Eye Institute's Web site on macular degeneration: **www.nei.nih.gov/publications/armd.htm**

The Web site of the Foundation Fighting Blindness: **www.blindness.org**

The Web site of RetNet, which has information on genetic eye diseases: **www.sph.uth.tmc.edu/Retnet**

BRYAN CHRISTIE

THE OCEAN has overtaken a now abandoned house on Isles Dernieres ("last islands" in French), an eroding barrier island that once protected the Mississippi Delta against the encroaching sea.

Drowning New Orleans

By Mark Fischetti • Photographs by Max Aguilera-Hellweg

A major hurricane could swamp New Orleans under 20 feet of water, killing thousands. Human activities along the Mississippi River have dramatically increased the risk, and now only massive reengineering of southeastern Louisiana can save the city

THE BOXES are stacked eight feet high and line the walls of the large, windowless room. Inside them are new body bags, 10,000 in all. If a big, slow-moving hurricane crossed the Gulf of Mexico on the right track, it would drive a sea surge that would drown New Orleans under 20 feet of water. "As the water recedes," says Walter Maestri, a local emergency management director, "we expect to find a lot of dead bodies."

New Orleans is a disaster waiting to happen. The city lies below sea level, in a bowl bordered by levees that fend off Lake Pontchartrain to the north and the Mississippi River to the south and west. And because of a damning confluence of factors, the city is sinking further, putting it at increasing flood risk after even minor storms. The low-lying Mississippi Delta, which buffers the city from the gulf, is also rapidly disappearing. A year from now another 25 to 30 square miles of delta marsh—an area the size of Manhattan—will have vanished. An acre disappears every 24 minutes. Each loss gives a storm surge a clearer path to wash over the delta and pour into the bowl, trapping one million people inside and another million in surrounding communities. Extensive evacuation would be impossible because the surging water would cut off the few escape routes. Scientists at Louisiana State University (L.S.U.), who have modeled hundreds of possible storm tracks on advanced computers, predict that more than 100,000 people could die. The body bags wouldn't go very far.

A direct hit is inevitable. Large hurricanes come close every year. In 1965 Hurricane Betsy put parts of the city under eight feet of water. In 1992 monstrous Hurricane Andrew missed the city by only 100 miles. In 1998 Hurricane Georges veered east at the last moment but still caused billions of dollars of damage. At fault are natural processes that have been artificially accelerated by human tinkering—levying rivers, draining wetlands, dredging channels and cutting canals through marshes [*see map on pages 80 and 81*]. Ironically, scientists and engineers say the only hope is more manipulation, although they don't necessarily agree on which proposed projects to pursue. Without intervention, experts at L.S.U. warn, the protective delta will be gone by 2090. The sunken city would sit directly on the sea—at best a troubled Venice, at worst a modern-day Atlantis.

As if the risk to human lives weren't enough, the potential drowning of New Orleans has serious economic and environmental consequences as well. Louisiana's coast produces one third of the country's seafood, one fifth of its oil and one quarter of its natural gas. It harbors 40 percent of the nation's coastal wetlands and provides wintering grounds for 70 percent of its migratory waterfowl. Facilities on the Mississippi River from New Orleans to Baton Rouge constitute the nation's largest port. And the delta fuels a unique element of America's psyche; it is the wellspring of jazz and blues, the source of everything Cajun and Creole, and the home of Mardi Gras. Thus far, however, Washington has turned down appeals for substantial aid.

Fixing the delta would serve as a valuable test case for the country and the world. Coastal marshes are disappearing along the eastern seaboard, the other Gulf Coast states, San Francisco Bay and the Columbia River estuary for many of the same reasons besetting Louisiana. Parts of Houston are sinking faster than New Orleans. Major deltas around the globe—from the Orinoco in Venezuela, to the Nile in Egypt, to the Mekong in Vietnam—are in the same delicate state today that the Mississippi Delta was in 100 to 200 years ago. Lessons from New Orleans could help establish guidelines for safer development in these areas, and the state could export restoration technology worldwide. In Europe, the Rhine, Rhône and Po deltas are losing land. And if sea level rises substantially because of global warming in the next 100 years or so, numerous low-lying coastal cities such as New York would need to take protective measures similar to those proposed for Louisiana.

Every 24 minutes Louisiana loses one acre of land.

Overview/*Why Save a Sinking City?*

- The New Orleans area is home to more than two million people, and it fuels a unique part of America's national psyche.
- The Mississippi Delta is the poster child for problems threatening the world's deltas, coastal wetlands and cities on the sea.
- Southern Louisiana produces one third of the country's seafood, one fifth of its oil and one quarter of its natural gas.
- The state's coastline harbors 40 percent of the nation's coastal wetlands and provides wintering grounds for 70 percent of its migratory waterfowl.
- Facilities along the Mississippi River from New Orleans to Baton Rouge constitute the nation's largest port.

Seeing Is Believing

SHEA PENLAND is among those best suited to explain the delta's blues. Now a geologist at the University of New Orleans, he spent 16 years at L.S.U.; does contract work for the U.S. Army Corps of Engineers, which builds the levees; sits on federal and state working groups implementing coastal restoration projects; and consults for the oil and gas industry. His greatest credential, however, is that he knows the local folk in every little bayou town, clump of swamp and spit of marsh up and down the disintegrating coast—the people who experience its degradation every day.

Penland, dressed in jeans and a polo shirt on a mid-May morning, is eager to get me into his worn red Ford F150 pickup truck so we can explore what's eating the 50 miles of wet landscape south of

New Orleans. The Mississippi River built the delta plain that forms southeastern Louisiana over centuries by depositing vast quantities of sediment every year during spring floods. Although the drying sands and silts would compress under their own weight and sink some, the next flood would rebuild them. Since 1879, however, the Corps of Engineers, at Congress's behest, has progressively lined the river with levees to prevent floods from damaging towns and industry. The river is now shackled from northern Louisiana to the gulf, cutting off the sediment supply. As a result, the plain just subsides below the encroaching ocean. As the wetlands vanish, so does New Orleans's protection from the sea. A hurricane's storm surge can reach heights of more than 20 feet, but every four miles of marsh can absorb enough water to knock it down by one foot.

The flat marsh right outside New Orleans is still a vibrant sponge, an ever changing mix of shallow freshwater, green marsh grasses and cypress swamp hung with Spanish moss. But as Penland and I reach the halfway point en route to the gulf, the sponge becomes seriously torn and waterlogged. Isolated roads on raised stone beds pass rusted trailer homes and former brothels along now flooded bayous; stands of naked, dead trees; and browned grasses and reaches of empty water.

Down in Port Fourchon, where the tattered marsh finally gives way to open gulf, the subsidence and erosion are aggressive. The lone road exists only to service a collection of desolate corrugated buildings where oil and natural-gas pipelines converge from hundreds of offshore wellheads. Countless platforms form a gloomy steel forest rising from the sea. To bring in the goods, the fossil fuel companies have dredged hundreds of miles of navigation channels and pipeline canals throughout the coastal and interior marshes. Each cut removes land, and boat traffic and tides steadily erode the banks. The average U.S. beach erodes about two feet a year, Penland says, but Port Fourchon loses 40 to 50 feet a year—the fastest rate in the country. The network of canals also gives saltwater easy access to interior marshes, raising their salinity and killing the grasses and bottomwood forests from the roots up. No vegetation is left to prevent wind and water from wearing the marshes away. In a study funded by the oil and gas industry, Penland documented that the industry has caused one third of the delta's land loss.

Alligator Science

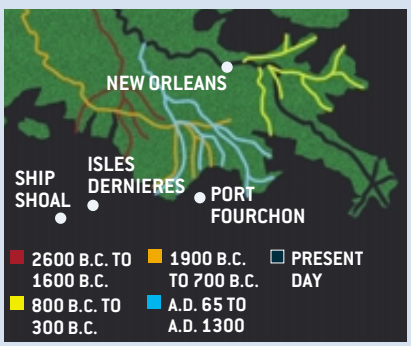
THE DUET BROTHERS know firsthand how various factors accelerate land loss beyond natural subsidence. Toby and Danny, two of Penland's local pals along our route, live on a 50-foot beige barge complex anchored in the middle of 15 square miles of broken marsh, some 20 miles northwest of Port Fourchon.

CYPRESS SWAMPS south of New Orleans die from the roots up as saltwater intrudes. The swamps then erode, allowing the gulf waters to advance even farther inland.

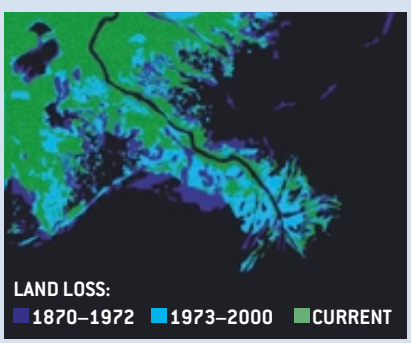
Sinking out of Sight

Human beings have dramatically increased the rate of land loss in southeastern Louisiana—and made themselves more vulnerable to hurricanes—by restricting certain natural processes and accelerating the delta's natural subsidence. Even now, vast portions of the region lie only a few feet above sea level, and another 60 acres disappear every day. At this rate, New Orleans will be exposed to the open sea by 2090.

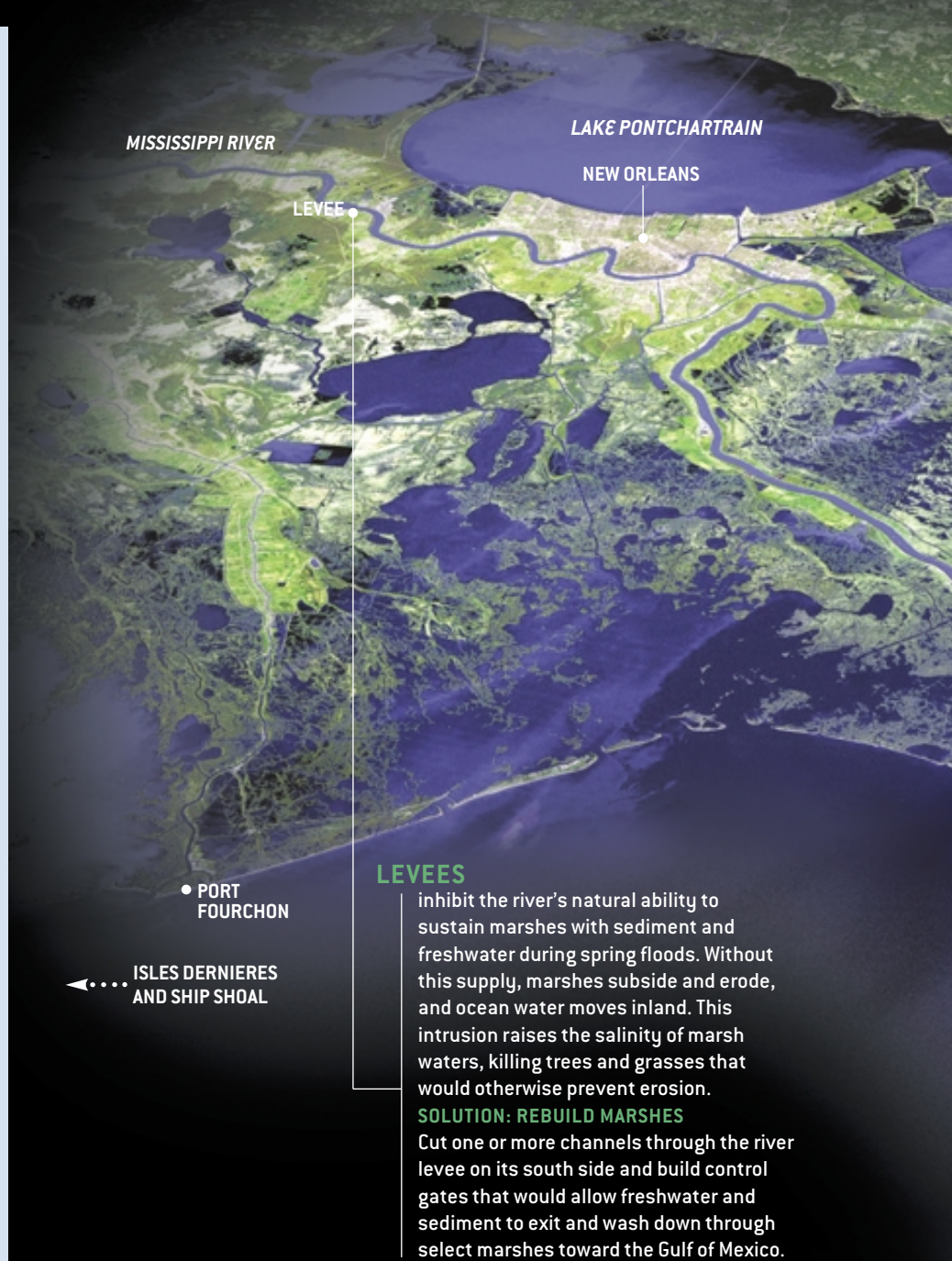
SOUTHEASTERN LOUISIANA is a valuable test case for disappearing coastal wetlands around the world.



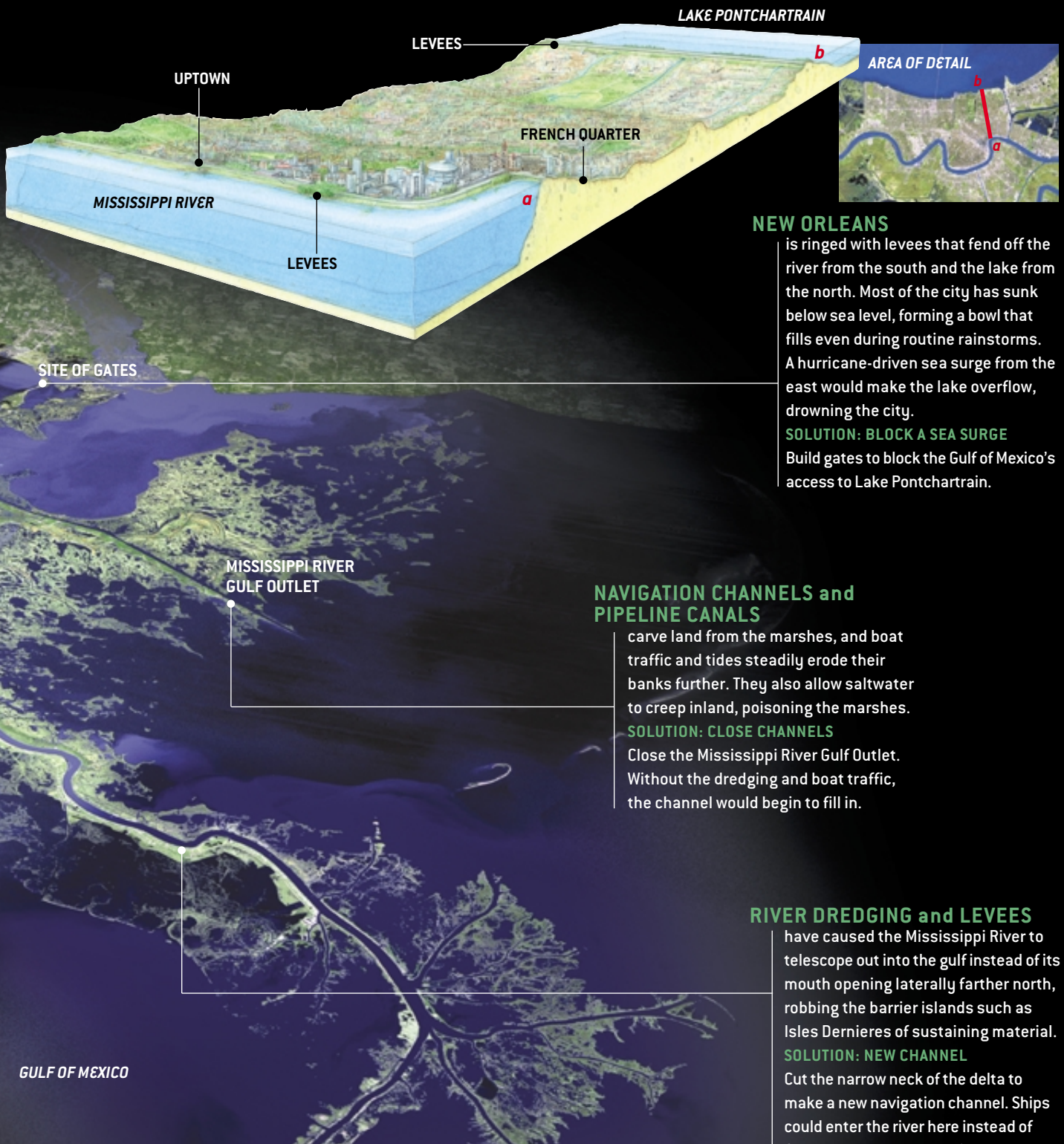
LIKE ANY RIVER, the mighty Mississippi changes course over time. Over the past 4,600 years it has built four distinct deltas by depositing vast quantities of sediment each year during spring floods.



LAND LOSS is exacerbated by human-made levees that shackle the river from northern Louisiana to the Gulf of Mexico and cut off the supply of sediment to surrounding marshlands. Between 1932 and 1990, the delta lost more than 1,000 square miles of land.



BRYAN CHRISTIE, SOURCE: L.S.U. (*main map*); DON FOLEY (*inset maps*), SOURCE: L.S.U. (*bottom inset*). SOURCE: U.S. ARMY CORPS OF ENGINEERS (*middle inset*); NATIONAL GEOGRAPHIC BOOK DIVISION (*New Orleans cross section*); SOURCE: L.S.U. (*area of detail*)



NEW ORLEANS

is ringed with levees that fend off the river from the south and the lake from the north. Most of the city has sunk below sea level, forming a bowl that fills even during routine rainstorms. A hurricane-driven sea surge from the east would make the lake overflow, drowning the city.

SOLUTION: BLOCK A SEA SURGE

Build gates to block the Gulf of Mexico's access to Lake Pontchartrain.

NAVIGATION CHANNELS and PIPELINE CANALS

carve land from the marshes, and boat traffic and tides steadily erode their banks further. They also allow saltwater to creep inland, poisoning the marshes.

SOLUTION: CLOSE CHANNELS

Close the Mississippi River Gulf Outlet. Without the dredging and boat traffic, the channel would begin to fill in.

RIVER DREDGING and LEVEES

have caused the Mississippi River to telescope out into the gulf instead of its mouth opening laterally farther north, robbing the barrier islands such as Isles Dernieres of sustaining material.

SOLUTION: NEW CHANNEL

Cut the narrow neck of the delta to make a new navigation channel. Ships could enter the river here instead of farther south; then dredging could be halted at the end of the delta. The channels would fill with sediment and begin overflowing to the west, sending sand and silt back to the barrier islands. Engineers could also mine the vast store of sand at Ship Shoal to rebuild the island.

Their family leased the land from oil companies, for fishing and hunting, 16 years ago when it was merely wet. Now it lies under five to eight feet of water. They filter rain for drinking water, process their own sewage, catch the food they eat and make money hosting overnight fishing parties for sportsmen. A dozen wellheads dot the marsh where Toby picks us up by boat. Heading out to the barge through one canal, he says, "I used to be able to spit to the mud on either side. Now they run big oil containers through here."

Inside the barge's wide-open room, Danny offers other measures: "Two years ago we drove a wooden two-by-four into the mud on the edge of a canal, to stake our alligator trap. I went past it the other day; the edge has receded 18 feet from the stake. Doesn't much matter, though. The gators are gone. Water's too salty."

With the marsh disappearing, the delta's only remaining defense is some crumbling barrier islands that a century ago were part of the region's shoreline. The next morning Penland and I travel an hour down the coast to the Louisiana Universities Marine Consortium, a scientific outpost in Cocodrie, an encampment of scientists and fishermen on the coast's edge. From there we head out in one of the consortium's gray research boats.

The boat pounds across what appears to be choppy sea for 50 minutes before we reach Isles Dernieres ("last islands" in French). But the open surf is never more than seven feet deep. The vast reach of shallow water was once thick with swaying grasses, parted occasionally by narrow, serpentine waterways full of shrimp, oysters, redfish and trout. Penland beaches us in the bayside mud. We walk across a mere 80 yards of barren sand before we toe the ocean. A similarly diminutive outcrop is visible in the distance to either side. They are what remains of a once very long, staunch island lush with black mangroves. "It broke up ocean waves, cut down storm surges and held back saltwater so the marsh behind it could thrive," Penland says in mourning. Now the ocean rushes right by.

DANNY AND TOBY DUET live on a barge moored in eight feet of water a mile from solid ground. Sixteen years ago the site was spongy land thick with marsh grasses.

Louisiana's barrier islands are eroding faster than any around the country. Millions of tons of sediment used to exit the Mississippi River's mouth every year and be dragged by longshore currents to the islands, building up what tides had worn away. But in part because levees and dredging prevent the river's last miles from meandering naturally, the mouth has telescoped out to the continental shelf. The sediment just drops over the edge of the underwater cliff into the deep ocean.

Back in New Orleans the next day it becomes apparent that other human activities have made matters worse. Cliff Mugnier, an L.S.U. geodesist who also works part-time for the Corps of Engineers, explains why from the third floor of the rectangular, cement Corps headquarters, which squats atop the Mississippi River levee the Corps has built and rebuilt for 122 years.

Mugnier says that the earth beneath the delta consists of layers of muck—a wet peat several hundred feet deep—formed by centuries of flooding. As the Corps leveed the river, the city and industry drained large marshes, which in decades past were considered wasteland. Stopping the floods and draining surface water lowered the water table, allowing the top mucks to dry, consolidate and subside, hastening the city's drop below sea level—a process already under way as the underlying mucks consolidated naturally.

That's not all. As the bowl became deeper, it would flood during routine rainstorms. So the Corps, in cooperation with the city's Sewerage and Water Board, began digging a maze of canals to

collect rainwater. The only place to send it was Lake Pontchartrain. But because the lake's mean elevation is one foot, the partners had to build pumping stations at the canal heads to push the collected runoff uphill into the lake.

The pumps serve another critical function. Because the canals are basically ditches, groundwater seeps into them from the wet soils. But if they are full, they can't take on water during a storm. So the city runs the pumps regularly to expel seepage from the canals, which draws even more water from the ground, leading to further drying and subsidence. "We are aggravating our own problem," Mugnier says. Indeed, the Corps is building more canals and enlarging pumping stations, because the lower the city sinks, the more it floods. In the meantime, streets, driveways and backyards cave in, and houses blow up when natural-gas lines rupture. Mugnier is also worried about the parishes (counties) bordering the city, which are digging drainage canals as they become more populated. In St. Charles Parish to the west, he says, "the surface could subside by as much as 14 feet."

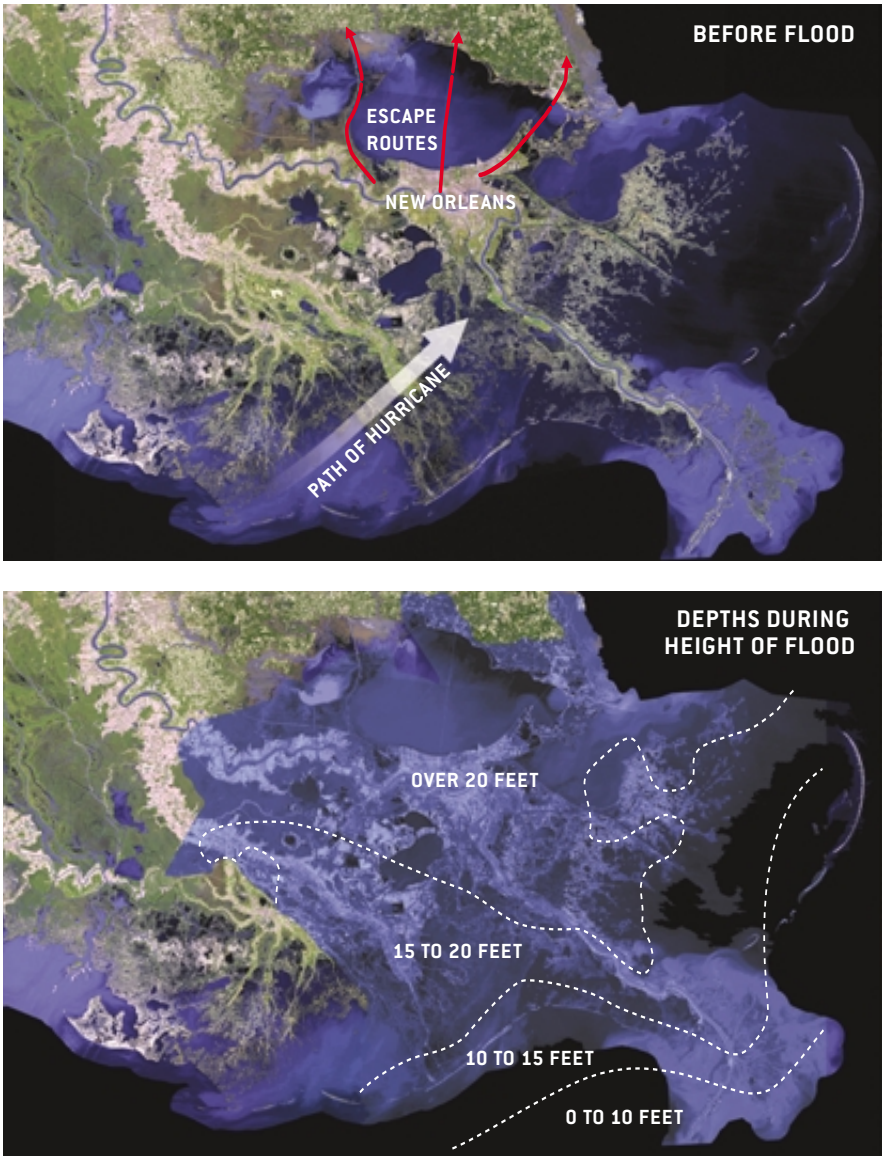
The Scare

HUMANKIND CAN'T STOP the delta's subsidence, and it can't knock down the levees to allow natural river flooding and meandering, because the region is developed. The only realistic solutions, most scientists and engineers agree, are to rebuild the vast marshes so they can absorb high waters and reconnect the barrier islands to cut down surges and protect the renewed marshes from the sea.

Since the late 1980s Louisiana's senators have made various pleas to Congress to fund massive remedial work. But they were not backed by a unified voice. L.S.U. had its surge models, and the Corps had others. Despite agreement on general solutions, competition abounded as to whose specific projects would be most effective. The Corps sometimes painted academics' cries about disaster as veiled pitches for research money. Academia occasionally retorted that the Corps's solution to everything was to bulldoze more dirt and pour more concrete, without scientific rationale. Meanwhile oystermen and shrimpers complained that the proposals from both the scientists and the engineers would ruin their fishing grounds.

Len Bahr, head of the governor's Coastal Activities Office in Baton Rouge, tried to bring everyone together. Passionate about southern Louisiana, Bahr has survived three governors, each with different sympathies. "This is the realm in which science has to operate," Bahr says. "There are five federal agencies and six state agencies with jurisdiction over what happens in the wetlands." Throughout the 1990s, Bahr says with frustration, "we only received $40 million a year" from Congress, a drop compared with the bucket of need. Even with the small projects made possible by these dollars, Louisiana scientists predicted that by 2050 coastal Louisiana would lose another

The Disaster: A Worst-Case Scenario



COMPUTER MODELS by researchers at Louisiana State University predict that the counterclockwise winds of a slow-moving, Category 4 hurricane (characterized by winds of up to 155 mph with storm surges) crossing the Gulf of Mexico from the southwest would drive a sea surge 30 miles inland, right to New Orleans's back door. Surging water would also fill Lake Pontchartrain, which would then overflow its western bank and pour into the city. At the height of the flood, the downtown would be under more than 20 feet of water only about 33 hours after the first storm winds touched the southern barrier islands.

BRYAN CHRISTIE, SOURCES: U.S. ARMY CORPS OF ENGINEERS; L.S.U., LOUISIANA WATER RESOURCES RESEARCH INSTITUTE

1,000 square miles of marsh and swamp, an area the size of Rhode Island.

Then Hurricane Georges arrived in September 1998. Its fiercely circulating winds built a wall of water 17 feet high topped with driven waves, which threatened to surge into Lake Pontchartrain and wash into New Orleans. This was the very beast that L.S.U.'s early models had warned about, and it was headed right for the city. Luckily, just before Georges made landfall, it slowed and turned a scant two degrees to the east. The surge collapsed under suddenly chaotic winds.

A Grand Plan

THE SCIENTISTS, engineers and politicians who had been squabbling realized how close the entire delta had come to disaster, and Bahr says that it scared them into reaching a consensus. Late in 1998 the governor's office, the state's Department of Natural Resources, the U.S. Army Corps of Engineers, the Environmental Protection Agency, the Fish and Wildlife Service and all 20 of the state's coastal parishes published *Coast 2050*—a blueprint for restoring coastal Louisiana.

No group is bound by the plan, however, and if all the projects were pursued, the price tag would be $14 billion. "So," I ask in the ninth-floor conference room adjacent to the governor's office in Baton Rouge, "give me the short list" of *Coast 2050* projects that would make the most difference. Before me are Joe Suhayda, director of L.S.U.'s Louisiana Water Resources Research Institute, who has modeled numerous storm tracks and knows the key scientists, Corps engineers, and city emergency planners; Vibhas Aravamuthan, who programs L.S.U.'s computer models; Len Bahr; and Bahr's second-in-command, Paul Kemp. All were involved in designing *Coast 2050*.

First and foremost, they decide, build a river diversion at several critical spots along the Mississippi, to restore disappearing marshland. At each location the Corps would cut a channel through the river levee on its south side and build control gates that would allow freshwater and suspended sediment to wash down through select marshes toward the gulf. The water could disrupt oyster beds, but if the sites were carefully selected, deals could be made with landowners.

The second step: rebuild the southern barrier islands using more than 500 million cubic yards of sand from nearby Ship Shoal. Next, the Corps would cut a channel in the narrow neck of the river delta at about halfway down. Ships could enter the river there, shortening their trip to interior ports and saving them money. The Corps could then stop dredging the southern end of the river. The mouth would fill with sediment and begin overflowing to the west, sending sand and silt back into those longshore currents that could sustain the barrier islands.

WALTER MAESTRI, Jefferson Parish emergency management director, in his floodproof underground command bunker outside New Orleans, says, "Even though I have to plan for it, I don't even want to think about the loss of life a huge hurricane would cause."

The channel plan might be integrated into a larger state proposal to build an entire new Millennium Port. It would provide deeper draft for modern container ships than the Port of New Orleans and its main channel, the Mississippi River Gulf Outlet (MRGO, pronounced Mr. Go), which the Corps dredged in the early 1960s. The outlet has eroded terribly—from 500 feet across, originally, to 2,000 feet in places—and let in a relentless stream of saltwater that has killed much of the marsh that once protected eastern New Orleans against gulf storms. If the channel or the Millennium Port were built, the Corps could close MRGO.

A remaining chink in the delta's armor is the pair of narrow straits on Lake Pontchartrain's eastern edge where it connects to the gulf. The obvious solution would be to gate them, just as the Netherlands does to regulate the North Sea's flow inland. But it would be a tough sell. "We've proposed that in the past, and it's been shot down," Bahr says. The project's costs would be extremely high.

This list of the most promising *Coast 2050* projects is only one small group's vision, of course, yet other established experts concur with its fundamentals. Ivor van Heerden, a geologist who is deputy director of L.S.U.'s Hurricane Center, concurs that "if we're going to succeed, we've got to mimic nature. Building diversions and reestablishing barrier-island sediment flows are the closest we can come." Shea Penland pretty much agrees, although he warns that the Mississippi River may not carry enough sediment to feed multiple diversions. U.S. Geological Survey studies by Robert Meade show that the supply of suspended sediment is less than half of what it was prior to 1953, diverted mostly by dams along the river's course through middle America.

As far as the Corps is concerned, all of the *Coast 2050* projects should be implemented. The first to become a reality is the Davis Pond diversion, due to begin operating by the end of this year. Project manager Al Naomi, a 30-year Corps civil engineer, and Bruce Baird, a biological oceanographer, brought me to the construction site on the Mississippi's southern levee, 20 miles west of New Orleans. The structure looks like a modest dam, in line with the levee. Steel gates in its midsection, each large enough to drive a bus through, will open and close to control water flowing through it. The water will exit into a wide swath of cleared swamp that extends south for a mile, forming a shallow riverbed that will gradually disperse into boundary-less marsh. The structure will divert up to 10,650 cubic feet per second (cfs) of water from the Mississippi, whose total flow past New Orleans ranges from less than 200,000 cfs during droughts to more than one million cfs during floods. The outflow should help preserve 33,000 acres of wetlands, oysterbeds and fishing grounds.

The Corps is bullish on Davis Pond because of its success at Caernarvon, a smaller, experimental diversion it opened in 1991 near MRGO. By 1995 Caernarvon had restored 406 acres by increasing the marsh's sediment and reducing its salinity with freshwater.

Who Should Pay?

THE CORPS OF ENGINEERS is hiring more scientists for projects such as Davis Pond, a signal that the fragmented parties are beginning to work better together. Bahr would like to integrate science and engineering further by requiring independent scientific review of proposed Corps projects before the state signed on—which Louisiana would need to do because Congress would require the state to share the cost of such work.

If Congress and President George W. Bush hear a unified call for action, authorizing it would seem prudent. Restoring coastal Louisiana would protect the country's seafood and shipping industries and its oil and natural-gas supply. It would also save America's largest wetlands, a bold environmental stroke. And without action, the million people outside New Orleans would have to relocate. The other million inside the bowl would live at the bottom of a sinking crater, surrounded by ever higher walls, trapped in a terminally ill city dependent on nonstop pumping to keep it alive.

Funding the needed science and engineering would also unearth better ways to save the country's vanishing wetlands and the world's collapsing deltas. It would improve humankind's understanding of nature's long-term processes—and the stakes of interfering, even with good intentions. And it could help governments learn how to minimize damage from rising seas, as well as from violent weather, at a time when the U.S. National Oceanic and Atmospheric Administration predicts more storms of greater intensity as a result of climate change.

With no action, one million people could be trapped.

Walter Maestri doesn't welcome that prospect. When Allison, the first tropical storm of the 2001 hurricane season, dumped five inches of rain a day on New Orleans for a week in June, it nearly maxed out the pumping system. Maestri spent his nights in a flood-proof command bunker built underground to evade storm winds; from there he dispatched police, EMTs, firefighters and National Guardsmen. It was only rain, yet it stressed the response teams. "Any significant water that comes into this city is a dangerous threat," he says. "Even though I have to plan for it, I don't even want to think about the loss of life a huge hurricane would cause." SA

Mark Fischetti is a contributing editor.

MORE TO EXPLORE

Coast 2050: Toward a Sustainable Coastal Louisiana. Louisiana Department of Natural Resources, 1998. Available at **www.coast2050.gov/report.pdf**

Holding Back the Sea: The Struggle for America's Natural Legacy on the Gulf Coast. Christopher Hallowell. HarperCollins, 2001.

Transforming New Orleans and Its Environs: Centuries of Change. Edited by Craig E. Colten. University of Pittsburgh Press, 2001.

COMPUTER MOUSE

Mice and Men

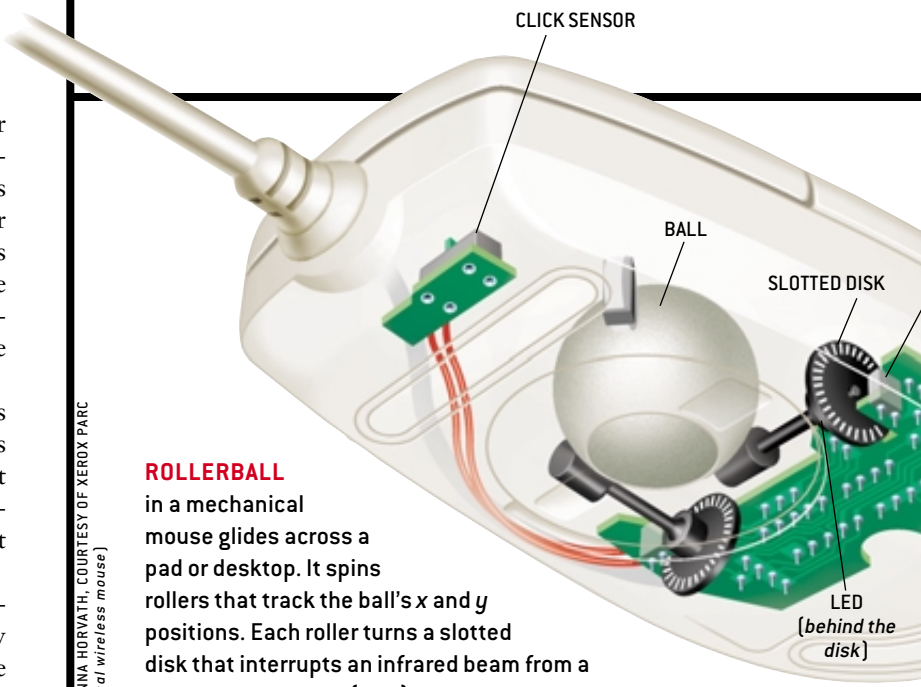
Without the mouse, millions of people might never have tried a computer or ventured online. The interface made possible the powerful menus and windows concepts, as well as the "point and click" motif for icons and Internet links. Yet Douglas Engelbart's 1968 invention didn't roar commercially until the early 1980s, when it arrived with primordial personal computers like the Xerox Star, the Apple and the IBM PC.

Since then, the handy helper has sported all kinds of buttons, wheels and spheres. The blocky design has also given way to curves intended to improve comfort and lessen hand strain. "The original mice have become unrecognizable," says Scott Broderick, product marketing manager at Apple Computer.

Throughout most of its evolution, the mouse remained an electromechanical tool. A ball in its belly rolled across a desktop, and sensors translated the ball's motion into signals that moved a cursor. But in the late 1990s the optical mouse arrived. Its light illuminates the underlying surface, and a tiny camera takes 1,500 images or more a second to chart the critter's movement across that surface and direct the cursor. This breed more accurately tracks a user's hand motions, according to Matt Barlow, group product manager at Microsoft. But the biggest advantage is that it doesn't require cleaning. A ball collects dust that can clog internal rollers, causing the cursor to skip or stall. Optical mice also work better on uneven surfaces, including your pant leg. Some optical mice now operate by taking pictures of a topside trackball, which the user moves with his fingers.

Mouse prices have dropped steadily over the years. Microsoft's 1983 mouse cost $195, whereas today's mice run less than $50. This year Logitech and others introduced wireless optical mice; there's no tail connected to the computer. Onboard logic circuits rapidly put the mouse's batteries in and out of low-power and sleep modes to conserve energy even during a user's short pause.

And what about that red glow underneath the optical mice? "Red is the best color for accurate camera tracking," Barlow says. "But consumers also think red taillights are cool." —*Mark Fischetti*



ROLLERBALL in a mechanical mouse glides across a pad or desktop. It spins rollers that track the ball's *x* and *y* positions. Each roller turns a slotted disk that interrupts an infrared beam from a light-emitting diode (LED) to a detector. The rate of light pulses indicates the mouse's speed and distance along one axis. A processor translates the detector signals into digital instructions and sends them through a cord to a computer's cursor controller. The processor also transmits button clicks.

DOUGLAS ENGELBART invented a wooden mouse and first demonstrated it, with a companion keypad, on December 9, 1968, at the Fall Joint Computer Conference in San Francisco.

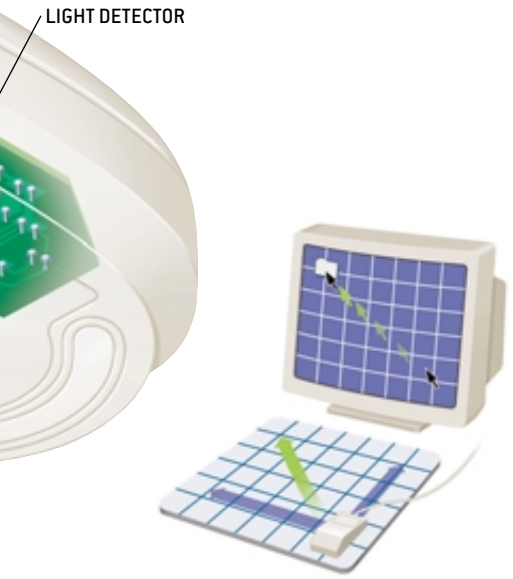
ILLUSTRATIONS BY GEORGE RETSECK; BOOTSTRAP INSTITUTE (*Engelbart photographs*); DEANNA HORVATH, COURTESY OF XEROX PARC (*two-button mouse*); MICROSOFT (*two-button mouse and optical mouse*); LOGITECH (*optical wireless mouse*)

DID YOU KNOW . . .

➤ WATER RAT: Last year the Scripps Institution of Oceanography in La Jolla, Calif., needed a sea mouse for a camera that divers could use in the deep ocean. Scripps imaging expert Jules Jaffe replaced the housing of a commercial optical mouse with a watertight acrylic case. He also replaced the spring-loaded buttons—which could be activated by the constant high water pressure at great depths—with piezoelectric crystals that generate current only when a diver pushes special contacts with his finger, creating a change in ambient pressure.

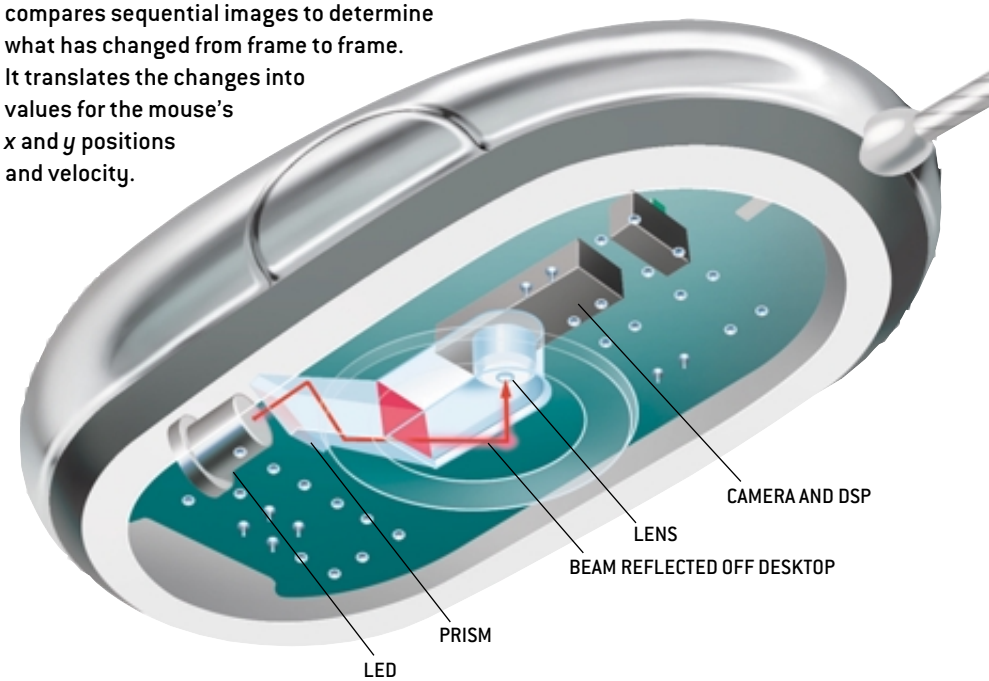
➤ AHEAD OF HIS TIME: Douglas Engelbart devised the mouse at the Stanford Research Institute in Menlo Park, Calif., as part of a larger project. In 1968 he staged a 90-minute demonstration of the NLS (oNLine System). Seated at a computer, he had the world's first mouse in his right hand and a five-key pianolike keyboard in his left. He proceeded to open and reshape file windows, highlight text, click on hyperlinks to documents on networked computers and hold a video teleconference. All these operations long preceded the first Windows-based operating systems, the networked Internet and the hyperlinked World Wide Web.

➤ VERBAL MICE: Engelbart called his creation an "*x*-*y* position indicator." The nickname "mouse" arose in part because the cord resembles a tail. Now a verb form has emerged. When Microsoft's Melinda Graetz announced a new optical mouse in March, she said, "We wanted to deliver the best possible optical mousing experience."



MOUSE'S MOVEMENT along its *x* and *y* axes controls a cursor's horizontal and vertical positions.

LIGHT-EMITTING DIODE in an optical mouse shines onto the surface below. A lens focuses the reflection into a camera, which takes 1,500 or more pictures a second. A digital signal processor (DSP) compares sequential images to determine what has changed from frame to frame. It translates the changes into values for the mouse's *x* and *y* positions and velocity.



1981
Xerox Star, *rollerball*

1987
Microsoft "Dove Bar," *rollerball*

2000
Microsoft Trackball Explorer, *optical*

2001
Logitech MouseMan, *optical wireless*

Have an idea for a future column? Send it to workingknowledge@sciam.com

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A Wide Web of Worlds

NEW INTERNET BROWSERS ADD AN EXTRA DIMENSION—BUT LITTLE DEPTH

BY W. WAYT "NEMESIS" GIBBS

San Francisco—The Bulgarians standing before me are nothing but skin and bones. Strike that: they are nothing but bones, arranged in the form of skeletal avatars who are loitering in a gazebo that rises bizarrely from the middle of a mountain lake. "Hello, we're Bulgarians," one says, or rather types. "Where are you from?"

"I'm from the Planet Newbie," I type back, in a lame attempt at chat-room humor. The skeletons are unimpressed. One turns to the other and mutters into the scrolling chat window, "toia mi miri6e [sic]," which I imagine is what a virtual Bulgarian says when he can't raise his hand to make the shape of an L on his bony forehead. A moment later the figures disintegrate with a zap.

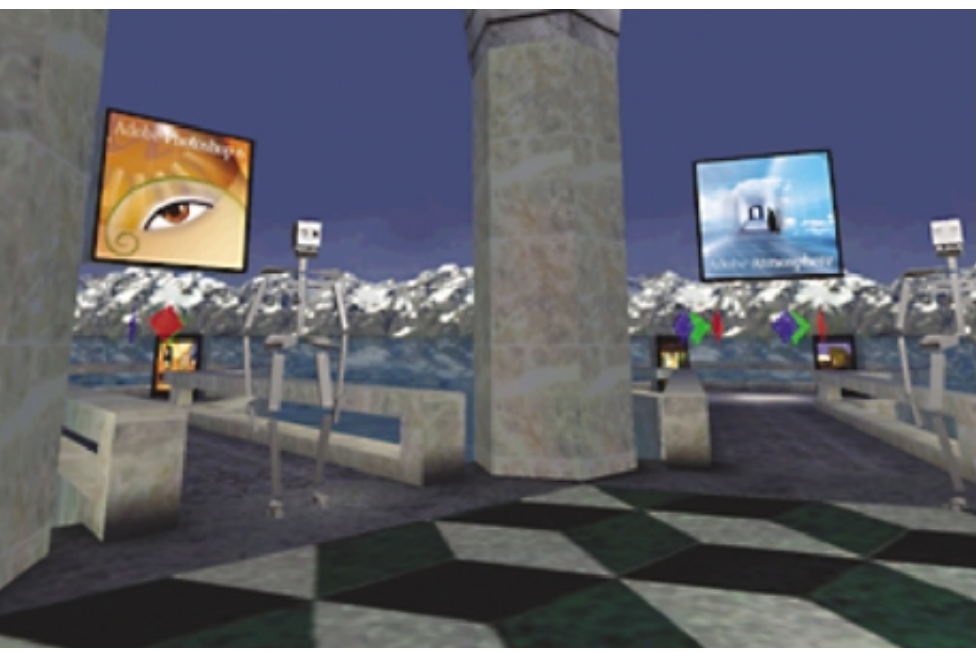
This was not exactly the welcome I expected when I fired up the beta version of Adobe Atmosphere, a three-dimensional Web browser that the company offers free on its Web site. "Integration of 2-D and 3-D content lets users navigate the Web in a more intuitive way," the company asserts in its introductory pages. "An Atmosphere world is a medium for conveying all types of information and provides a richer sensory experience than a traditional 2-D Web site."

Those are ambitious claims, and they gave me hope that perhaps software engineers had overcome the chronic problems that thwarted past attempts to add a third dimension to the Web. Advocates of VRML, virtual-reality modeling language, similarly touted that open standard in 1997 as a way for Web designers to display a wide assortment of useful information in spaces rather than on pages. Netscape and Microsoft obligingly bundled VRML plug-ins with their browsers. But 3-D VRML worlds are much harder to create and connect than Web pages, and visitors tend to get disoriented exploring them. Text and VRML don't mix well. And until recently, PCs couldn't render complicated 3-D scenes quickly enough. So although the Internet contains 3-D objects here and there that users can spin and examine, 3-D cyberworlds remain a scattered archipelago.

There is a notable exception, and that is the growing part of the Internet devoted to online multiplayer games. Nearly all combat and racing computer games now allow players from around the world to compete against one another in virtual arenas. The players' positions, actions and even voices are communicated via a steady flow of Internet packets.

Atmosphere seems designed to exploit that proven demand for social interaction. Launch the program, and it opens a window with three panes. One is a view of your "home world," which starts out blocky and indistinct but fills in with details as more data stream in from the network server on which the world resides. A second pane holds snapshots of "bookmarked" worlds and controls to

CYBERWORLDS seem surreal in Adobe Atmosphere. Navigating these spaces—and trying to follow the chitchat of the multinational teenagers who tend to populate them—also makes the head spin.



KATY ROE (*top*); ADOBE SYSTEMS, INC. (*bottom*)

select your avatar's name and appearance. I chose "Nemesis" (the handle I used in my video game–playing teenage years) and the "boxter" avatar, a pair of eyes peering through a slit in an overturned cardboard box. In the third pane scroll comments typed by other denizens of this cyberworld.

Touring several dozen Atmosphere sites put online by Adobe, other companies and private individuals, I found many that were pretty to look at but few that were inhabited or connected to the rest of the Web. When I downloaded the Atmosphere builder program (also free, at least for now), I discovered the reason. Constructing a small cyberspace was straightforward; within five hours I had built a two-story wood-and-stone cottage with a spiral staircase and skylight. I even set it on a manicured lawn and gave it views of Scottish highlands. But making it do something—link to other Web sites, say—means writing JavaScript programs. Animating objects within the scene is trickier still. And as with VRML, the only way to display text in an Atmosphere world is to paint it on some flat surface.

Chatting may be the easiest service for 3-D Web sites to offer, but there must be more useful applications for three-dimensional Web browsers. One occurred to me on a flight down the California coast from my home of San Francisco to Los Angeles. Like many renters in this overpriced city, I have been toying with the notion of buying a house in one of the cheaper outlying towns. Out the airplane window I saw several interesting-looking communities tucked in the foothills and valleys and imagined a real-estate site that would let users fly around the Bay Area. Models composed from satellite data and aerial photographs could be annotated with virtual signs that would pop up to show information about houses for sale in the neighborhood below. Home buyers could see how close markets, transit stops and schools were to the property.

Atmosphere could not handle such large-scale terrains, but two other programs now available can. TerraVision, developed by SRI International in Menlo Park, Calif., can integrate digital topographic databases, satellite and aerial photographs, and 3-D models of buildings. The TerraVision server software sends the composite images over the Internet to a 3-D browser program (offered

free at www.tvgeo.com). Like Atmosphere, the software is still under development, so it runs slowly on standard PCs and crashes frequently. But the project leaders at SRI describe an appealing vision of a whole new top-level domain—.geo, like .com—that will make it possible to surf the Web in a way that is a lot more like actual surfing. We could glide over a virtual landscape to locate businesses, institutions and information by geographic rather than lexical similarity.

A Swiss company, Geonova (www.geonova.ch), has recently demonstrated that the idea of a geography-based Web is feasible with today's PCs. Engineers there created two impressively detailed models of Switzerland—one of the entire nation with 25-meter resolution and another of two central cantons at 50-centimeter resolution. Using the free G-Vista plug-in developed by Geonova's partner, G-Graphix, I flew into the valleys, skimmed the lakes and explored the snow-covered peaks of the Alps. The software moved fluidly, and it gradually increased details of the scene as new data arrived. Navigation was as intuitive here as it had been frustrating in TerraVision and Atmosphere. Text and iconic labels hovered quite legibly above towns, lakes, companies and tourist attractions; clicking on the labels opened associated Web pages.

It is not at all clear whether the virtual worlds constructed for Atmosphere, TerraVision, G-Vista and the numerous other 3-D browsers can ever be connected into a comprehensive universe the way that 2-D Web sites are. Until either a new open standard or a de facto format replaces VRML as the "official" language of the 3-D Web, few designers are likely to invest much time or money in the creation of sophisticated 3-D sites. But at last the hardware is in place to add a new dimension to the Internet. The rest is a small matter of programming. ; -) SA

SWISS ALPS are annotated with iconic links to tourist attractions at Geonova's 3-D Web site.

GEONOVA/G-GRAPHIX

ON THE WEB

WWW.SCIENTIFICAMERICAN.COM The scientific reason to go online.

NASA JOHNSON SPACE CENTER

FEATURED STORY

The Astronaut's New Clothes

If and when NASA sends a crewed mission to Mars, the astronauts are going to require new suits. Creating suits for planetary exploration, as opposed to space exploration, poses considerable challenges to designers. The new garments will need to be lighter than those currently in use to compensate for the weighty effects of gravity on Mars. At the same time, though, they must protect against the intense radiation that bathes the Red Planet. The company that made the *Apollo* team's suits is already developing a design—complete with wearable computers—to meet those demands.

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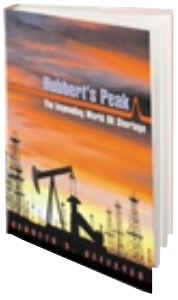
The End of Oil

WILL GAS LINES IN THE COMING DECADE MAKE THOSE OF 1973 LOOK SHORT? **BY PAUL RAEBURN**



HUBBERT'S PEAK: THE IMPENDING WORLD OIL SHORTAGE
by Kenneth S. Deffeyes
Princeton University Press, 2001 ($24.95)

You have to wonder about the judgment of a man who writes, "As I drive by those smelly refineries on the New Jersey Turnpike, I want to roll the windows down and inhale deeply." But for Kenneth S. Deffeyes, that's the smell of home. The son of a petroleum engineer, he was born in Oklahoma, "grew up in the oil patch," became a geologist and worked for Shell Oil before becoming a professor at Princeton University. And he still knows how to wield a 36-inch-long pipe wrench.

In *Hubbert's Peak,* Deffeyes writes with good humor about the oil business, but he delivers a sobering message: the 100-year petroleum era is nearly over. Global oil production will peak sometime between 2004 and 2008, and the world's production of crude oil "will fall, never to rise again." If Deffeyes is right—and if nothing is done to reduce the increasing global thirst for oil—energy prices will soar and economies will be plunged into recession as they desperately search for alternatives.

It's tempting to dismiss Deffeyes as just another of the doomsayers who have been predicting, almost since oil was discovered, that we are running out of it. But Deffeyes makes a persuasive case that this time it's for real. This is an oilman and geologist's assessment of the future, grounded in cold mathematics. And it's frightening.

Deffeyes's prediction is based on the work of M. King Hubbert, a Shell geologist who in 1956 predicted that U.S. oil production would peak in the early 1970s and then begin to decline. Hubbert was dismissed by many experts inside and outside the oil industry. Pro-Hubbert and anti-Hubbert factions arose and persisted until 1970, when U.S. oil production peaked and started its long decline.

The Hubbert method is based on the observation that oil production in any region follows a bell-shaped curve. Production increases rapidly at first, as the cheapest and most readily accessible oil is recovered. As the difficulty of extracting the oil increases, it becomes more expensive and less competitive with other fuels. Production slows, levels off and begins to fall.

Hubbert demonstrated that total U.S. oil production in 1956 was tracing the upside of such a curve. To know when the curve would most likely peak, however, he had to know how much oil remained in the ground. Underground reserves provide a glimpse of the future: when the rate of new discoveries does not keep up with the growth of oil production, the amount of oil remaining underground begins to fall. That's a tip-off that a decline in production lies ahead.

Deffeyes used a slightly more sophisticated version of the Hubbert method to make the global calculations. The numbers pointed to 2003 as the year of peak production, but because estimates of global reserves are inexact, Deffeyes settled on a range from 2004 to 2008.

Three things could upset Deffeyes's prediction. One would be the discovery of huge new oil deposits. A second would be the development of drilling technology that could squeeze more oil from known

SCENES OF DRIVERS waiting to fill their gas tanks were common in the U.S. in the early 1970s.

BETH PHILLIPS (*above*); AP PHOTO (*right*)

reserves. And a third would be a steep rise in oil prices, which would make it profitable to recover even the most stubbornly buried oil.

In a delightfully readable and informative primer on oil exploration and drilling, Deffeyes addresses each point. First, the discovery of new oil reserves is unlikely—petroleum geologists have been nearly everywhere, and no substantial finds have been made since the 1970s. Second, billions have already been poured into drilling technology, and it's not going to get much better. And last, even very high oil prices won't spur enough new production to delay the inevitable peak.

"This much is certain," he writes. "No initiative put in place starting today can have a substantial effect on the peak production year. No Caspian Sea exploration, no drilling in the South China Sea, no SUV replacements, no renewable energy projects can be brought on at a sufficient rate to avoid a bidding war for the remaining oil."

The only answer, Deffeyes says, is to move as quickly as possible to alternative fuels—including natural gas and nuclear power, as well as solar, wind and geothermal energy. "Running out of energy in the long run is not the problem," Deffeyes explains. "The bind comes during the next 10 years: getting over our dependence on crude oil."

The petroleum era is coming to a close. "Fossil fuels are a one-time gift that lifted us up from subsistence agriculture and eventually should lead us to a future based on renewable resources," Deffeyes writes. Those are strong words for a man raised in the oil patch. For the rest of us, the end of the world's dependence on oil means we need to make some tough political and economic choices. For Deffeyes, it means he can't go home again. SA

Paul Raeburn covers science and energy for Business Week *and is the author of* Mars: Uncovering the Secrets of the Red Planet *(National Geographic, 1998).*

THE EDITORS **RECOMMEND**

THE BREAST CANCER WARS: HOPE, FEAR, AND THE PURSUIT OF A CURE IN TWENTIETH-CENTURY AMERICA

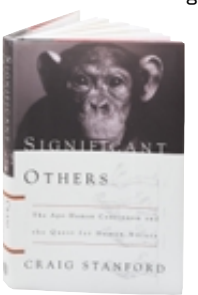
by Barron H. Lerner. Oxford University Press, New York, 2001 ($30)

Lerner, who teaches internal medicine, medical history and bioethics at the Columbia University College of Physicians and Surgeons, presents a thoroughly researched and deeply reflective history of breast cancer and the methods that have been employed to treat it. His premise is that "disease cannot be understood outside its social and cultural context." And he describes the contexts in which radical mastectomy dominated as the method of treatment for much of the century and then yielded to less disfiguring procedures. He gives much space to the successful effort by women to gain a voice in choosing their treatment. There is, he says, a "basic tension" that has characterized all the breast cancer wars: "Although we may intuitively associate more aggressive action with better outcomes, this occurs only in some instances." And so, "rather than feeling compelled to reach decisions that are objectively 'right,' women should choose what is right for themselves."

SIGNIFICANT OTHERS: THE APE-HUMAN CONTINUUM AND THE QUEST FOR HUMAN NATURE

by Craig Stanford. Basic Books, New York, 2001 ($28)

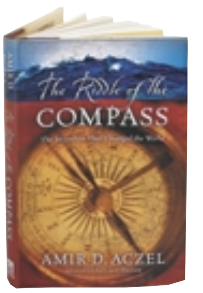
"Apes and humans are cut from the same evolutionary cloth; all that fundamentally distinguishes us is posture, we being upright walkers and the apes quadrupeds. Everything else, from the size and function of our brains to the other aspects of our shared anatomies, is a difference of degree and not of kind." In eloquently laying out his argument, Stanford touches on many elements of modern anthropology, including its disagreements. Serving simultaneously as associate professor of anthropology at the University of Southern California, co-director of the Jane Goodall Research Center there and director of the Great Ape Project in Uganda's Bwindi Impenetrable National Park, he brings a rich background to his presentation.



THE RIDDLE OF THE COMPASS: THE INVENTION THAT CHANGED THE WORLD

by Amir D. Aczel. Harcourt, 2001 ($23)

The compass, Aczel says, was "the most important technological invention since the wheel" because its contribution to navigation "allowed goods to be transported efficiently and reliably across the seas and opened up the world to maritime exploration." Inspired by that thought, Aczel (associate professor of mathematics at Bentley College) set out to trace the history of the device. "The compass," he found, "was invented in antiquity in China, where it did not immediately improve navigation but was used in feng shui." It was the mariners of Amalfi, then a maritime city-state in Italy, who around 1300 transformed the instrument into the compass we know today. Citing it and other devices that only gradually found their technological niche, Aczel concludes that it "seems to be a law of nature that a technology is developed and then waits a long time for people to discover their need for it, rather than the other way around."



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

BETH PHILLIPS

Crowns of the Minotaur

BY DENNIS E. SHASHA

Early in the life of the ferocious Minotaur (the fabled half man/half bull), King Minos of Crete spoke to three of his youthful prisoners who were sharing a cell just outside Daedalus's Labyrinth. "You know that you will die if you fight the Minotaur unarmed. I propose therefore a chance at reprieve. I will separate and blindfold you and place either a red or a blue crown on your head. I will choose the color in each case by flipping one of my lovely Cretan coins, which you can assume to be fair. I will then place you at three spots evenly spaced around my lovely stadium.

"You will be surrounded by a screen that will permit your fellows to see your crown and you to see theirs. The screen will prevent you from sending and receiving any signals. (A guard standing next to you will cut off your head if you try.) So you cannot communicate with one another once you are in the stadium. At that point, I will have the guards remove your blindfolds.

"Here is the proposition: each of you has 10 seconds to tell your guard either 'blue,' 'red' or 'pass' concerning the color of the crown on your head. After 15 seconds, the guard next to someone who guessed correctly will give a thumbs-up. The guard next to someone who guessed incorrectly will present a thumbs-down. A pass, and the guard will keep his hand flat. If you all say 'pass,' you all go to the Minotaur. If all who don't pass are correct, you all go free. If some of you who don't pass make a mistake, then again you all go to the Minotaur. If any of you tries to signal another, those still living go to the Minotaur."

(Warm-up: What is the probability that the prisoners will win if they all bet? Answer: Only 1 in 8, because each has a probability of 1 in 2 of being wrong each time.)

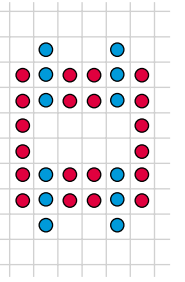
"Now," the king continued, "you may think that you have only half a chance of surviving by simply designating one prisoner as the guesser. But if you are clever, you will realize that you can design a strategy such that you have a 3-in-4 chance of winning. The strategy involves a rule that each prisoner must follow but that requires no communication among the prisoners once they are in the stadium. What is that rule?

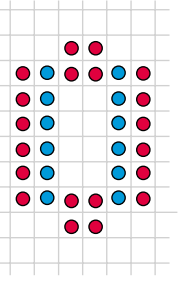
"We can change the strategy so that each prisoner can 'bet' zero or more points about the color of the crown on his head. The prisoner team wins or loses that many points depending on whether he is right—and the prisoner team wins if it earns more points than it loses. This may improve the chance that the prisoners will win. Can you design a rule to make it so?" SA

MATT COLLINS

Answer to Last Month's Puzzle

The dancers move in stages from their starting configuration to these two patterns:





Now the dancers can reach the final configuration with one more step.

Web Solution

For a peek at the answer to this month's problem, visit www.sciam.com

The Farm Report

A NEW WAY TO STUDY FARM LIFE MAKES ONE WONDER: WHAT IF ANIMAL BEHAVIOR WERE TAKEN LITERARILY? BY STEVE MIRSKY

Late in June the Agricultural Research Service of the U.S. Department of Agriculture issued a press release describing what they called a new discipline. The idea is for behavioral scientists to study farm animals using standard wild-animal study tools, such as remote cameras, binoculars and observations from hidden areas called blinds. The press release noted that this kind of research has already led to a new feeding schedule that has decreased aggression among cattle.

Anyway, this new type of fieldwork conjures up a possible research report that might go something like this. (If this were a television sitcom, the screen would now get all wavy.)

Highlights of long-term investigation of animal behavior on farm of Mr. J:

Boar captures attention of all other animals, including dogs, pigs, hens, pigeons, sheep and cows, three horses (large one with white stripe on nose), goat, donkey, ducklings, cat. Animals become noisy, farmer J blasts gun from inside house, animals scatter to sleeping areas.

Three days later, boar dies. Now early March. Two pigs (henceforth A and B) dominate animal assemblages, occurring numerous times per week.

June. Animals generally neglected by Mr. J, farmhands. Cow breaks down door of food shed, animals commence feeding. Mr. J arrives, attempts to whip animals to stop feeding. Animals attack J and farmhands, who flee. Animals slam gate, run around entire periphery of farm. Go to buildings and destroy instruments of their subjugation, for example, bits and nose rings. They discard items down pit, or well. (Remarkable turn of events, could rate article in ag journal.) Pig A leads assembly back to shed for more food. All animals making large amounts of noise in repetitious fashion. All then sleep. Two pigs definitely appear leaders.

Pig B seems to be climbing ladder while third pig holds bucket of paint. Pig B appears to be writing on side of barn. Pigs seem to be milking cows. (Article could make cover of ag journal!) Pig B leads away group, Pig A ingests all milk.

Next days, animals harvesting hay—without human supervision. Horse is working tail off, so to speak.

Autumn. Animals seem to be—no other description comes to mind—perusing written materials. Pig A hides nine newborn puppies in loft.

Early October. Mr. J, men return. Animals—in what looks, despite all common sense, to be planned defensive strategy—drive men off. (What gives?)

January. Pigs A and B in obvious conflict, apparently over alpha position. Pig A calls dogs hidden as puppies, now full-grown, to drive Pig B off premises.

Spring. Animals working 60-hour week. Unknown man appearing regularly on Mondays, interacting with Pig A. Pigs have moved into house, sleeping later than other animals.

Winter. Animals building structure? Farm now selling eggs to outside world—unknown man intermediary? (Don't expect to see farm selling ham to outside world anytime soon.)

Next autumn. Structure (windmill) nearing completion. Group of men attack farm, blow up windmill. Major battle between animals and humans. Nearly everyone wounded, some deaths. Pig A loses tip of tail. Later, Pig A, wearing bowler hat, comes out of farmhouse, runs around yard, apparently drunk as skunk. Thirty-one pigs are born to four sows; all offspring appear to be descendants of Pig A. Other animals now give pigs the right-of-way when they meet.

Summer. Big horse still working hard but looks poorly, then lies down in field, mouth bleeding. Van arrives at farm and removes horse.

Years later. Pigs commence walking on hind legs. Pig A carrying whip. (Forget ag journal, will submit to *Nature* or *Science*.) Pigs later begin wearing Mr. J's clothing. Humans arrive, interact socially with pigs, in house. No longer able to visually discriminate pigs from men, or men from pigs. (Forget journal article—this could be book, by George!) SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

Why does the shower curtain move toward the water?

—P. Wood, Philadelphia

David Schmidt, an assistant professor of mechanical and industrial engineering at the University of Massachusetts at Amherst, offers this explanation:

Maybe it happened to you this morning: you entered the shower, and the curtain moved in to engulf you. I have recently discovered a new explanation for this common phenomenon, thanks to modern fluid-simulation technology.

Until now, explanations for the shower curtain's movements were theoretical. Most ideas drew on the Bernoulli effect or on buoyancy effects. The Bernoulli principle, which explains how an airplane's wings produce lift, states that as a fluid accelerates, its pressure perpendicular to the direction of flow drops. But the Bernoulli effect is based on the balance between pressure forces and acceleration and does not allow for the presence of droplets.

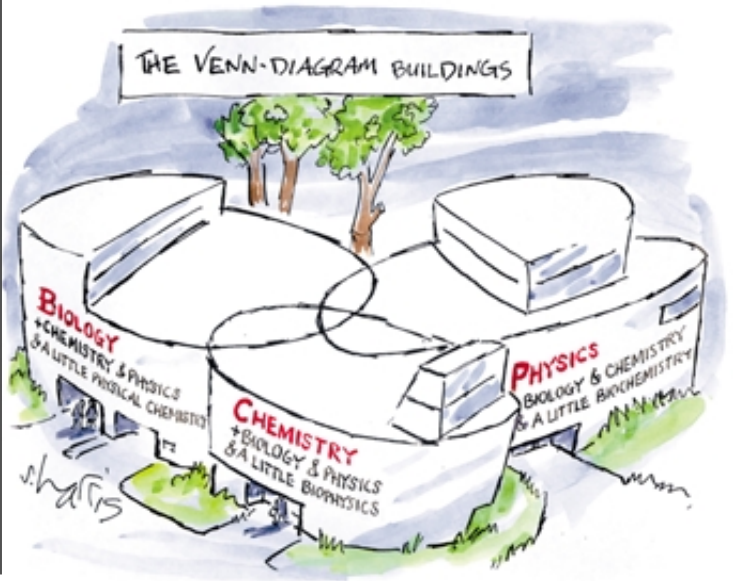
The buoyancy theory supposes that the hot shower causes the temperature of the air in the shower to rise, reducing its density. In that case, the pressure will be lower on the shower side of the curtain than on the other side of the curtain at the same height—causing the curtain to move toward the lower pressure. The problem with this explanation is that the curtain will move inward during a cold shower, too.

A modern way to study fluid-flow problems is to use computers to solve the basic equations of fluid motion. These equations are based on conservation of mass and momentum. Because of the limitations of computer power and of current mathematics, however, the solution process can be difficult and time-consuming. Spray simulations are particularly challenging because they involve two different phases of water: liquid and gas.

I drafted a model of a typical shower and divided the shower area into 50,000 minuscule cells. The tub, the showerhead, the curtain rod and the room outside the shower were all included. I ran the software for two weeks on my home computer in the evenings and on weekends to simulate 30 seconds of actual shower time.

When the simulation was complete, it showed that the spray drove a vortex. The vortex rotates continuously around an axis perpendicular to the shower curtain. The center of this vortex—much like the center of a cyclone—is a low-pressure region, which is what pulls in the shower curtain.

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



SIDNEY HARRIS

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