

Who Were the First Americans? • Veggie Vaccines • Femtosecond Flashes

SCIENTIFIC AMERICAN

SEPTEMBER 2000

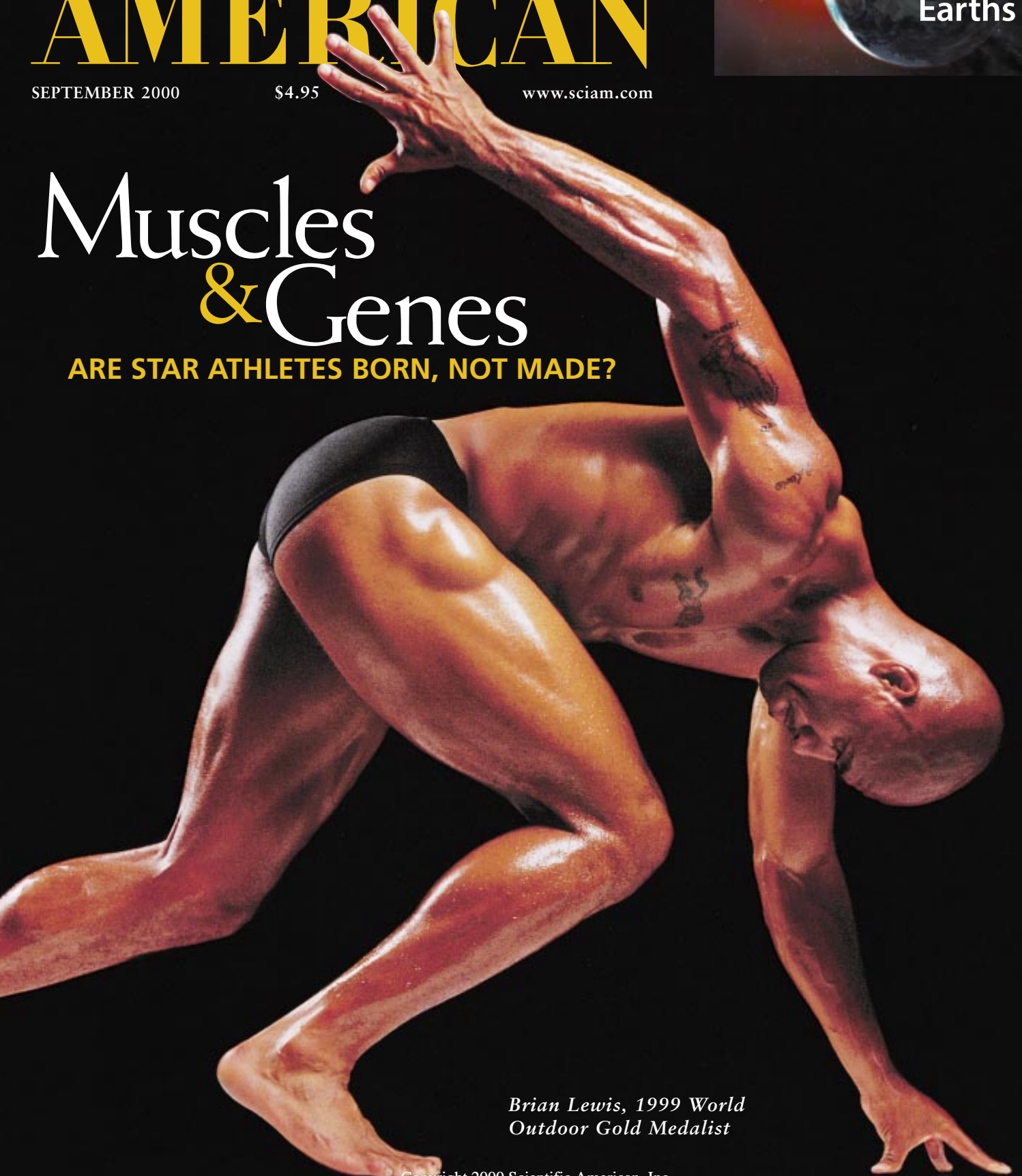
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Muscles & Genes

ARE STAR ATHLETES BORN, NOT MADE?



*Brian Lewis, 1999 World
Outdoor Gold Medalist*

COVER STORY

Muscle, Genes and Athletic Performance

48

Jesper L. Andersen, Peter Schjerling and Bengt Saltin

The dazzling feats of Olympic athletes depend on top-notch performance by their powerfully conditioned muscles. But conditioning can only go so far—recent research suggests that when it comes to the essential ratio of fast- to slow-twitch muscle fibers, some champions really are born, not made. Still, future genetic technologies could change even that.



Searching for Shadows of Other Earths

58

Laurance R. Doyle, Hans-Jörg Deeg and Timothy M. Brown



A new, more direct technique for finding planets near distant stars can spot not only Jupiter-like giants but also worlds with roughly the size and composition of our own.

Edible Vaccines

66

William H. R. Langridge

One day children may get immunized by munching on modified bananas or potatoes instead of by enduring painful shots. More important, food vaccines may prevent disease in millions who now die for lack of access to traditional inoculants.

Ultrashort-Pulse Lasers: Big Payoffs in a Flash

72

John-Mark Hopkins and Wilson Sibbett

Imaging, microelectronic manufacturing, fiber optics and industrial chemistry are eagerly adopting lasers that emit light in powerful bursts lasting only quadrillionths of a second.

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TRENDS IN ARCHAEOLOGY

Who Were the First Americans?

Sasha Nemecek, staff writer

If your answer was fur-clad mammoth hunters who walked across the Bering Strait, guess again. The consensus emerging now is that humans reached the Americas much earlier than had been thought, possibly by boat, and that their livelihoods depended far more on fishing, small game and collecting food.



The Plan to Save Fallingwater
Robert Silman

Fallingwater, the stunning house regarded as Frank Lloyd Wright's masterpiece, was in danger of collapsing, a victim of its own design flaws. Now engineers have devised a way to save it.



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Alan Rabinowitz, finder of new species.



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Airbus and Boeing prepare to build super-jumbo jets, but does the idea of bigger planes fly at commercial airports?

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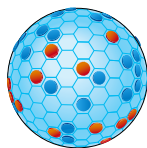
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Kites carry eyes in the sky.



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The mind-bending challenge of Hex.

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Was philosopher Thomas Kuhn's view of science radical or just realistic? Also, **The Editors Recommend.**

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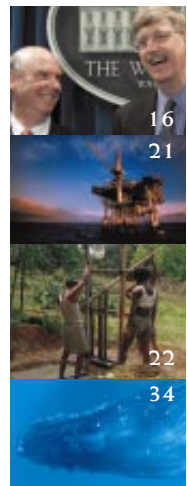
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Photograph by Howard Schatz,
Schatz/Ornstein Studio.

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EDITOR JOHN RENNIE

Muscle-bound Science

The Olympic Games celebrate amateur athletes rather than professionals because, philosophically, they want to honor how much individuals can achieve through pure love of the sport. Any similarity between that ideal and the modern Olympics may seem coincidental; the ancient Greeks revered Nike, goddess of victory, without hoping to win an endorsement deal from her. Today's Olympians, especially those most competitive for medals, train as intensively, expensively and single-mindedly as any of the pros, and that typically means using advanced technological training methods beyond the dreams of Jim Thorpe.

We fans might want to believe that when it counts, sheer determination can beat physical obstacles and competitors' superior strengths. (Think Kerri Strug at the 1996 Olympics, successfully vaulting after severely injuring her ankle.) But aside from a cruelty in the logic of that sentiment—does everyone who fails to get the gold simply not want it enough?—it ignores a harsher reality known to drill sergeants and athletic coaches alike: In a crisis, you don't rise to the occasion. You sink to the level of your training.

Modern science continues to refine training regimens by peeling away mysteries of human sports physiology. Fascinating results of that work appear in "Muscle, Genes and Athletic Performance," beginning on page 48, in which the authors describe how the protein makeup of muscles changes in response to exercise. One provocative finding is that nature really has given some individuals a head start by genetically blessing them with proportionally more fast- or slow-twitch muscle fibers.

But future technology will render such details ever less restrictive. So what if certain genes confer an advantage on marathoners? Runners lacking those genes can compensate by training in ways that optimize what they have. The protein products of those genes might be supplied as drugs. Conceivably, desired genes (from people or animals) could someday be inserted into muscles to give them a literally superhuman boost. Whether those techniques would be safe is another story, however, and future Olympic committees might look as dimly on them as they now do on blood doping and steroids.

Does all this cheapen the role of human spirit in sports? It shouldn't. The most vital training always goes on between the ears. Great athletes muster the courage to push their bodies to the limit, over and over again. And in the crisis of competition, their determination holds them up, telling them with every heartbeat that they must win because they *will not* lose.



In a crisis, you don't rise to the occasion. You sink to the level of your training.

John Rennie
editors@sciam.com

P.S. Readers who would like to know more about the state of sports science may wish to read SCIENTIFIC AMERICAN PRESENTS: *Building the Elite Athlete*, available now on newsstands or on-line through www.sciam.com.

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SUBSCRIPTION INQUIRIES sacust@sciam.com

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PHONE: (212) 754-0550

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Reader response to Carol Ezzell's coverage of Zimbabwe's AIDS epidemic in "Care for a Dying Continent" was swift and impassioned, particularly concerning the social issues surrounding the tragedy. That article and others from the May issue, including Mark Alpert's news story on patient safety, are the subjects of this month's letters.

WHOSE RESPONSIBILITY?

Your article on AIDS in Zimbabwe throws light on a problem whose magnitude is not fully appreciated, but I felt that the crucial political dimension was sorely neglected. The background to the tragedy is a government that spends half again as much on its military as it does on health, that does little to publicize the disease's risks or preventative measures, and that for many years suppressed the true extent of the problem for spurious reasons of national pride.

Instead of sending donations for people who are doomed no matter what, your readers would bring about greater long-term change by lobbying their local representatives to send election monitors to the upcoming parliamentary elections in Zimbabwe and in the meantime withholding all financial aid to that country. Money from institutions such as the IMF, the World Bank and USAID has for too long propped up corrupt and destructive African governments that would have otherwise long ago given way to more responsible leadership.

CRAIG BLACK
Harare, Zimbabwe

It was with growing anger that I read of the callousness of the men who infect their wives with HIV, their refusal to use condoms, their demand that women engage in the painful (for women) practice of "dry sex" and their overall feeling that they have "bought" their wives and therefore can do with them as they please.

Where are the human rights organizations? Where are the United Nations resolutions condemning these outrageous practices? Where is the voice of the U.N. secretary-general? The silence is deafening.

NATHAN AVIEZER
Ramat-Gan, Israel

HOLDING PHYSICIANS ACCOUNTABLE

Physician "errors" ["Physician, Heal Thyself," by Mark Alpert, News and Analysis] are just a specific instance of a more general problem in the medical profession: inadequate feedback on performance. In other endeavors, performance feedback is critical to improvement, but a doctor's poor performance neither puts him out of business nor affects his income, except in the most extreme cases. How often does a physician find out that a diagnosis was incorrect or a treatment



SIX-YEAR-OLD BOY spends his final days at a Harare AIDS hospice.

ineffective? A patient who gets little help from a doctor does not call to complain but rather goes to another doctor, eventually gets well or suffers in silence. Even following up on a small percentage of patients to see whether they have recovered or a medicine has worked would provide a tremendous learning opportunity. Databases on adverse reactions to medication, on long-term efficacy of surgical interventions and chemotherapy treatments, and on the performance of medical devices would be extremely beneficial. Surgical outcomes and cancer survival rates could also be made available to patients.

People should have the right to choose a doctor who achieves better outcomes. By the same token, it should be easier to remove physicians who demonstrate gross incompetence, and their removal should be national, so they cannot simply relocate. Only timely and public feedback will effectively promote continuous improvement.

CRAIG LOEHLE
Naperville, Ill.

THE MAIL

URBANITES ESPECIALLY IDENTIFIED with Frans B. M. de Waal, Filippo Aureli and Peter G. Judge's findings in "Coping with Crowding" [May]. Toronto resident Doug Martin sent us notes on his own experience: "I boarded a subway car just as a major service disruption was announced. For the next 45 minutes I stood in a population density of three million primates per square kilometer. Dozens of riders followed the 'elevator script' to a T (eyes averted, minimal movement, hushed conversation). When a small child began crying tiredly," Martin recounts, "I was impelled to mutter sotto voce, 'I know how you feel,' and was disappointed that no one registered my attempted contribution to order and comity. When the conductor announced the name of the next interchange, adding 'finally,' a laugh ran the entire length of the car." Demonstrating that, in our own species anyway, a sense of humor can at least mitigate a too-close-for-comfort situation.



Editors' note:

The U.S. Department of Veterans Affairs, in a program that will be the first of its kind, will soon offer no-penalty error reporting in all 172 of its hospitals.

THRESHOLDS

Coping with Crowding" argues that the sort of effects crowding has on the behavior of rats may not obtain in the case of humans, and they give a number of persuasive examples as evidence.

Isn't it possible, however, that in both

rats and humans there is a threshold below which increased crowding does not increase violent aggression significantly but above which crowding does increase aggression immensely?

Perhaps the authors are considering human populations that, though dense by normal standards, have not yet reached a threshold equivalent to that of the experimental rats?

STEVEN GOLDBERG
Chairman, Department of Sociology
City University of New York

The authors of "Coping with Crowding" comment that people in an elevator reduce social friction by minimizing eye contact, large body movements and loud verbalizations. In my experience, though, people with cell phones speak loudly even in the hushed confines of an elevator. Indeed, they seem to speak *louder* in an elevator. Can this be proof that cell-phone users are a separate species?

NEIL ROBERTSON
via e-mail

De Waal replies:

In some of the short-term crowding experiments conducted by others and ourselves, monkeys were literally packed together, without much room to avoid body contact, in a cramped space for periods of up to a few hours. No dramatic aggression increases were measured. In fact, in my last conversation with the late John Calhoun, he mentioned having created layers of rats on top of each other and having been surprised at how passively they reacted. I have never been able to find a published report on this experiment, but it fits the findings on monkeys, which makes me think that extremely high crowding levels do not necessarily induce more aggression than moderate ones.

Letters to the editors should be sent by e-mail to editors@sciam.com or by post to Scientific American, 415 Madison Ave., New York, NY 10017. Letters may be edited for length and clarity.

ERRATUM

In "Boomerang Effect," by George Musser [News and Analysis, July], a sentence at the bottom of the second column on page 14 should have read "The height of the peaks represents the *maximum* [not minimum] amount of compression ... or of rarefaction ... in initial-dense regions."

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Sandra Ourusoff
PUBLISHER
saourusoff@sciam.com

NEW YORK ADVERTISING OFFICES
415 MADISON AVENUE, NEW YORK, NY 10017
212-451-8523 fax 212-754-1138

Denise Anderman
ASSOCIATE PUBLISHER
danderman@sciam.com

Millicent Easley
SALES DEVELOPMENT MANAGER
easley@sciam.com

Wanda R. Knox
wknox@sciam.com

Darren Palmieri
dpalmieri@sciam.com

DETROIT
Edward A. Bartley
MIDWEST MANAGER
248-353-4411 fax 248-353-4360
ebartley@sciam.com

LOS ANGELES
Lisa K. Carden
WEST COAST MANAGER
310-234-2699 fax 310-234-2670
lcarden@sciam.com

SAN FRANCISCO
Debra Silver
SAN FRANCISCO MANAGER
John Bergan
415-403-9030 fax 415-403-9033
dsilver@sciam.com
jbergan@sciam.com

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CANADA
FENN COMPANY, INC.
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U.K. AND SCANDINAVIA
Roy Edwards
INTERNATIONAL ADVERTISING DIRECTOR
Julie Swaysland
Chester House, 25 Ecclestone Place
London SW1W 9NE, England
+44 207 881-8434/35 fax +44 207 881-8503
redwards@sciam.com
jswaysland@sciam.com

GERMANY
Rupert Tonn
John Orchard
PUBLICITAS GERMANY GMBH
Oederweg 52-54
D-60318 Frankfurt am Main, Germany
+49 69 71 91 49 0 fax +49 69 71 91 49 30
rtonn@publicitas.com
jorchard@publicitas.com

FRANCE
Christine Paillet
AMECOM
115, rue St. Dominique
75007 Paris, France
+331 45 56 92 42 fax +331 45 56 93 20

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LE SCIENZE

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INVESTIGACION CIENCIA

Investigacion y Ciencia
Prensa Científica, S.A.
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08021 Barcelona, SPAIN
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العلم

Majallat Al-Oloom
Kuwait Foundation for the Advancement of Sciences
P.O. Box 20856
Safat 13069, KUWAIT
tel: +965-2428186

ŚWIAT NAUKI

Swiat Nauki
Proszynski i Ska S.A.
ul. Garazowa 7
02-651 Warszawa, POLAND
tel: +48-022-607-76-40
swiatnauki@proszynski.com.pl

日経サイエンス

Nikkei Science, Inc.
1-9-5 Otemachi, Chiyoda-ku
Tokyo 100-8066, JAPAN
tel: +813-5255-2821

CBIT HAYKI

Svit Nauky
Lviv State Medical University
69 Pekarska Street
290010, Lviv, UKRAINE
tel: +380-322-755856
zavadka@meduniv.lviv.ua

ΕΛΛΗΝΙΚΗ ΕΚΔΟΣΗ
Scientific American Hellas SA
35-37 Sp. Mercouri St.
Gr 116 34 Athens GREECE
tel: +301-72-94-354
sciam@otenet.gr

科学

Ke Xue
Institute of Scientific and Technical Information of China
P.O. Box 2104
Chongqing, Sichuan
PEOPLE'S REPUBLIC OF CHINA
tel: +86-236-3863170

Science Greats Look Back—and Ahead

SEPTEMBER 1950

In this month, *Scientific American* published a special issue, "The Age of Science, 1900–1950," featuring 10 articles and an introduction by leading scientists of the day.

OPENING COMMENTARY—"All the reports are pervaded, with varying emphasis, by a sense of the dual role of science. The purpose and the fruits of science are discovery and understanding. Yet equally, though in a quite different sense, its purpose and its fruits are a vast extension of human resources, of man's power to control and alter the environment in which he lives, works, suffers and perishes. —J. R. Oppenheimer, theoretical physicist and wartime director of the Los Alamos Scientific Laboratory"



J. R. Oppenheimer

ASTRONOMY—"Scarcely a question asked of doctoral candidates today would have made sense to the giants of 1900. They would have been baffled, helpless and perhaps suspicious in the face of inquiries concerning photomultipliers, quantum theory, solar spicules, the carbon cycle, shell stars, the expanding universe, radio 'hot spots,' the Schmidt reflector, Pluto, cosmic rays and other common topics. Pride in our advances should be mellowed, however, by the contemplation of how much beyond us the astronomical world of 2000 A.D. is likely to be. —Harlow Shapley, director of the Harvard College Observatory"



Harlow Shapley

PHYSICS—"In the final analysis the most striking difference between physics in 1900 and in 1950 is the complete victory

of atomistics. The speculations of the ancient Greek philosophers and the dreams of the alchemists have come true. With



Max Born

rather primitive instruments Frederick Soddy and Ernest Rutherford first analyzed the process of radioactive disintegration and found that it consists of a series of transformations of one atom into another. Thus the belief in the invariability of the chemical elements was shattered. —Max Born" [Editors' note: Awarded the Nobel Prize in Physics, 1954.]

CHEMISTRY—"The half-century we are just completing has seen the evolution of chemistry from a vast but largely formless body of empirical knowledge into a coordinated science. The new ideas about electrons and atomic nuclei were speedily introduced into chemistry, leading to the formulation of a powerful structural theory which has welded most of the great mass of chemical facts into a unified system. What will the next 50 years bring? We may hope that the chemist of the year 2000 will have obtained such penetrating knowledge of the forces between atoms and molecules that he will be able to predict the rate of any chemical reaction. —Linus Pauling" [Editors' note: Awarded the Nobel Prize in Chemistry, 1954; Nobel Prize in Peace, 1962.]



Linus Pauling

GEOLOGY—"One of the major turn-of-the-century controversies that is still alive is the question of the stability of the continents. The continental-drift hypothesis, abhorrent as it is to many geologists today, has not yet gone to limbo, and it has gained some new support from the cu-



Reginald A. Daly

mulative evidence of the plasticity of the depths below the crust. The drift theorists hold that over this weak underpinning, floating blocks of the continental crust may have migrated many hundreds of miles. But no one has yet suggested a generally convincing explanation of what forces made the continents move about. —Reginald A. Daly, professor of geology emeritus at Harvard University"

MATHEMATICS—"Although during the past 50 years pure mathematicians have become more and more rigorous, the restraints on applied mathematicians have been, in practice, altogether removed. For instance, P.A.M. Dirac of Cambridge introduced a 'delta-function' that has the property of being infinite at one point and zero everywhere else but has a finite integral, and the applied men now make the most reckless use of it without incurring any censure. Probably such a state of things is really quite healthy: first get on with the discoveries in any way possible, and let the logic be cleaned up afterward. —Sir Edmund Whittaker, one of the foremost mathematicians of the past half-century"



Edmund Whittaker

GENETICS—"Man's deepest urge, after all, is to understand himself and his place in the Universe—to fathom his own nature as a living organism and the interactions between heredity and environment that shape the development of his body and mind. The discovery of the basic laws of heredity is one of the major conquests of 20th-century science, and the field of genetics has become the cornerstone of modern biology. Genetics will surely play a major role in the still infant technol-



Theodosius Dobzhansky

SEPTEMBER 1900

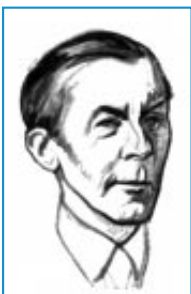
ogy of biological engineering. Already it has borne a huge harvest of 'practical' results through improvements in breeds of food plants and animals.—Theodosius Dobzhansky, one of the principal contributors to the relationship between genetics and the study of evolution"

BIOCHEMISTRY—"Early in this century a movement headed by Jacques Loeb of the U.S. and Otto Warburg of Germany felt strongly that all living beings had much in common. As a result of this shift in view, the study of mammals as a whole was largely replaced by intensive investigation of the metabolism and the physical chemistry of cells that are homogeneous—sea-urchin eggs, yeast, bacteria, blood corpuscles, any cell that could reveal the physiological processes of life at the most fundamental and universal level. Looking ahead to the next half-century, we must be clear that the most important discoveries cannot be planned or predicted. They stem from genius and creative intuition; techniques and skills play no other role than they played for Michelangelo in painting the Sistine Chapel.—Otto Meyerhof, awarded the Nobel prize in Physiology and Medicine for 1922"



Otto Meyerhof

PHYSIOLOGY—"The interest of the physiologist is shifting in the direction of biophysics and biochemistry. In the study of the endocrine glands the most spectacular leap ahead came in 1922: the discovery by F. G. Banting and C. H. Best of the pancreatic hormone insulin, which resulted in the immediate saving of thousands of lives. In studies of nerve fibers, the realization that the nerve impulse is an 'all-or-nothing' reaction at each point in the fiber has focussed attention on the surface membrane as the trigger mechanism. The nerve membrane is alive and seems to undergo some surprising changes, but these are no longer beyond the reach of experiment. If they can be understood, we shall have mas-



E. D. Adrian

tered one of the most important properties of the living cell: its power to react suddenly to changes in its surroundings.—E. D. Adrian, awarded the Nobel prize in physiology and medicine in 1932"

PSYCHOLOGY—"The development of psychology in the past half-century shows three major trends that appear to have taken place during that period. First there has been a trend away from atomistic approach toward the integrated study of the whole man. We now know that the elements of experience become totally meaningless when taken out of the experiential process. Second, there has been an increasing tendency to consider man and his environment together rather than as separate absolutes. The third trend we have to consider is the return of many psychologists to the laboratory, this time to study much more inclusive problems than the fragmentary ones that occupied psychologists at the beginning of the century.—Hadley Cantril, professor of psychology at Princeton University"



Hadley Cantril

ANTHROPOLOGY—"The most significant accomplishment of anthropology in the first half of the 20th century has been the extension and clarification of the concept of culture, the idea that a society's customs, traditions, tools and ways of thinking play the dominant part in shaping the development of human beings. The outstanding consequence of this conceptual extension has been the toppling of the doctrine of racism—that bland assumption of race superiority. We have learned that social achievements and superiorities rest overwhelmingly on cultural conditioning. The racist illusion rests on a naive failure to distinguish fixed biological processes from variable cultural processes. Hitlerism represented its last, die-hard, desperate lashing out as an organized national creed.—A. L. Kroeber, one of the leading generalizers of modern anthropology"



A. L. Kroeber

—A. L. Kroeber, one of the leading generalizers of modern anthropology"

PHOTOENGRAVING—"The general introduction of photo-mechanical engraving processes has wrought a revolution in the publishing world. It has changed entirely the character of many magazines and weekly papers, and now it is possible even for daily papers to make half-tone plates in a space of time which a few years ago would have seemed nothing less than marvelous. The adoption of the half-tone process for the illustration of high-class periodicals and books practically sounded the death-knell to wood-engraving, so that in a few years wood-engraving will be practiced, perhaps, only in art schools."

SPIDER SILK—"The Professional School of Tananarive, in Madagascar, is experimenting with the utilization of the thread of the silk-producing spiders (*Nephila Madagascarensis*). The 'Halabé' (as the Malagashes call this spider) is quite difficult to reproduce, since the female, which alone yields the thread, is so ferocious and ravenous that in most cases, she kills and eats the male. The spiders are placed in a frame in groups of up to two dozen. The Malagash girls touch the end of the abdomen of the prisoners with the finger and carry twenty-four threads to a hook that unites them into a single one, to the bobbin upon which they are wound."

SEPTEMBER 1850

TAKE A BITE OUT OF CRIME—"In the case of the murder of Dr. George Parkman, the bones of the cranium had been calcined by throwing them into a furnace, the ashes of which were examined; and amongst them, artificial mineral teeth were found. Inquiry was made amongst the dentists, and Dr. Nathan Keep, a celebrated dentist of the place, instantly identified the work, placed them upon his working model, and at once supplied an important link of evidence, he having made the teeth a few months previously. This instance shows how important a connection there exists between a proper knowledge of the dental art, and its application as an auxiliary of medical jurisprudence."

HOT AIR—"Major Browne, of Great Portland Street, London, has proposed a balloon railway across the desert of Africa. He suggests the establishment of a terminus near Morocco, where he would lay 1,500 miles of single track rails into the desert, for the guidance of balloons. An immense and lucrative trade with the interior, the Major conceives, could be carried on."

Gully Gee Whiz

Even as you read this, water might be flowing on Mars

After a while, news stories about Mars—the happy ones, that is—all begin to sound the same. Scientists make new observations, find new evidence that the Red Planet used to be agush with liquid water. They speculate that it used to be cozier, that microbes used to live there. But the latest observations by the Mars Global Surveyor space probe call for a dramatic revision. The operative verb when talking about water on Mars may not be “used to be” but “is.”

Ever since the Mariner 9 and Viking missions of the 1970s, scientists have known about two types of water-carved landforms on Mars: outflow channels, which look like the aftermath of colossal flash floods, and valley networks, which look something like river basins on Earth. Other possible sculptors besides water—glaciers, wind, lava, liquid carbon dioxide—would have left a different imprint. Judging from the density of meteor craters on these features, they formed from one billion years ago (for some of the outflow channels) to four billion years ago (for the valley networks). When scientists talk about blue skies and balmy temperatures on primordial Mars, they are referring to the intricate valleys, whose hewing may have required a milder climate.

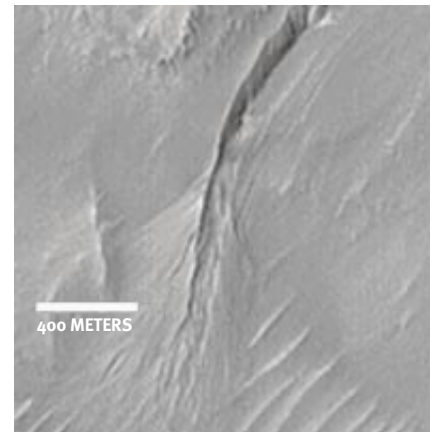
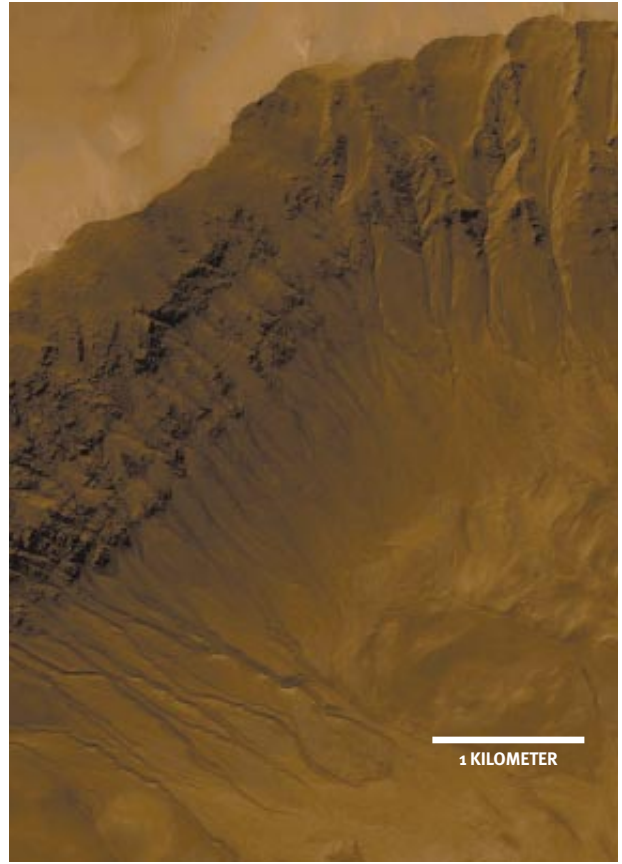
Like those earlier probes, Global Surveyor has piled on evidence for the past action of water. The robotic craft, whose success is sometimes forgotten amid the National Aeronautics and Space Administration’s recent failures, arrived at Mars in September 1997 and began its high-resolution mapping in March 1999. It has seen signs of dry lake beds, sedimentary layering, water-related mineral deposits, even shorelines—all fascinating, if not entirely unexpected.

But no one foresaw the latest findings: small, unassuming gullies you could practically jump across. “It’s clearly one of the most important discoveries that have been made since the Viking mission,” says Mars theorist Stephen M. Clifford of the Lunar and Planetary Institute in Houston.

First hinted at two years ago in preliminary images, the little gullies have been identified as such only in the high-resolution images, which reveal details as small as two meters across. In the June 30 *Science*, Michael C. Malin and Kenneth S. Edgett of Malin Space Science Systems in San Diego described gullies at 120 distinct locations. Running down the walls of craters, valleys or pits, they have three parts: an alcove (a collapsed, amphitheater-shaped area high up on the wall, a few hundred meters below the top), one or more channels (several hundred meters long and perhaps two meters deep) and an apron (a low-lying delta).

Two things make the gullies especially bizarre. First, their location: all but a few are found in regions above 30 degrees latitude and on slopes that face toward the poles, places where the mercury never gets above -70 degrees Celsius. “They form in the coldest locations on the planet, which is exactly the opposite of what you’d have expected,” Malin says. Second, their relative youth: they cut into terrain that itself is thought to have formed comparatively recently, including sand dunes, crater-free landscapes and the “polygons” that pop up when new permafrost undergoes freeze-thaw cycles. Most also seem to have avoided burial by Mars’s perennial dust storms. “Geologically, they’re as fresh as newfallen snow,” Edgett says.

Of course, what counts as recent to a geologist could be a long time ago to the rest of us. It might be yesterday, or a few million years ago, or longer. Planetary scientists consider it a victory when they can pin down ages to within half a billion years—way too imprecise to understand the gullies. In any case, a process that is geologically recent may well still be active.



A RIVULET RAN THROUGH IT: Dozens of gullies slice an unnamed crater (top) and overlie some sand dunes (bottom).

By and large, planetary scientists accept the pair’s basic interpretation of the gullies. Although it might sound impossible for water to run across the Martian surface under present conditions, calculations show that a stream could survive for several days before evaporating away. The real controversy is where the liquid came from. Malin and Edgett propose intermittent discharge from a shallow aquifer, but even they admit their doubts. What would keep such an aquifer from being frozen solid? Geothermal heating, perhaps? Yet

according to Clifford, keeping ground-water liquid would require 10 times as much heat as Mars could reasonably generate. Although Viking and Global Surveyor have seen inklings of relatively recent volcanism, such as pristine lava flows, the gullies do not occur in potential hot spots.

Many researchers, including Clifford, Kenneth L. Tanaka of the U.S. Geological Survey, David Paige of the University of California at Los Angeles and Fraser Fanale of the University of Hawaii, say that there is no need to posit aquifers when everyone already knows a potential source of the water: underground ice. Oddly deformed topography and muddy crater debris, both interpreted as the handiwork of ice, are ubiquitous at latitudes above 30

degrees, which is exactly where models suggest ice would have accumulated.

Under present conditions, near-surface ice cannot thaw out, but the Martian climate is thought to go through huge swings triggered, like Earth's ice ages, by wobbles in axial tilt. Mars sometimes leans over as much as 60 degrees, which makes the pole-facing slopes—now the coldest places on the planet—the hottest. Depending on the season, topography and soil properties, the ice could start to melt. Extreme tilt might even set off a self-reinforcing greenhouse effect. Lovers of Martian microbes like the idea because it would give any critters a chance to emerge from hibernation, stretch their cilia and lay in supplies for the next cold spell.

As an explanation for the gullies, how-

ever, this model has its own difficulties. Michael H. Carr of the USGS worries about the details of the heat distribution. He says that scientists need to consider alternatives to water, such as dry or gas-lubricated landslides. Carr's skepticism is all the more forceful because he made his reputation arguing for the past existence of water on Mars.

As the Mars Global Surveyor continues its mapping, scientists from the European Space Agency and NASA are preparing new Mars probes to set forth in 2003. Mars may turn out to be a more alive planet than seemed possible before the gullies came to light. Says Bruce M. Jakosky of the University of Colorado, "Mars is not quite the simpler-than-Earth planet we've been treating it as." —George Musser

GENOMICS _ ANNOTATION

Beyond the First Draft

Making the genome data useful may depend on the public project Ensembl

Unprecedented fanfare greeted the June 26 announcement that scientists had completed a draft of the human genome sequence. The truth is, however, that figuring out the order of the letters in our genetic alphabet was the easy part. Now comes the hard part: deciphering the meaning of the genetic instruction book.

The next stage goes by a deceptively prosaic name: annotation. Strictly speaking, "annotation" comprises everything that can be known about a gene: where it works, what it does and how it interacts with fellow genes. Right now, scientists often use the term simply to signify the first step: gene finding. That means discovering which parts of a stretch of DNA belong to a gene and distinguishing them from the other 96 percent or so that have no known function, often called junk DNA.

Several companies have sprouted up to provide bioinformatics tools, software and services [see "The Business of the Hu-

man Genome," *SCIENTIFIC AMERICAN*, July]. Their success, though, may hinge on a peaceful spot south of England's University of Cambridge. It is home to the Sanger Center, the U.K. partner in the publicly funded Human Genome Project (HGP) consortium, and the European Bioinformatics Institute (EBI), Europe's equivalent of the National Center for Biotechnology Information (NCBI) at the National Institutes of Health. Sanger and EBI are collaborating on the Ensembl project, which

consists of computer programs for genome analysis and the public database of human DNA sequences. New DNA sequences arrive in bits and pieces; automated routines scan the sequences, looking for patterns typically found in genes. "One of the important things about Ensembl is that we're completely open, so you can see all our data, absolutely everything," says EBI's Ewan Birney.

No matter how talented their algorithms, however, computers can't get all the genes, and they can't get them all right. Many additions and corrections, plus the all-important information about how genes are regulated and what they do, are tasks for human curators. That problem may be solved for Ensembl by a distributed computing system under development by Lincoln Stein of the Cold Spring Harbor Laboratory on Long Island, N.Y. The plan is to provide human anno-

HISTORY WAS MADE when Celera Genomics head J. Craig Venter (*left*) and Francis S. Collins, the U.S. director of the Human Genome Project, announced the completion of the first draft of the human genome.



RICK BOWMER AP Photo

tation—corrections and suggestions and research findings from scientists around the world—layered on top of Ensembl's automatic annotation. Stein's Distributed Sequence Annotation System, DAS for short, borrows an approach from Napster, the controversial software that allows people to swap music files over the Internet.

The plan is that different labs will publish their own annotations (on dedicated servers) according to specifications of some commonly accepted map of the genome—like Ensembl's. "Then the browser application would be able to go out onto the Web, find out what's there and bring it all into an integrated view so that you could see in a graphical way what different people had to say about a region of the genome," Stein explains. In this way DAS may solve a huge problem that plagues biology databases: the lack of a standard format for archiving and presenting data, which, among other disadvantages, makes it impossible to search across them and compare contents.

The DAS model is not universally beloved. NCBI director David Lipman is concerned that the human annotations may be full of rubbish because they will not be peer-reviewed. Stein acknowledges the possibility but hopes that good annotation will drive out bad. He is more concerned about whether the spirit of volunteerism will flag when faced with personnel changes and the vagaries of funding. Keeping a lab's Web server running and up-to-date is a long-term commitment.

As opposed to the well-publicized rivalry between the HGP and the privately owned Celera Genomics in sequencing the genome, many bioinformatics firms don't regard Ensembl as an organization to beat. In fact, several commercial players endorse collaboration; financial opportunity will come from using the data in a unique way. James I. Garrels, president of Proteome in Beverly, Mass., expects to partner with and provide help to public-domain efforts to amass a basic description of each gene, its protein and a few of the protein's key properties. But Proteome also believes that nothing beats the vast and versatile human brain for making sense of the vast and versatile human genome. The company's researchers scour the literature, concentrating on proteins—the product most genes make—and since 1995 have built protein databases on three model organisms: the roundworm *Caenorhabditis elegans* and two species of yeast. Now they are adding data on the human, mouse and rat ge-

nomes. The company's niche will be integrating all that information. "That's not the type of effort contemplated in the public domain," Garrels points out.

Proteome's strength is likely to lie in its customers' ability to compare sequences across species. Because evolution has conserved a great many genes and used them over and over, such comparisons are a rich source of hints: a human gene whose job is currently a mystery will often be nearly identical to one present in other species.

Randy Scott, president of Incyte Genomics in Palo Alto, Calif., is another fan of sharing the load. Besides, "there's plenty of ways to make money," Scott declares. "We assume there are going to be broadly annotated databases available in the public domain, and the sooner we can get there, the faster Incyte can focus on downstream, on how we take that information to create new levels of information." For instance, the company has picked a group of genes it believes will be important for

diagnostics and other applications and is concentrating its annotation efforts on them. It also has databases that permit some cross-species comparisons.

Given Ensembl's open-source code, distributed annotation and determination to stay free, comparisons to the free Linux computer operating system—which may someday challenge Microsoft Windows's supremacy—are natural. But the parallel doesn't go very far. Thinking of public and commercial annotation products as rivals misses the point, observers say. In the words of Sean Eddy of Washington University, who is working on DAS: "The human genome is too big for anybody to look at alone. We're going to have to figure out ways for the public and private sectors to work collaboratively rather than competitively." —*Tabitha M. Powledge*

TABITHA M. POWLEDGE, a writer based near Washington, D.C., focuses on genetics, neuroscience, archaeology and policy.

Genome Scientists' To-Do List

1. Correct errors and proofread. The original plan was to repeat the sequencing up to 12 times to prune away the mistakes that inevitably accompany a project involving 3.1 billion pieces of data. In the rush to make the joint announcement, the privately funded Celera Genomics and the publicly funded international consortium Human Genome Project settled temporarily for less than half that goal. Proofreading will probably take another year or two.

2. Fill tens of thousands of gaps in the sequence. These holes amounted to about 15 percent of the genome on June 26. Most gaps lie in stretches of short sequences repeated hundreds or thousands of times, which makes them enormously difficult to get right.

3. Sequence the 7 percent of the human genome that was originally excluded by design. This region is heterochromatin, highly condensed DNA long believed to contain no genes. But this past March, analysis revealed that fruit fly heterochromatin (about one third of the fly's genome) appears to contain about 50 genes—so human heterochromatin probably contains a few genes, too.

4. Finish finding all the genes that make proteins. This step takes place after the sequence is cleaned up and deemed 99.99 percent accurate. About 38,000 protein-coding genes have been confirmed so far. Recent estimates have tended to fall below 60,000. A few respected authorities are still holding out for 100,000 or more.

5. Find the non-protein-making genes. There are, for instance, genes that make RNA rather than protein. They tend to fall below the threshold of today's gene-finding software, so new ways of discovering them will have to be devised.

6. Discover the regulatory sequences that activate a gene and that govern how much of its product to make.

7. Untangle the genes' intricate interactions with other molecules.

8. Identify gene functions. Because a gene may make several proteins, and each protein may perform more than one job, the task will be stupendous.

As they check each item off the list, researchers will be generating the information that will make it possible to attack and even prevent a vast array of human ills. But how long will it take to get through the checklist? If anyone knows, it should be Celera president J. Craig Venter. On announcement day Venter predicted that the analysis will take most of this century. —*T.M.P.*

Worrying about Wireless

Researchers are still unsure whether cellular phones are safe

Like bursts of annoying static, questions about the safety of cellular phones have popped up repeatedly over the past decade. The controversy began in earnest in 1993, when a Florida man appearing on the television talk show *Larry King Live* claimed that his wife's brain cancer had been caused by the low-power radiation emitted by her cell phone. Other cancer victims soon made similar allegations in lawsuits against the phones' manufacturers. The Cellular Telephone Industry Association (CTIA) vigorously denied the claims, but at the same time it agreed to sponsor a six-year research program that would investigate whether cell phones pose any health risk.

Unfortunately, that question is still unanswered. The CTIA's research program, completed last year, yielded few worthwhile studies in return for the \$25 million spent. The research on cell-phone safety has been wildly haphazard, and the results have created more confusion than ever.

In recent years scientists have found intriguing indications that cell-phone radiation may indeed have some effects on biological tissues. Whether those effects are harmful or benign, however, is another issue: no study to date has shown a clear link between cell-phone use and cancer or any other disease. Nevertheless, some scientists are urging cell-phone customers to take precautions. "With so many people using cellular phones over such a long time, even a slight effect could have many consequences," says Henry Lai, a professor of bioengineering at the University of Washington.

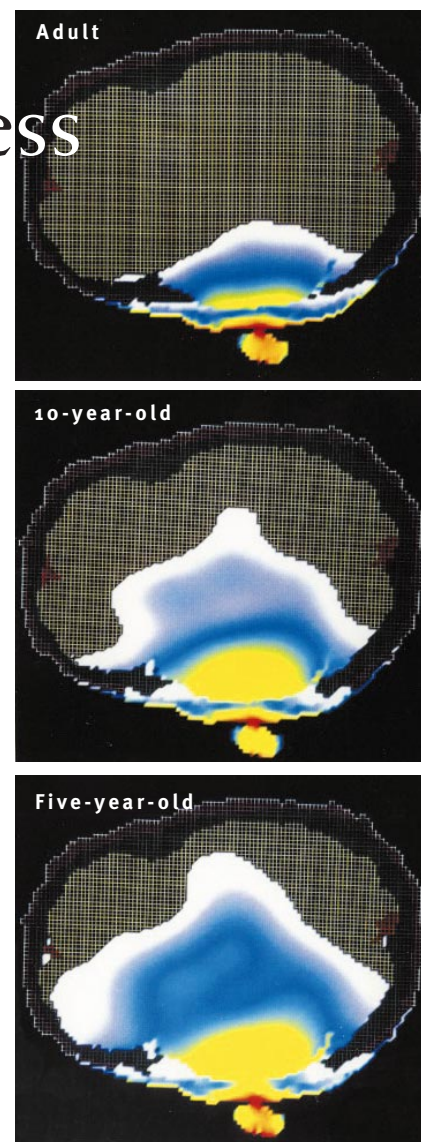
Many radiation experts maintain that it is physically impossible for cellular phones to have any biological effects. Cell-phone emissions range in frequency from about 800 to 2,000 megahertz. (Emissions below 1,000 megahertz are radio waves, whereas those above are microwaves.) At high power, such radiation can heat organic material—that's the way microwave ovens work—but cell-phone emissions are much too weak to cook human tissues. The average power transmit-

ted by a typical mobile phone is about a quarter of a watt. If the phone's antenna is placed next to someone's head for a few minutes, the waves will raise the temperature of the nearby brain cells by a maximum of about 0.1 degree Celsius.

Because this heating is about one tenth the normal fluctuations of the brain's temperature, it is unlikely to affect the organ. What is more, cell-phone radiation is non-ionizing: unlike the high-energy photons in x-rays and gamma rays, which can shatter DNA molecules and thereby trigger cancer-causing mutations, radio and microwave photons are not energetic enough to break the chemical bonds of organic molecules.

Several experiments, however, suggest that low-power radio and microwaves can affect the mental performance of people and animals. For example, a 1999 study by Alan Preece of the University of Bristol in the U.K. asked a group of volunteers to perform an array of cognitive tasks while they were exposed to simulated cell-phone emissions from headsets. The emissions had no apparent effect on short- or long-term memory, but the exposure significantly decreased the subjects' reaction times as they pressed buttons to match the words "yes" and "no" flashed on a computer screen. In other words, the radiation made the volunteers quicker on the draw. Finnish scientists conducted a similar test and also found decreased reaction times. But when rats were exposed to low-power microwaves in several experiments done by Lai, the animals took longer to find their way through a maze than the rats in the control group did.

Research on health effects has yielded more disturbing results. A 1997 study conducted by investigators at the Royal Adelaide Hospital in Australia used mice that had been genetically engineered to be susceptible to lymphoma, the cancer of the lymphoid tissues. For one hour per day, the scientists exposed the transgenic mice to low-power radio waves similar to those emitted by digital cellular phones. After 18 months the inci-



CELL-PHONE ENERGY penetrates more deeply into a child's brain than an adult's, as shown in these models.

dence of lymphoma in the exposed mice was twice as high as that in the control group. In contrast, a 1999 study led by William Ross Adey of the University of California at Riverside found that digital cell-phone signals actually decreased the incidence of tumors in rats that had been exposed to a chemical carcinogen before birth. "We're seeing effects," Adey says, "but we can't figure out why."

Some biophysicists speculate that the electromagnetic fields generated by mobile phones could interfere with the body's sensitive electrical activities. For instance, one hypothesis proposes that the fields induce small movements in the positively charged calcium ions that activate key receptor sites on cell membranes. Under the right conditions, even

a weak field could significantly increase or decrease the membrane's permeability. This would alter the concentrations of ions and free radicals in the cell and possibly lead to higher rates of DNA damage.

In 1995 Lai and his colleague Narendra P. Singh provided some evidence for this hypothesis. They exposed rats to low-power microwaves for two hours, then extracted the DNA from the rats' brain cells. They found a greater number of breaks in the DNA strands of the exposed rats than in those of a control group. But other researchers' attempts to replicate these results have failed. A group led by Joseph L. Roti Roti of Washington University found no changes in DNA strand breaks in half a dozen similar experiments.

A surer test of cell-phone safety would be a comprehensive epidemiological study that measured the incidence of cancer and other diseases in thousands of long-term cell-phone users. Preliminary results from a small CTIA-funded study suggest that cell-phone use could be associated with a higher rate of a rare type of brain cancer, but that research has not yet been published. A broader study conducted by the National Cancer Institute is expected to be out by the end of the year.

In the meantime many scientists are advising cell-phone users to be prudent. This past May a panel of experts commissioned by the British government released a report recommending that children be discouraged from using mobile phones for nonessential calls. The recommendation is partly based on evidence that a cell phone's electromagnetic field penetrates more deeply into a child's head than an adult's, so any possible health effects are likely to be more pronounced in children. The panel also recommended that wireless companies stop promoting the use of mobile phones by children. In the U.S., such promotions are commonplace. AT&T Wireless, for example, says it does not market to kids, but the company sells cell-phone faceplates with pictures of Mickey Mouse and other Disney characters.

In the end, though, the worries about wireless may be misplaced. Researchers have proved only one certain danger from cell phones: they lead to higher rates of traffic accidents when customers use them while driving (a practice that AT&T Wireless, to its credit, strongly discourages). And even the most pessimistic scientists admit that the potential health hazards from cell-phone radiation are meager compared with the dangers of,

cigarette smoking. If you're still worried, you can buy a "hand-free" headset for your cell phone, which will at least shift the radiation from your head to another part of your body. You may also want to consider giving up hair dryers, which radiate powerful, low-frequency fields close to the head. But there's little

sense in fearing the transmission towers used by cell-phone networks: beyond a few meters from the antennas, their fields fall off to practically nothing. Adds Singh: "Psychological stress may also cause DNA strand breaks. So simply worrying about cell phones could be unhealthy, too."

—Mark Alpert

GEOLOGY_PETROLEUM

Awash in Oil

There's plenty of cheap oil, says the U.S. Geological Survey

The debate over this summer's skyrocketing gasoline prices—an issue that has drawn the ire of both U.S. presidential candidates, Congress and the Federal Trade Commission—obscures what may be a larger truth: there's gobs of oil out there.

In June, after a five-year study, the U.S. Geological Survey raised its previous estimate of the world's crude oil reserves by 20 percent, to a total of 649 billion barrels. The USGS team believes the largest reserves of undiscovered oil lie in existing fields in the Middle East, the northeast Greenland Shelf, the western Siberian and Caspian areas, and the Niger and Congo delta areas of Africa. Significant new reserves were found in northeast Greenland and offshore Suriname, both of which have no history of production. "What we did is look into the future and predict how much will be discovered in the next 30 years based on the geology of how it gets trapped," explains

Suzanne D. Weedman, program coordinator of the USGS World Petroleum Assessment 2000. "We also believe that the [oil] reserve numbers are going to increase."

Besides relying on geological surveys, the USGS also based its numbers on changes in drilling technology that are making it easier to find new supplies and to squeeze more oil out of existing fields. Petroleum companies are flushing out oil with pressurized water and carbon dioxide and using improved robot technology to construct offshore drilling rigs in up to 3,500 feet of water. They are also conduct-

ing three-dimensional seismic imaging of underground and underwater fields.

The idea of an expanding "reserve growth" of undiscovered oil isn't shared by everyone. Colin J. Campbell, an oil industry analyst based in Ireland, believes the USGS estimates are overly optimistic. "It's only the low end of this scale that has any practical meaning; the other end of the scale is a very bad estimate," argues



OIL THE TIME? At least for the next 30 years.

Campbell, who warned of an impending crunch, based on projections of current production and reserves, in an article in *Scientific American* ["The End of Cheap Oil," March 1998]. Weedman says the USGS report is documented with 32,000 pages of data. "We've looked at all the information," she states, "and tried to predict on the basis of science and not on past [oil] production." —Eric Niller

ERIC NILLER, a journalist based in San Diego, described the vanishing biodiversity on Guadalupe Island in the August issue.

Drinking without Harm

Arsenic poisoning or deadly diarrhea? Bangladesh may no longer have to choose

In the early 1970s the United Nations Children's Fund (UNICEF) and the Bangladeshi government embarked on a massive program to install hundreds of thousands of groundwater wells. They were to provide safe drinking water for the 125 million people of Bangladesh, who long relied on surface water that was often laden with lethal amounts of bacteria. Thanks to that initiative, today some 12 million wells supply 97 percent of the drinking water, sparing the desperately poor coun-

son, Jr., of Columbia University, who has traveled to Bangladesh twice this year.

Arsenic doesn't flavor, color or scent the water. "It has all the sensory impressions that would say to you, 'This is good water,'" Simpson explains. And, unlike pathogenic surface water, arsenic-tainted groundwater doesn't sicken you right away. One can ingest low doses of arsenic for eight to 14 years before white or black spots, called melanosis, start mottling the skin. If the poisoning continues, scaly, leprosylike skin lesions then encrust the palms and soles, eventually rotting into gangrenous ulcers. Finally come renal diseases, cancers—particularly of the bladder and lungs—and death.

Occurring naturally in rock and soil, arsenic is not an uncommon problem around the globe. The World Health Organization's standard for arsenic in drinking water is no more than 10 parts per billion. The current U.S. standard is 50 ppb, but the Environmental Protection Agency wants to lower it to five ppb. The Bangladeshi standard is also 50 ppb, but wells there have tested at levels as high as 4,000 ppb, reports Dipankar Chakraborti, head of the School of Environmental Studies at Jadavpur University in Calcutta.

In response to the crisis, the Bangladeshi government, which officially acknowledged the problem in 1995, has urged citizens to drink only boiled surface water and water from deep wells—those that descend more than 300 feet into a lower aquifer. (Wells typically go down 50 to 250 feet.) "Deep wells are providing safe water," says A. Mush-taque R. Chowdhury, a research director at the Bangladesh Rural Advancement Committee. "But we don't know how long they remain safe. And these wells are expensive compared to any other option."

Simpson and a multidisciplinary team of 23 others may have found a more cost-effective alternative. In March the researchers began testing 5,000 wells in a region east of Dhaka, the capital city. These tests marked the start of a five-year project meant to examine the crisis based on geological, hydrological, health and social surveys. Besides finding 60 percent of the wells contaminated, they discovered, somewhat surprisingly, that water from shallow wells—those no more than 30 feet deep—contains little arsenic.

One reason, according to team member Yan Zheng of Queens College, can be attributed to a well-known chemical fact about arsenic: it can be locked up in iron-oxide sediment in oxygen-rich waters. Filtering the water through, say, fine sand, was thought to remove arsenic-laced sediment. But experiments showed that this simple method, probably because of other compounds in Bangladeshi water, did not lower arsenic concentrations to a safe level, according to George Korfiatis of the Stevens Institute of Technology.

Without testing equipment, says co-principal investigator Alexander van Geen of Columbia University, "I would go for a shallow well that doesn't have iron visibly precipitating," meaning that the water doesn't turn yellowish or reddish when exposed to air. Preferring water without the iron that can hold arsenic may seem illogical, but van Geen reasons that if no iron has leached from underground mineral surfaces, then, quite likely, neither has arsenic, because both are often released into groundwater under similar low-oxygen conditions. Further research is needed to corroborate the team's findings.

Phase two of the Columbia project began in July, when the health group returned to tell each family the arsenic level of its well. Unfortunately, the team lacks funding for a full-blown social-scientific study of people's water-drinking and well-digging behavior. "Here you have an epidemic, and they're still drilling wells," laments Columbia's Joseph H. Graziano, who notes that out of the 5,000 wells surveyed, some were just 15 days old. "You pay someone a few bucks, and they'll do it." A first step in the epidemic could be a matter of sharing information. "If we can find the man who drills those wells and tell him what depth to drill," van Geen speculates, "perhaps we could deal with the problem like that." —*Kimberly Masibay*

KIMBERLY MASIBAY is a science and environmental journalist based in New York City.



NOT WELL: In Bangladesh, installing wells for drinking water may tap into arsenic-contaminated aquifers.

try the 250,000 deaths from waterborne illness that used to occur every year.

But the wells have left the Bangladeshi people in an untenable position: although the groundwater has no deadly pathogens, it does harbor high levels of arsenic, which has caused at least 7,000 deaths since the early 1990s, say local officials. And uncounted thousands bear signs of long-term arsenic poisoning. "It is a gargantuan tragedy that nobody's seen anything like before," says geochemist H. James Simp-

Unlimited Light

Researchers make pulses that travel faster than light—sort of

PRINCETON, N.J.—First things first: Einstein has not left the building.

Despite some recent virtuoso experiments with pulses of light widely reported to far exceed the speed of light, physicists still agree that no object or information has been made to travel superluminally. Cause-and-effect is preserved. But the strange intricacies of light are requiring scientists to examine closely the nature of the ultimate speed limit and, with it, what a pulse of light really is.

Creating the most recent hubbub is a clever experiment in which a pulse of light propagates superluminally through a cell of cesium gas. The group velocity—the velocity of a pulse undistorted in shape—is negative, a counterintuitive situation that means the peak of the pulse arrives at the end of the cell in a time that is less than that of an equivalent pulse traveling through a vacuum. In fact, because the group velocity is negative, it exits the cell even before it enters it. “This is not at odds with special relativity,” maintains Lijun Wang, who performed the experiment with his colleagues Alexander Kuzmich and Arthur Dogariu at the NEC Research Institute in Princeton, N.J. “In fact, we hope our experiment can clarify some subtle misunderstood implications of relativity.”

Those misunderstandings center around the exact meaning of the famous statement from Einstein’s theory of relativity that “nothing can travel faster than the speed of light in a vacuum.” Most optical physicists now agree that it does not pertain to the group velocity, contrary to countless classroom lectures and prominent textbooks. Instead it applies to a more idealized quantity called the “front velocity”—the speed of the edge of a light pulse that is abruptly, instantaneously switched on.

Unfortunately, although physicists can talk about infinitely abrupt pulses, “we don’t know how to make them in the lab,” says physicist Aephraim Steinberg of the University of Toronto. “And we know how to make pulses that look infi-

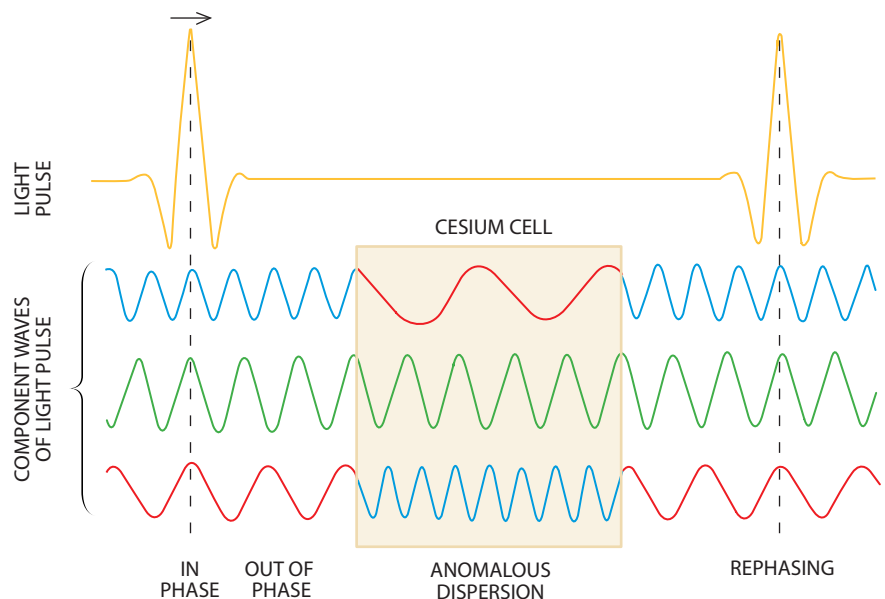
nitely smooth, like a [bell-shaped] curve, but we don’t know how to talk theoretically about the information in them. There’s no rigorous theory about that middle ground yet.”

Past experiments, including a demonstration by Steven Chu of Stanford University in 1982 of superluminal group velocity in an opaque material, have hinted at different aspects of the faster-than-light phenomenon, first predicted in 1970. The work by Wang and his colleagues, published in the July 20 *Nature*, may be the most impressive so far: more than 40 percent of the pulse gets through the cesium gas medium, as opposed to previous experiments largely involving quantum mechanical tunneling, in which very little incident light made it through. The researchers used a combination of laser beams to create an unusual region of “anomalous dispersion” in the six centimeters of cesium gas, where the veloci-

ty of light is higher for higher frequencies of light (ordinarily, higher frequencies mean lower speeds).

This region causes the pulse to “re-phase,” according to Wang. The light pulse, all of whose constituent wavelengths overlap constructively, loses its phase alignment as it propagates toward the cell, causing the waves to cancel one another out. Inside the cell, anomalous dispersion causes shorter wavelength components of the pulse to become longer, and vice versa. That enables the waves to attain phase alignment after exiting the cell. The result is the same pulse but advanced in time by a factor of 310—specifically, 62 nanoseconds better than the 0.2 nanosecond it takes for light to travel that distance in a vacuum.

Some physicists, such as Raymond Chiao of the University of California at Berkeley, have viewed the effect as a pulse reshaping akin to squeezing a long balloon filled with water. The cesium atoms amplify the early, front parts of the pulse by stimulated emission of radiation (the quantum process that creates laser beams), whereas later parts are deamplified by stimulated absorption. In other words, the system re-creates the entire pulse based on the front part of the pulse. “Nature knows how to extrapolate from the information that you gave in the earlier parts of the



TRANS-LIGHT SPEED: A light pulse is made of component waves spreading forward and backward in space; where all the peaks line up in phase defines the center of the pulse. Sent through a cell of laser-soaked cesium gas, the waves encounter a region of anomalous dispersion that makes high frequencies low and low frequencies high, causing the waves to “rephase.” The peaks line up again outside the cell, thus producing the original pulse—even before that pulse has traversed the cell. The effect is greatly exaggerated here—the pulse is 1,500 times longer than the cell.

SOCIOECONOMICS_POVERTY

Hard Times in the Delta

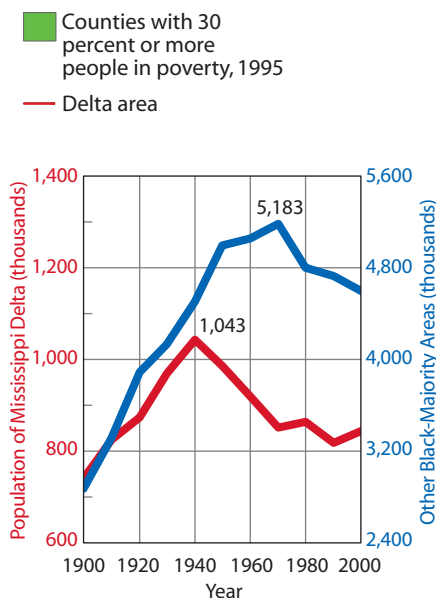
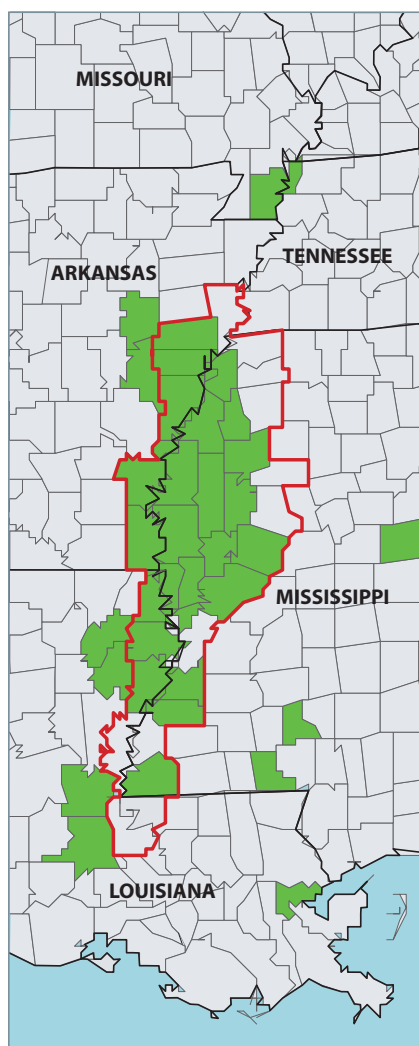
The Mississippi Delta is perhaps the most fertile place on the earth, yet the people there are among the poorest in the country. The root of their poverty goes back to the early 19th century, when many Easterners realized that the climate and the rich alluvial soil—20 to 40 feet thick throughout much of the area—had extraordinary potential for growing cotton. But the lush, swampy land had to be cleared and drained, an enterprise less suitable for ordinary yeoman farmers than for those with substantial resources, such as slave owners. The land was opened early in the 19th century, and by 1860 there were 343 plantations, each with 100 or more slaves, in the 35-county Delta region shown on the map. This area is not the true delta of the Mississippi valley but includes the Yazoo-Mississippi Delta—hence the name—plus other counties in Arkansas, Louisiana and Mississippi bordering the Mississippi River between Memphis, Tenn., and West Baton Rouge, La. This region is the most extensive black-majority area in the U.S. today.

For years the planters were less than enthusiastic about bringing in new industry that would compete with them for unskilled black workers. Thus, when mechanized agriculture came to the region beginning in the 1930s, there were few industrial jobs to absorb laid-off field hands. Many of them, particularly in rural areas, became progressively more enmeshed in poverty, whereas the young and better-educated left the region. Indeed, the Delta was the largest subregion in the U.S. that contributed to the historic exodus of Southern blacks to Northern cities in the 20th century. The result has been, over the past 50 years, a population decline almost unprecedented for any major subregion. Most other black-majority counties in the

Wang plans to investigate several aspects of the superluminal group velocity, including trying to measure the velocity of energy transport (he suspects it will be bounded by the vacuum speed of light), creating a pulse that allows the front velocity to be measured and exploring the case of only a few photons. “This is the

important first proof of principle,” Steinberg remarks of the current studies. “Extending it to the single-photon level and understanding where it can be used seems like an exciting frontier.” —David Appell

DAVID APPELL is a freelance journalist based in Gilford, N.H.



SOURCE: U.S. Bureau of the Census

of adults there had achieved a bachelor's degree or higher, compared with 21 percent in other black-majority areas; 18 percent had completed less than the ninth grade, compared with 13 percent in other black-majority counties. The gap probably has not narrowed much in the past decade.

The moderate increase in Delta population from 1990 to 2000 occurred wholly because of the suburbanization of De Soto County, Mississippi, which is just south of Memphis. Delta towns such as Greenwood and Tunica in Mississippi are doing comparatively well, despite recent losses of some labor-intensive jobs to Mexico and Asia. It is the rural areas that, even with the assistance of such federal programs as the Mid-Delta Empowerment Zone, continue to suffer the worst effects of the region's unusual history.

—Rodger Doyle (rdoyale2@aol.com)

U.S. outside the Delta have also lost population, but generally not as much. (One of the few with strong population growth is Fulton County, Georgia, home to Atlanta.)

One reason why the Delta has fared worse than other black-majority counties is low educational attainment. The 1990 U.S. Census showed that only 16 percent

PSYCHOLOGY

A Gripping Start

Firmer is definitely better when it comes to a good first impression. Researchers at the University of Alabama examined gender differences and the correlation between handshakes and personality traits such as friendliness, dominance and neuroticism. A subset of self-assessed personality traits, including openness and extroversion, was highly correlated with strong handshakes, suggesting that the traits can predict certain behaviors. The findings, which appear in the



Make it firm

STEVE CHENN Corbis

July Journal of Personality and Social Psychology, bode especially well for women weary of being judged as overly aggressive: those who introduce themselves with an assertive gesture by way of a firm handshake were perceived as being intellectual and open to new experiences. —Rebecca Lipsitz



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“You were to have inherited all this, son, but genetic screening has indicated you’re too big of a health risk.”

MEDICINE

Got Statins?

Two studies in the June 28 *Journal of the American Medical Association* suggest that a class of drugs known as statins may help prevent fractures. Statins have been prescribed for more than 10 years to reduce blood cholesterol levels, but as is more commonly becoming the case for many drugs, they have been found to have additional and unforeseen therapeutic qualities. In one of the studies, incidence of all types of bone fractures was 45 percent lower among statin users; the other study discovered that risk for hip fractures declined by as much as 50 percent if statins had been used within the past six months. Further testing is needed to ensure that the effect has a medical basis and is not just an observed correlation. —R.L.

PALEONTOLOGY

Down with Dino Birds?

Birds descended from dinosaurs, according to the prevailing view. But a paper in the June 23 *Science* claims that reptiles, not dinosaurs, may be the evolutionary predecessors of birds. That conclusion is based on the most complete fossil of the reptile *Longisquama*, discovered in the former Soviet republic of Kyrgyzstan in 1969. Last year it was on exhibit at a shopping mall in Kansas City, Mo., giving researchers the opportunity to study it. The team, led by John A. Ruben of Oregon State University, noted that the specimen contained about eight pairs of long appendages with features resembling feathers. *Longisquama* is believed to be 220 million years old—75 million years older than the first known birdlike dinosaur, *Archaeopteryx*. Other paleontologists have criticized the assessment: they argue that although the structures are indeed unique, they are probably scales, not feathers. —R.L.



Feathers or scales?

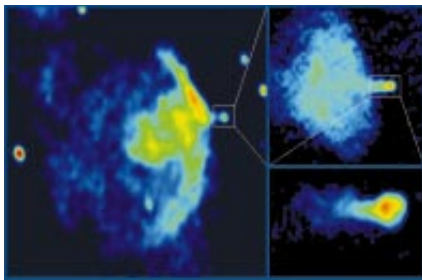
SCIENCE

ASTRONOMY

Not Slowing with Age

Pulsars—spinning neutron-star remnants of supernovae—may be older than previously thought. In the July 13 *Nature*, astronomers examining a supernova remnant that ejected a pulsar in an asymmetrical explosion determined the remnant (dubbed G5.4–1.2) to be at least 39,000 years old and possibly as old as 170,000 years. That suggests that the pulsar, flying off at about 560 kilometers per second, is of similar vintage. But the standard method of pulsar-age determination, based on the gradual slowing of the pulsar's rotation, produces evidence for an age of only 16,000 years. The discrepancy implies that theories of pulsar formation and the physics of neutron stars need to be rethought.

—Philip Yam



NATIONAL RADIO ASTRONOMY OBSERVATORY

SUPERNOVA REMNANT, shown in a mosaic of radio-frequency images, has a pulsar flying off to the right and leaving an ionization trail.

DATA POINTS

No Fun in the Sun



Melanoma rate per 100,000 persons in the U.S. in 1973: **5.7**

In 1996: **13.8**

Estimated number of persons who will be diagnosed with melanoma in 2000: **47,700**

Number of melanoma deaths expected: **7,700**

Chance that an American will develop skin cancer in his or her lifetime: **1 in 5**

Attendance at lifeguarded beaches in 1998: **256,721,418**

Average percent of lifetime sun exposure received by age 18: **80**

Year when atmospheric chlorofluorocarbon levels are expected to peak: **2000**

Year when expected ozone recovery may first be conclusively detected: **2010**

Soonest year by which Antarctic ozone layer will recover: **2050**

Number of ozone molecules that can be destroyed by one chlorine atom: **100,000**



MATT COLLINS

SOURCES: American Cancer Society; National Oceanic and Atmospheric Administration; U.S. Lifesaving Association; Environmental Protection Agency; National Association of Physicians for the Environment

DEFENSE POLICY

Miss-ile Defense

On July 8 a much-heralded Pentagon test of an antimissile system over the Pacific again failed to intercept its target. The failure, especially on top of an ostensibly successful intercept last October that the Pentagon later admitted was flawed, caps a growing chorus of criticism of a national missile defense (NMD) system. In April the 42,000-strong American Physical Society issued a statement arguing that it was too soon to decide to start deploying such a system, warning that “the tests ... fall far short of those required to provide confidence in the ‘technical feasibility’ called for in last year’s NMD deployment legislation.” And 50 U.S. Nobel laureates urged President Clinton to reject the \$60-billion project on the grounds that “the system would offer little protection” and would harm the nation’s security interests [see “Why National Missile Defense Won’t Work,” by George N. Lewis, Theodore A. Postol and John Pike; *SCIENTIFIC AMERICAN*, August 1999].

—Graham P. Collins

BIOLOGY

What’s That Pinging in My Ear?

Male humpback whales sing long, complex and predictable songs to woo eligible females—that is, until they are distracted by human-made sounds of similarly low frequency. Marine mammals generally seem to move away from loud sounds, but in the June 22 *Nature* researchers at the Woods Hole Oceanographic Institution reported that singing humpback whales change their tunes instead. In response to a low-frequency, active (LFA) sonar broadcast from a nearby U.S. Navy vessel, one quarter of the observed whales cut their songs short. Other whales crooned almost 30 percent longer than normal, presumably to compensate for the noise. At full force, the navy LFA sonar—recently developed for extended-range submarine detection and opposed by many environmental groups—could affect whales hundreds of miles away.

—Sarah Simpson



DOUG PERRINE Peter Arnold, Inc.

Save the Muntjacs

And warty pigs, saolas, zebra-striped rabbits—helping to discover and preserve new animals is this biologist's game

There are few sounds in the forest this late afternoon: only branches up high being lifted by an almost absent wind and the cracking of twigs as Alan R. Rabinowitz, director of science and exploration at the Wildlife Conservation Society, hikes down a slope and through a flat section of forest. There are no animals in sight. We are talking about the pleasure of wandering in woods, of discovery, when Rabinowitz finds an empty shotgun shell. "They won't stay off," he fumes. Hunters have been sneaking onto the posted land, and no amount of discussion or threat has deterred them. "They feel they have a right to it because they have been coming here forever," Rabinowitz says, glowering.

"Here" could well be a forest in Myanmar or Laos or Thailand or Belize or any of the many countries where Rabinowitz has worked for the past two decades to protect wildlife from poachers, among other threats. Indeed, just up the hill sits a cabin filled with some of the items unique to a Rabinowitz-style field station, no matter how remote: weight-lifting equipment and a punching bag. And although we are standing in a mere 25 acres of temperate woods on a small mountain in Putnam County, an hour north of New York City, the issues that excite Rabinowitz—and infuriate him—are the same ones that consume him when he is in real wilderness.

Rabinowitz—an outspoken, dynamic, charismatic and at times controversial biologist—

CHAMPIONING the cause of threatened animals is a passion Alan R. Rabinowitz developed from childhood stuttering, which drew him to pets: "I couldn't speak, and they couldn't speak."

has been involved directly and indirectly in the recent discoveries of several species of animal. The appearance of sizable mammals unknown to science—one of them, the saola (*Pseudoryx nghetinhensis*), resembles an antelope—in Vietnam, Laos and Myanmar has delighted biologists and conservationists overwhelmed by an era of environmental doom and gloom and extinction. For Rabinowitz, whose work studying large cats in forests largely empty of animals had been depressing him, the finds have restored his optimism and stoked his already intense desire to save creatures. "There are these huge areas of relatively unexplored, unprotected wilderness that we need to go out and find and protect when nobody cares about them," he explains to me as we later sit in the study of his house atop the hill. Most important, adds Rabinowitz, who has recently become a father, is the impact these remarkable discoveries have on the young: "Kids have

been getting a totally hopeless message, and we have been doing them a complete injustice by saying it is hopeless and there is no more to discover."

Rabinowitz has been able to get into some of these remote regions and set up programs for the Wildlife Conservation Society (which is based at the Bronx Zoo in New York City) by flying in blind and by passionate persistence. After Laos opened its borders to outsiders in the late 1980s, for instance, he quickly found a way around the government's requirement that only foreigners in tour groups be admitted. "I went to a shady travel agent in Bangkok, of which there are many, and he said, 'We can book a group tour, a tour of about 10 people, but all the names will be fictional except yours,'" Rabinowitz explains. "So I went to Laos, and [a guide] met me at the airport, and I said, 'At the last minute everyone got some kind of bug in their food, and I was the only one who didn't eat



the food. Everybody is in the hospital in Bangkok. But I paid all this money, and I just had to go.”

A short tour and a bribe later, Rabinowitz approached the government and, after months of negotiations, set off to explore the Annamite Mountains in southeastern Laos with colleagues. The Annamites proved to be biologically interesting because they served as refugia during the climatic shifts between 2.5 million and 10,000 years ago, offering animals isolated havens where they evolved distinctly from their relatives in other isolated havens. Exploration in the range had suggested as much: in 1992 scientists surveying terrain in Vietnam near the Ho Chi Minh Trail had found the saola. Soon after, Rabinowitz and other researchers working just across the border in Nakai Nam Theun, Laos's largest protected area, also found the saola. Later surveys revealed a new species of barking deer (the giant muntjac) and a zebra-striped rabbit, as well as the Roosevelt muntjac and the Vietnamese warty pig, which had been thought to be extinct.

In Rabinowitz's mind, the mother lode lay in the northern part of Myanmar, in a corner of the Himalayas, and so he set out to convince the government of that. His efforts ultimately led to the creation of Hkakaborazi, a 1,472-square-mile protected area, after an expedition in 1997 revealed yet another species of deer: the leaf muntjac. Rabinowitz and his colleagues subsequently found a black muntjac, blue sheep and a marten, all previously thought to be confined to China.

Rabinowitz will soon return to continue surveying and to bring salt to villagers in an effort to forestall hunting. In northern Myanmar, trade in animals with neighboring China is driven by a desperate need for salt to prevent the devastating consequences of iodine deficiency. Trade in animal parts has emptied many of the forests of Southeast Asia. In Laos, in particular, mile-long walls of thatch and saplings force animals into snares; in many places the forest is completely silent.

Rabinowitz's peregrinations have taken him far from the urban landscape of his childhood. Born in New York City in 1953, he spent his childhood in Brook-

lyn. His father—a physical education teacher who coached Dodger pitching legend Sandy Koufax in basketball and urged him not to pursue baseball—taught Rabinowitz to weight lift when he was quite young. Being strong and fit has served him well in the jungle, helping him survive disease and many accidents, including a plane crash and a helicopter crash. And it may have earned him his job with the Wildlife Conservation Society, because he was able to set a rigorous pace during a hike with George Schaller, a renowned biologist at the society who



NEW SPECIES found in Southeast Asia include the diminutive leaf muntjac (top) and the striped rabbit (taken after it tripped an automatic camera). The forests may harbor other undiscovered creatures.

had been visiting the University of Tennessee, where Rabinowitz was finishing his Ph.D. thesis on raccoons. After the hike Schaller offered him a job tracking elusive jaguars and assessing the size of their population in Belize. “I immediately said yes,” recalls Rabinowitz. “And thought, ‘Where’s Belize?’”

Strength was especially important when Rabinowitz was younger, because he stuttered: “I could always beat up anybody.” Despite the misery often caused by the stuttering—Rabinowitz once stabbed a pencil through his hand to avoid having to give a presentation—he says he is grateful for it: “Now I see it as the greatest blessing. I love stuttering because stuttering put me apart from people.” Stuttering drew him to pets, including a turtle, a hamster and some garter snakes. “I would talk to them. And I came to love

animals because they allowed me to be me,” he says. “I came to champion their cause or associate with them because I saw them as very similar to me. I couldn’t speak, and they couldn’t speak.”

This advocacy has been criticized at times, in part because Rabinowitz has been outspoken against people living in wildlife refuges and scoffs at the idea of “sustainable development” as a fantasy born by armchair philosophers. He clashed with the environmental and human-rights activist group International Rivers Network regarding a dam in Laos, for instance. Ra-

binowitz believes the dam can be a good idea—if it is constructed according to plans by the World Bank—because the country has no manufacturing base, because the area to be flooded is “completely degraded” and because the people who will be displaced will be getting what they want: schools and housing. “They aren’t living in any kind of harmony. They frequently get sick; they have high child mortality,” he says. “Go into the field and live with these people and then tell me what kind of a wonderful life they live when you get sick with them.”

Despite his oft-repeated claim to prefer animals over humans, Rabinowitz obviously loves and admires the people he works with in the field—something even a quick read of two of his books, *Jaguar* and *Chasing the Dragon’s Tail*, makes clear. And so he was incensed by a British newspaper’s claim that he was colluding with Myanmar’s military government to evict members of the Karen tribe from a national park. “We weren’t even close to that area,” he says, jabbing at a map: Hkakaborazi is to the very north, bordering Tibet; the conflicted Karen region is to the southeast. “I would love to go in the Karen area, but I can’t because they are fighting a civil war.”

Rabinowitz is already thinking of other places that he can study or protect. “You don’t know how many nights when I am burned out or bored or whatever, I pore over maps and look at the places in the world that for political reasons or whatever have now opened up,” he says. “Exploration is not just about finding something that nobody has ever seen before or finding a new species. It is also about ways of looking at the world.”

—Marguerite Holloway

AVIATION _ COMMERCIAL FLIGHT

Supersized

Airbus commits to building the world's biggest commercial jumbo jet



In spirit at least, the new airliner resembles one of those visionary "World of Tomorrow" concepts that industrial designer Norman Bel Geddes drew in the 1930s: a huge cylindrical affair, more ocean liner than mere people tube, replete with office space for the busy executive-on-the-go and a child-care center where parents can drop off children while they relax in exercise rooms and shops. Only a promenade deck seems missing.

After talking about building a new super-jumbo jet for years, the European aircraft consortium **Airbus Industrie** has finally gone and done something about it. The company has committed to developing a 550- to 940-passenger airliner—for a cool \$12 billion—that it has dubbed the A3XX. In contrast, the world's largest

jetliner for now (and for the past 30 years), the **Boeing Company's** 747, in its latest incarnation can hold around 416 passengers—520, tops.

Building an aircraft to carry more than 500 passengers is not an overwhelming engineering problem, especially if you aren't concerned with issues such as size; Howard Hughes's wood-frame 1947 H-4 *Spruce Goose* was designed to hold 700 fully equipped soldiers. But that was a seaplane, with a tremendous 320-foot wingspan, and seaplanes are seldom constrained by whether their wingspan is too great for an airfield. (The end of World War II rendered the *Spruce Goose*, which flew only once and for about a mile, unnecessary.) The modern challenge comes with making the new jumbo small: it must fit within the current air-

SUPER JUMBO OR MUMBO JUMBO? Airbus Industrie thinks there's profit to be made with the A3XX, shown here in an artist's rendition, and plans to spend \$12 billion to develop it.

port infrastructure of runways, jetways and terminal slots—or rather, a box 262 feet (80 meters) square, the size agreed on by airlines and airport operators.

To keep the new Airbus within the box, engineers have been thinking outside of one. All those passengers will be seated on two full, double-aisled decks, giving the A3XX a length of just under 240 feet, compared with 232 for the partially double-decked jumbo, the 747-400. Early plans for the A3XX included wings that fold up while the airplane is on the ground, a technique incorporated on carrier-based navy aircraft to save precious deck space. But Airbus engineers have decided on a 261-foot, 10-inch span derived through some cunning weight-saving measures. Laser welding will replace heavier, traditional rivets, and the pressure inside the hydraulic systems is to be increased to 5,000 pounds per square inch from 3,000 psi, which Airbus engineers maintain will mean using less fluid and smaller pipes, thereby reducing weight. The landing gear will be mounted under the fuselage instead of under the wings, eliminating weighty wing-strengthening measures. Airbus's all-glass cockpit and fly-by-wire controls will help keep things light, too.

The company has also been forced to come up with materials solutions, including a new aluminum-alloy-and-fiberglass composite called Glare, which Airbus says



	747-400	A3XX-100	ANTONOV AN-225	H-4 SPRUCE GOOSE
WINGSPAN (feet)	211.42	261.83	290	319.92
LENGTH (feet)	231.83	239.5	275.83	218.67
HEIGHT (feet)	63.67	79.08	59.42	79.33
RANGE (miles)	8,380	8,800	N/A	1,575 (est.)
MAXIMUM TAKEOFF WEIGHT (pounds)	875,000	1,190,000	1,322,750	N/A

PLANE BIG: How the 747 and A3XX compare to two of history's biggest aircraft. The AN-225 was developed to carry the former Soviet Union's space shuttle; it is now largely spotted at air shows. The H-4 made one demonstration flight.

will reduce the A3XX's weight by several tons. But for now hard facts are scarce: according to company spokesperson Mary Anne Greczyn, "there are very few people who are authorized to speak directly to the press regarding the technical aspects of the A3XX—the innovation-design process is closely held information at the moment."

No matter how it is accomplished, packing so many people into so tight a space can lead to severe discomfort—not a trivial concern, given the rising incidence of passenger "air rage." Designers hope to combat it by paying special attention to ergonomics—giving the illusion of more space through lighting and overhead bin height, for instance.

Airbus sees a huge market in the category of 500-plus seats: 1,200 aircraft worth \$263 billion. And if its initial customer list is any indication—it includes **Singapore Airlines**, **Qantas** and **Emirates Airlines**—they will be devoted largely to long hauls along the Pacific Rim. But in the future

such jumbos may also be used as a response to the incredible leap in passengers flying the already overstuffed air-traffic system—which Airbus predicts will triple in the next two decades. In other words, instead of more flights, airlines may simply resort to carrying more people on short- and intermediate-distance routes, which Japanese carriers first pioneered, flying 747s for inter-island transportation. So when the first A3XX takes to the sky in around 2004, it will more likely have seats instead of shops and crèches. Back when the 747 was introduced, first-class passengers could relax in a piano bar in the upper deck, but when was the last time you saw a midair lounge act?

Boeing disagrees that there is a huge market for 500-seaters—365 is its best guess. (Airbus has stated that it needs to sell 240 of the planes before it starts to rake in a profit, but one source estimates the number to be 700.) But Boeing has also made noise about stretching its ven-

erable jumbo even further into a 747X variant, which will hold and haul between 500 and 620 passengers. "We believe the market is too small to justify an all-new airplane," says Debbie Nomaguchi, communications manager for Boeing Commercial Airplane Group.

Oddly, this rationale sounds like that of Boeing's competitors in the late 1960s, before the company first bent metal on the 747. It was the beginning of the end for the others: Boeing went on to dominate the market, and 30 years later it has either absorbed the other players or put them out of business. Last year Airbus accounted for 55 percent of the new airliner market and now has orders for more than 50 A3XXs. Undoubtedly, Airbus hopes that the history of jumbo planes will repeat itself. —Phil Scott

PHIL SCOTT is a freelance writer specializing in aviation technology. He is based in New York City.

Sonic Bust

Don't hold your breath for Mach 2 transport

Supersonically, it's the only way to fly—as far as airliners go. But the Mach 2, 100-passenger **Concorde** has a range of less than 4,000 miles—good for shooting across the Atlantic in under four hours, but forget the Pacific. And at some \$10,000 per round-trip ticket, a seat remains the prerogative of the privileged. A quarter-century after entering service, the Concorde is the first and only supersonic transport in regular service. But that's not for lack of trying.

During most of the 1990s the U.S. government and aerospace industry poured nearly \$200 million annually into the High Speed Civil Transport (HSCT) program, hoping to develop the technology necessary for a next-generation supersonic transport (SST) that, by around 2015, could carry 300 passengers 5,000 nautical miles at Mach 2.4 and at a cost only 20 percent above that of a subsonic ticket. The goal of the program was to make sure there weren't physics problems "that would be big showstoppers," says Wallace Sawyer, who led the HSCT program at the **National Aeronautics and Space Administration's** Langley Research Center in Hampton, Va. NASA projected a market for more than 500 of the aircraft—at nearly \$500 million a pop—generating 140,000 new jobs.

But last year Boeing, the only U.S. airline manufacturer, withdrew from the project, essentially shutting it down. The reason: "We can't close the price-cost loop," says Boeing



NOWHERE FAST: The defunct High Speed Civil Transport.

spokesperson Mary Jean Olsen. So what does that mean? "You and I couldn't afford to fly in the darn things," says Olsen. Astronomical development and operating costs, along with an economic downturn in the Pacific Rim—HSCT's envisioned market—sealed its fate.

But Wallace maintains that the American HSCT lives on, mostly in some of the technology that emerged from it. There's PETI-5, a high-temperature coating now being used on the X-37, an experimental craft that can land from space after being carried up by the space shuttle, and SuperVIEW, a synthetic vision system that can effectively replace an aircraft's windscreen and instruments. France and Japan still have HSCT programs, albeit scaled more modestly than the U.S. effort. "If Airbus and Japan got very serious, it would be interesting to see how that would change the American process," Wallace muses. —P.S.

Brace for Impact

Will MP4 do to movies what MP3 is doing to music?

SAN FRANCISCO—*The Perfect Storm* opened in theaters across the U.S. on Friday, June 30. By the following Tuesday a pirated version was already circulating on alt.binaries.movies. *Storm's* voyage from screen to Net was a bit shorter than the nine-day lapse between the debut of *Chicken Run* and its illegal ripoff but not quite as brief as the three-day run that *Titan A. E.* enjoyed.

It may surprise you that illicit copies go on-line so quickly. But the more shocking fact is that thousands of people are willing to spend hours downloading these 500- to 1,300-megabyte videos. The quality of the new releases is, to put it charitably, dismal. They are "cammers," made by enterprising cinema patrons who sneak video cameras into theaters. The creators then digitize the video recording, which is typically dark and jittery with muffled sound and subtitles in some foreign language. They then compress the file using MPEG-1, a decade-old technology that knocks the resolution down to well below that of a VHS videocassette. The trade in cammers seems to pose no greater threat to Hollywood now than the trade in bootleg concert recordings posed to the music industry in 1997. Which is to say, an enormous one.

Until three years ago only nerds and groupies swapped bootleg recordings. Then a Dutch hacker swiped MP3 compression software from programmers at the Fraunhofer Institute in Erlangen, Germany, and posted it to the Internet, putting the means for music larceny into the hands of millions, who then discovered that they could live with a little dishonesty if it was sufficiently safe and easy. Now a powerful new video com-

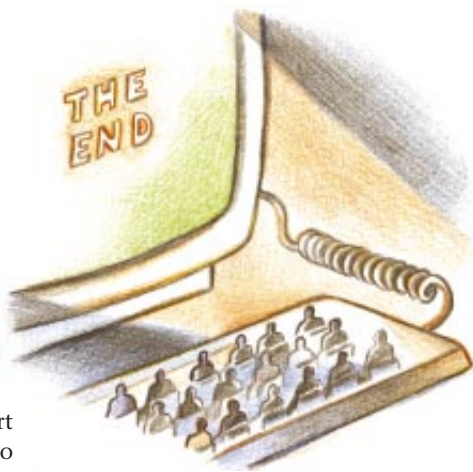
pression algorithm, variously called MPEG-4, MP4 or DivX, has slipped into the public domain. History seems headed for a second showing.

MP4 does to digital video (of the sort on DVDs) what MP3 does to digital audio (of the sort on compact discs): it compresses it to as little as 10 percent of its original size with barely perceptible losses in quality. Put another way, it can squeeze a two-hour movie onto a single disc—at HDTV resolution with a CD-quality Dolby Surround soundtrack.

MP4 was designed for professional broadcasters, not pirates, as a way to improve on the pointillistic flipbooks that pass on the Web for "live video." But last year a prerelease version of an MP4 compression module that works on data-intensive video such as DVD movies leaked out of Microsoft and into the hands of hackers. They renamed the program DivX—probably as a jab at the failed Circuit City DVD format that allowed renters only a few days to watch the disc before it disabled itself and demanded more money. They then seeded the Net with versions for Windows, MacOS, Linux and even BeOS.

In July Microsoft was reportedly girding for legal battle against Web sites that offer links to the DivX codec, as it is called. But a concerted legal effort has yet to slow the distribution of DeCSS, software that cracks the superficial encryption on most DVDs. Arresting the author of DeCSS did not stop other programmers from incorporating his code into free programs, such as CladDVD, that make it simple to copy a movie from DVD to hard disk.

There are still four obstacles preventing



DivX from reshaping movie distribution in the way that MP3 is irrevocably altering the music business. First, converting a rented DVD into a DivX CD-ROM requires six gigabytes of hard disk space, a CD recorder and about 12 hours of processing time. That equipment, however, is now standard on \$1,400 PCs. And college students have plenty of free time.

Second, a DivX movie runs 500 to 1,200 megabytes, which takes up to 70 hours to download via modem. So a DSL connection (three to seven hours) or a cable modem (as little as one hour) is de rigueur. But American households are signing up for broadband connections nearly as fast as they are buying DVD players. And in July SBC Communications announced that it was giving away computers and DSL modems to families willing to sign a two-year contract for DSL service at \$60 per month.

A third stumbling block is that most people prefer to watch movies on their televisions, not their computers. But many newer video cards can be plugged directly into a TV or VCR. And if DivX catches on, electronics companies will no doubt make players that accept DivX CDs. This summer, after all, Philips began selling a portable CD player that also accepts MP3 files on CD-ROM, much to the record companies' dismay.

The last and largest obstacle saving the movie studios is that there is as yet no Napster for DivX, no easy way to find a movie that you want or to share those that you have. The newsgroups can handle only a trickle of such enormous files. Any Web operator who posts pirated movies risks huge copyright fines. And informal file-sharing networks such as Gnutella are unreliable for hours-long downloads. But if there is any lesson taught by the MP3 experience, it is to never underestimate the ingenuity of freeloaders.

—W. Wayt Gibbs

Déjà Vu—in Fast Forward

	CDs	DVDs
Discs first go on sale	1982	1996
Hard drive capable of holding entire disk is standard on new PCs	1995	1997
MPEG compression software leaked onto the Internet makes it feasible to download entire albums and movies	1997	1999
Pirated programs traded widely via Napster/Gnutella, newsgroups or FTP sites	1998	2000

Genes **Muscle,** and **Athletic Performance**

The cellular biology of muscle helps to explain why a particular athlete wins and suggests what future athletes might do to better their odds

by Jesper L. Andersen, Peter Schjerling
and Bengt Saltin



On your marks!” A hush falls as 60,000 pairs of eyes are fixed on eight of the fastest men on earth. The date is August 22, 1999, and the runners are crouched at the starting line of the 100-meter final at the track-and-field world championships in Seville, Spain.

“Get set!” The crack of the gun echoes in the warm evening air, and the crowd roars as the competitors leap from their blocks. Just 9.80 seconds later the winner streaks past the finish line. On this particular day, it is Maurice Greene, a 25-year-old athlete from Los Angeles.

Why, we might ask, is Maurice Greene, and not Bruny Surin of Canada, who finished second, the fastest man on earth? After all, both men have trained incessantly for this moment for years, maintaining an ascetic regimen based on exercise, rest, a strict diet and little else. The answer, of course, is a complex one, touching on myriad small details such as the athletes’ mental outlook on race day and even the design of their running shoes. But in a sprint, dependent as it is on raw power, one of the biggest single contributors to victory is physiological: the muscle fibers in Greene’s legs, particularly his thighs, are able to generate slightly more power for the brief duration of the sprint than can those of his competitors.

Recent findings in our laboratories and elsewhere have expanded our knowledge of how human muscle adapts to exercise or the lack of it and the extent to which an individual’s muscle can alter itself to meet different challenges—such as the long struggle of a marathon or the explosive burst of a sprint. The information helps us understand why an athlete like Greene triumphs and also gives us insights into the range of capabilities of ordinary people. It even sheds light on the perennial issue of whether elite runners, swimmers, cyclists and cross-country skiers are born different from the rest of us or whether proper training and determination could turn almost anyone into a champion.

Skeletal muscle is the most abundant tissue in the human body and also one of the most adaptable. Vigorous training with weights can double or triple a muscle’s size, whereas disuse, as in space travel, can shrink it by 20 percent in two weeks. The many biomechanical and biochemical phenomena behind these adaptations are enormously complex,

but decades of research have built up a reasonably complete picture of how muscles respond to athletic training.

What most people think of as a muscle is actually a bundle of cells, also known as fibers, kept together by collagen tissue [see illustration on pages 50 and 51]. A single fiber of skeletal muscle consists of a membrane, many scattered nuclei that contain the genes and lie just under the membrane along the length of the fiber, and thousands of inner strands called myofibrils that constitute the cytoplasm of the cell. The largest and longest human muscle fibers are up to 30 centimeters long and 0.05 to 0.15 millimeter wide and contain several thousand nuclei.

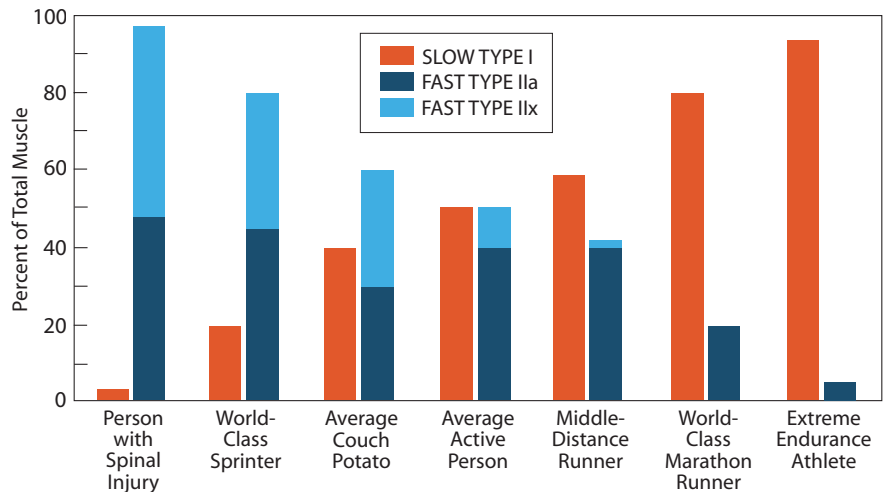
Filling the inside of a muscle fiber, the myofibrils are the same length as the fiber and are the part that causes the cell to contract forcefully in response to nerve impulses. Motor nerve cells, or neurons, extend from the spinal cord to a group of fibers, making up a motor unit. In leg muscles, a motor neuron controls, or “innervates,” several hundred to 1,000 or more muscle fibers. Where

tion a sarcomere shortens like a collapsing telescope, as the actin filaments at each end of a central myosin filament slide toward the myosin’s center.

One component of the myosin molecule, the so-called heavy chain, determines the functional characteristics of the muscle fiber. In an adult, this heavy chain exists in three different varieties, known as isoforms. These isoforms are designated I, IIa and IIx, as are the fibers that contain them. Type I fibers are also known as slow fibers; type IIa and IIx are referred to as fast fibers. The fibers are called slow and fast for good reason: the maximum contraction velocity of a single type I fiber is approximately one tenth that of a type IIx fiber. The velocity of type IIa fibers is somewhere between those of type I and type IIx.

The Stuff of Muscle

The differing contraction speeds of the fibers is a result of differences in the way the fibers break down a molecule called adenosine triphosphate in the myosin heavy chain region to derive the



WORLD-CLASS SPRINTER BRIAN LEWIS of the U.S. (*opposite page*) has a larger proportion of so-called fast muscle fibers in his legs than a marathoner or an extreme endurance athlete does. Fast IIx fiber contracts 10 times faster than slow type I fiber, and type IIa lies somewhere in between.

extreme precision is needed, for example, to control a finger, an eyeball or the larynx, one motor neuron controls only one or at most a few muscle fibers.

The actual contraction of a myofibril is accomplished by its tiny component units, which are called sarcomeres and are linked end to end to make up a myofibril. Within each sarcomere are two filamentary proteins, known as myosin and actin, whose interaction causes the contraction. Basically, during contrac-

tion energy needed for contraction. Slow fibers rely more on relatively efficient aerobic metabolism, whereas the fast fibers depend more on anaerobic metabolism. Thus, slow fibers are important for endurance activities and sports such as long-distance running, cycling and swimming, whereas fast fibers are key to power pursuits such as weight lifting and sprinting.

The “average” healthy adult has roughly equal numbers of slow and fast

fibers in, say, the quadriceps muscle in the thigh. But as a species, humans show great variation in this regard; we have encountered people with a slow-fiber percentage as low as 19 percent and as high as 95 percent in the quadriceps muscle. A person with 95 percent slow fibers could probably become an accomplished marathoner but would never get anywhere as a sprinter; the opposite would be true of a person with 19 percent slow fibers.

Besides the three distinct fiber types, there are hybrids containing two different myosin isoforms. The hybrid fibers fall in a continuum ranging from those almost totally dominated by, say, the slow isoform to fibers almost totally dominated by a fast one. In either case, as might be expected, the functional characteristics of the fiber are close to those of the dominant fiber type.

Myosin is an unusual and intriguing protein. Comparing myosin isoforms from different mammals, researchers have found remarkably little variation from species to species. The slow (type I) myosin found in a rat is much more similar to the slow isoform found in humans than it is to the rat's own fast myosins. This fact suggests that selective evolutionary pressure has maintained functionally distinct myosin isoforms and that this pressure has basically preserved particular isoforms that came about over millions of years of evolution. These myosin types arose quite early in evolution—even the most ancient and primitive creatures had myosin isoforms not terribly different from ours.

Bulking Up

Muscle fibers cannot split themselves to form completely new fibers. As people age, they lose muscle fibers, but they never gain new ones [see box on page 54]. So a muscle can become more massive only when its individual fibers become thicker.

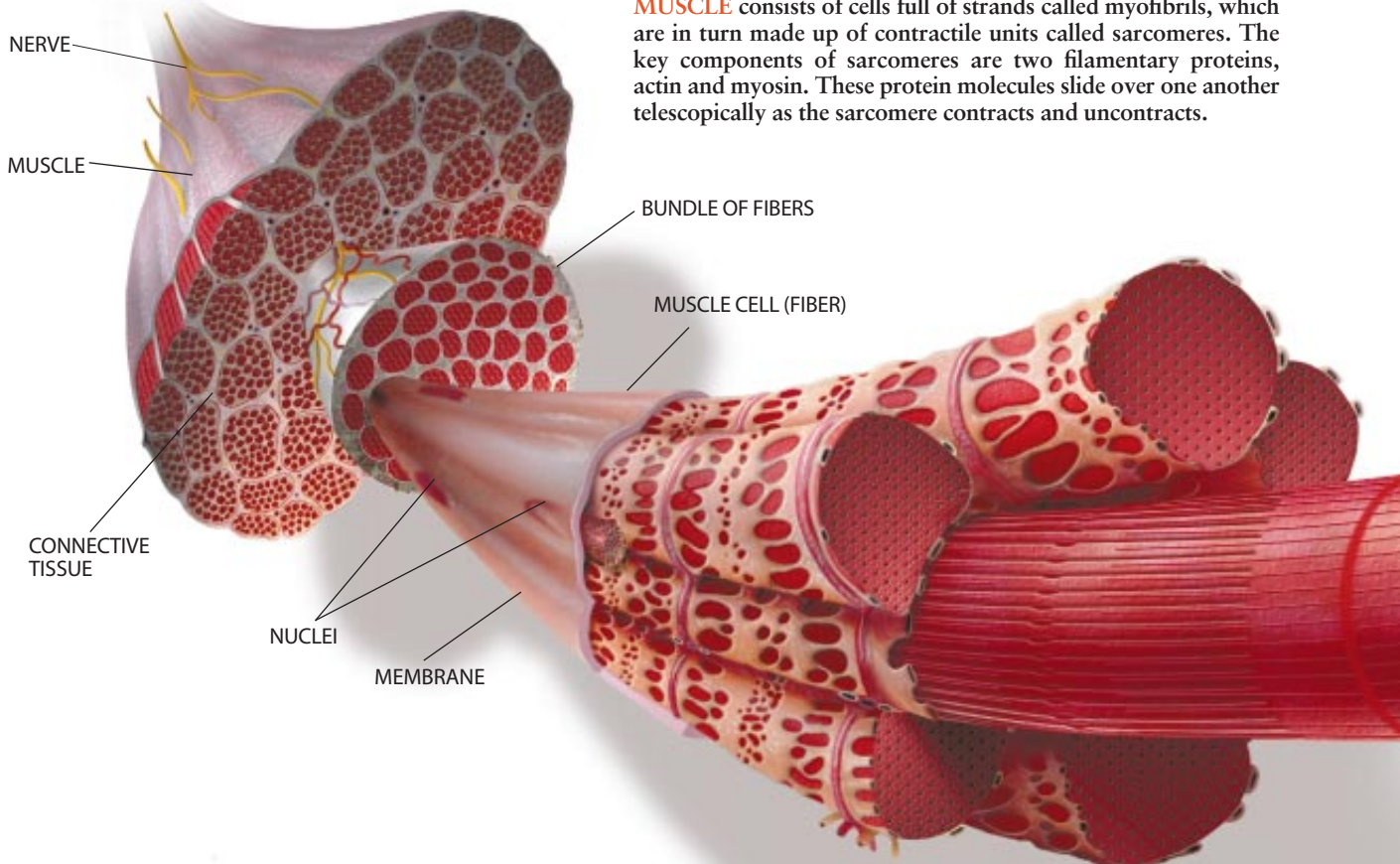
What causes this thickening is the creation of additional myofibrils. The mechanical stresses that exercise exerts on tendons and other structures connected to the muscle trigger signaling proteins that activate genes that cause the muscle fibers to make more contractile proteins. These proteins, chiefly myosin and actin, are needed as the fiber produces great amounts of additional myofibrils.

More nuclei are required to produce and support the making of additional

protein and to keep up a certain ratio of cell volume to nuclei. As mentioned, muscle fibers have multiple nuclei, but the nuclei within the muscle fiber cannot divide, so the new nuclei are donated by so-called satellite cells (also known as stem cells). Scattered among the many nuclei on the surface of a skeletal muscle fiber, satellite cells are largely separate from the muscle cell. The satellite cells have only one nucleus apiece and can replicate by dividing. After fusion with the muscle fiber, they serve as a source of new nuclei to supplement the growing fiber.

Satellite cells proliferate in response to the wear and tear of exercise. One theory holds that rigorous exercise inflicts tiny “microtears” in muscle fibers. The damaged area attracts the satellite cells, which incorporate themselves into the muscle tissue and begin producing proteins to fill the gap. As the satellite cells multiply, some remain as satellites on the fiber, but others become incorporated into it. These nuclei become indistinguishable from the muscle cell's other nuclei. With these additional nuclei, the fiber is able to churn out more proteins and create more myofibrils.

To produce a protein, a muscle cell—



MUSCLE consists of cells full of strands called myofibrils, which are in turn made up of contractile units called sarcomeres. The key components of sarcomeres are two filamentary proteins, actin and myosin. These protein molecules slide over one another telescopically as the sarcomere contracts and uncontracts.

like any cell in the body—must have a “blueprint” to specify the order in which amino acids should be put together to make the protein—in other words, to indicate which protein will be created. This blueprint is a gene in the cell’s nucleus, and the process by which the information gets out of the nucleus into the cytoplasm, where the protein will be made, starts with transcription. It occurs in the nucleus when a gene’s information (encoded in DNA) is copied into a molecule called messenger RNA. The mRNA then carries this information outside the nucleus to the ribosomes, which assemble amino acids into the proteins—actin or one of the myosin isoforms, for example—as specified by the mRNA. This last process is called translation. Biologists refer to the entire process of producing a protein from a gene as “expression” of that gene.

Two of the most fundamental areas of study in skeletal muscle research—ones that bear directly on athletic performance—revolve around the way in which exercise and other stimuli cause muscles to become enlarged (a process called hypertrophy) and how such activity can convert muscle fibers from one type to another. We and others have pursued these subjects intensively in re-

cent years and have made some significant observations.

The research goes back to the early 1960s, when A. J. Buller and John Carew Eccles of the Australian National University in Canberra and later Michael Bárány and his co-workers at the Institute for Muscle Disease in New York City performed a series of animal studies that converted skeletal muscle fibers from fast to slow and from slow to fast. The researchers used several different means to convert the fibers, the most common of which was cross-innervation. They switched a nerve that controlled a slow muscle with one linked to a fast muscle, so that each controlled the opposite type of fiber. The researchers also electrically stimulated muscles for prolonged periods or, to get the opposite effect, cut the nerve leading to the muscle.

In the 1970s and 1980s muscle specialists focused on demonstrating that the ability of a muscle fiber to change size and type, a feature generally referred to as muscle plasticity, also applied to humans. An extreme example of this effect occurs in people who have suffered a spinal cord injury serious enough to have paralyzed their lower body. The lack of nerve impulses and general disuse of the muscle cause a tremendous

loss of tissue, as might be expected. More surprisingly, the type of muscle changes dramatically. These paralyzed subjects experience a sharp decrease of the relative amount of the slow myosin isoform, whereas the amount of the fast myosin isoforms actually increases.

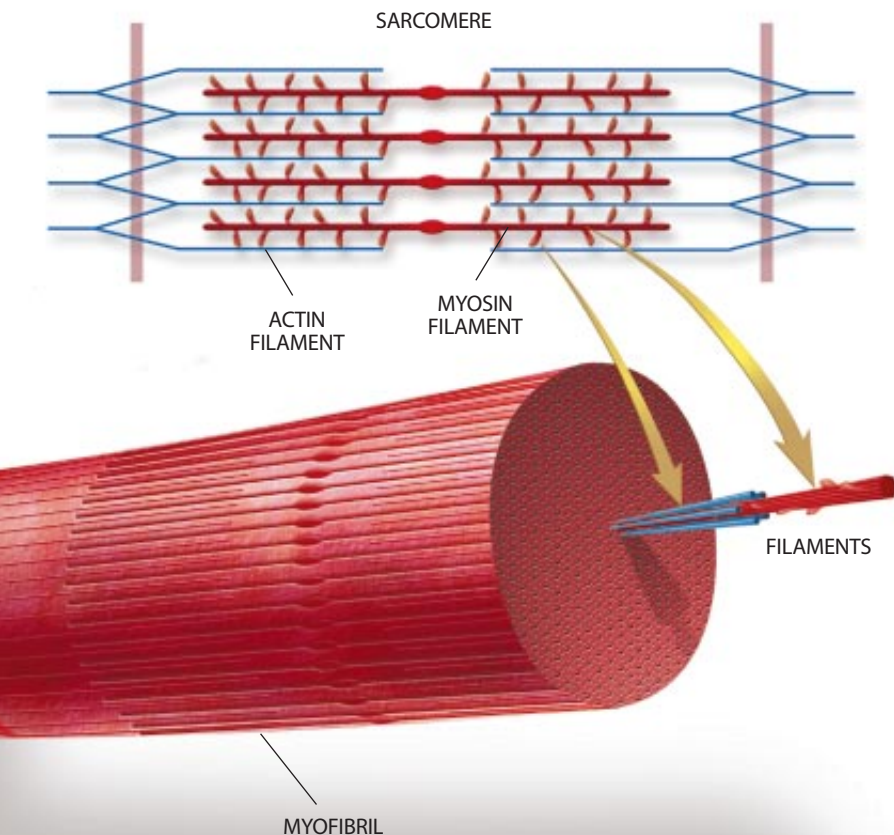
We have shown that many of these subjects have almost no slow myosin in their vastus lateralis muscle, which is part of the quadriceps in the thigh, after five to 10 years of paralysis; essentially all myosin in this muscle is of the fast type. Recall that in the average healthy adult the distribution is about 50–50 for slow and fast fibers. We hypothesized that the neural input to the muscle, by electrical activation, is necessary for maintaining the expression of the slow myosin isoform. Thus, electrical stimulation or electrically induced exercise of these subjects’ muscles can, to some extent, reintroduce the slow myosin in the paralyzed muscles.

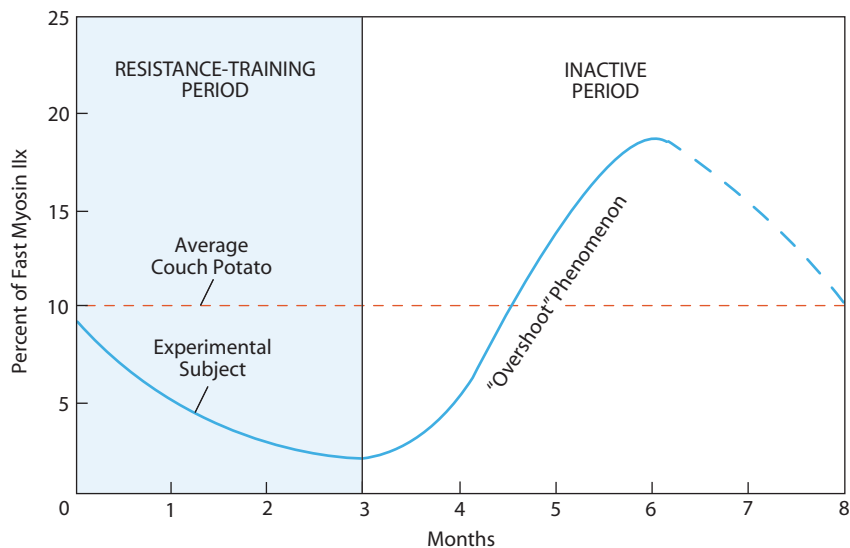
Converting Muscle

Conversion of muscle fibers is not limited to the extreme case of the reconditioning of paralyzed muscle. In fact, when healthy muscles are loaded heavily and repeatedly, as in a weight-training program, the number of fast IIX fibers declines as they convert to fast IIA fibers. In those fibers the nuclei stop expressing the IIX gene and begin expressing the IIA. If the vigorous exercise continues for about a month or more, the IIX muscle fibers will completely transform to IIA fibers. At the same time, the fibers increase their production of proteins, becoming thicker.

In the early 1990s Geoffrey Goldspink of the Royal Free Hospital in London suggested that the fast IIX gene constitutes a kind of “default” setting. This hypothesis has held up in various studies over the years that have found that sedentary people have higher amounts of myosin IIX in their muscles than do fit, active people. Moreover, complementary studies have found a positive correlation between myosin IIA and muscle activity.

What happens when exercise stops? Do the additional IIA fibers then convert back to IIX? The answer is yes, but not in the precise manner that might be expected. To study this issue, we took muscle samples (biopsies) from the vastus lateralis muscle of nine young, sedentary Danish men. We then had the subjects conduct heavy resistance training, aimed





UNEXPECTED EXPERIMENTAL RESULTS have practical applications for the athlete. The fast IIX myosin declined as expected during resistance training. But when training stopped, rather than simply returning to the pretraining level, the relative amount of IIX roughly doubled three months into detraining. So what does this mean for the sprinter, to whom IIX is crucial? Provide for a period of reduced training before a competition.

mainly at their quadriceps muscle, for three months, ending with another muscle biopsy. Then the subjects abruptly stopped the resistance training and returned to their sedentary lifestyle, before being biopsied for a third and final time after a three-month period of inactivity (corresponding to their behavior prior to entering the training).

As expected, the relative amount of the fast myosin IIX isoform in their vastus lateralis muscle was reduced from an average of 9 percent to about 2 percent in the resistance-training period. We then expected that the relative amount of the IIX isoform would simply return to the pretraining level of 9 percent during the period of inactivity. Much to our surprise, the relative amount of myosin IIX reached an average value of 18 percent three months into the detraining. We did not continue the biopsies after the three-month period, but we strongly suspect that the myosin IIX did eventually return to its initial value of about 9 percent some months later.

We do not yet have a good explanation for this “overshoot” phenomenon of the expression of the fast myosin IIX isoform. Nevertheless, we can draw some conclusions that can have useful applications. For instance, if sprinters want to boost the relative amount of the fastest fibers in their muscles, the best strategy would be to start by removing those that they already have and then slow down the training and wait for the fastest fibers to return twofold! Thus,

sprinters would be well advised to provide in their schedule for a period of reduced training, or “tapering,” leading up to a major competition. In fact, many sprinters have settled on such a regimen simply through experience, without understanding the underlying physiology.

Slow to Fast?

Conversion between the two fast fiber types, IIA and IIX, is a natural consequence of training and detraining. But what about conversion between the slow and fast fibers, types I and II? Here the results have been somewhat murkier. Many experiments performed over the past couple of decades found no evidence that slow fibers can be converted to fast, and vice versa. But in the early 1990s we did get an indication that a rigorous exercise regimen could convert slow fibers to fast IIA fibers.

Our subjects were very elite sprinters, whom we studied during a three-month period in which they combined heavy resistance training with short-interval running (these are the foundation exercises in a sprinter’s yearly training cycle). At around the same time, Mona Esbörnsson and her co-workers at the Karolinska Institute in Stockholm reported similar findings in a study involving a dozen subjects who were not elite athletes. These results suggest that a program of vigorous weight training supplemented with other forms of anaerobic exercise converts not only type IIX

fibers to IIA but also type I fibers to IIA.

If a certain type of exertion can convert some type I fibers to IIA, we might naturally wonder if some other kind can convert IIA to I. It may be possible, but so far no lengthy human training study has unambiguously demonstrated such a shift. True, star endurance athletes such as long-distance runners and swimmers, cyclists and cross-country skiers generally have remarkably high proportions—up to 95 percent, as mentioned earlier—of the slow type I fibers in their major muscle groups, such as the legs. Yet at present we do not know whether these athletes were born with such a high percentage of type I fibers and gravitated toward sports that take advantage of their unusual inborn trait or whether they very gradually increased the proportion of type I fibers in their muscles as they trained over a period of many months or years. We do know that if fast type IIA fibers can be converted to type I, the time required for the conversion is quite long in comparison with the time for the shift from IIX to IIA.

It may be that great marathon runners are literally born different from other people. Sprinters, too, might be congenitally unusual: in contrast with long-distance runners, they of course would benefit from a relatively small percentage of type I fibers. Still, a would-be sprinter with too many type I fibers need not give up. Researchers have found that hypertrophy from resistance training enlarges type II fibers twice as much as it does type I fibers. Thus, weight training can increase the cross-sectional area of the muscle covered by fast fibers without changing the relative ratio between the number of slow and fast fibers in the muscle. Moreover, it is the relative cross-sectional area of the fast and slow fibers that determines the functional characteristics of the entire muscle. The more area covered by fast fibers, the faster the overall muscle will be. So a sprinter at least has the option of altering the characteristics of his or her leg muscles by exercising them with weights to increase the relative cross section of fast fibers.

In a study published in 1988 Michael Sjöström and his co-workers at the University of Umea, Sweden, disclosed their finding that the average cross-sectional areas of the three main fiber types were almost identical in the vastus lateralis muscles of a group of marathon runners. In those subjects the cross-sectional area of type I fibers averaged 4,800 square microns; type IIA was 4,500; and type



SPRINTER



MARATHONER



SPRINTER AND MARATHONER reveal obvious differences in leg musculature. Fast fibers rely on anaerobic metabolism; slow fibers depend more on relatively efficient aerobic metabolism.

Thus, slow fibers are important in endurance sports, and fast fibers are key in events such as sprinting and weight lifting. The sprinter is Brian Lewis; the marathoner, Khalid Khannouchi.

IIx was 4,600. For a group of sprinters, on the other hand, the average fiber sizes varied considerably: the type I fibers averaged 5,000 square microns; type IIa, 7,300; and type IIx, 5,900. We have results from a group of sprinters that are very similar.

Although certain types of fiber conversion, such as IIa to I, appear to be difficult to bring about through exercise, the time is fast approaching when researchers will be able to accomplish such conversions easily enough through genetic techniques. Even more intriguing, scientists will be able to trigger the expression of myosin genes that exist in the genome but are not normally expressed in human muscles. These genes are like archival blueprints for myosin types that might have endowed ancient mammalian relatives of ours with very fast muscle tissue that helped them escape predators, for example.

Such genetic manipulations, most likely in the form of vaccines that insert artificial genes into the nuclei of muscle cells,

will almost certainly be the performance-enhancing drugs of the future. Throughout the recorded history of sports a persistent minority of athletes have abused performance-enhancing substances. Organizations such as the International Olympic Committee have for decades tried to suppress these drugs by testing athletes and censuring those found to have cheated. But as soon as new drugs are invented, they are co-opted by dishonest athletes, forcing officials to develop new tests. The result has been an expensive race pitting the athletes and their “doctors” against the various athletic organizations and the scientists developing new antidoping tests.

This contest is ongoing even now in Sydney, but within the near future, when athletes can avail themselves of gene therapy techniques, they will have taken the game to a whole new level. The tiny snippets of genetic material and the proteins that gene therapy will leave behind in the athletes’ muscle cells may be impossible to identify as foreign.

Gene therapy is now being researched intensively in most developed countries—for a host of very good reasons. Instead of treating deficiencies by injecting drugs, doctors will be able to prescribe genetic treatments that will induce the body’s own protein-making machinery to produce the proteins needed to combat illness. Such strategies became possible, at least in theory, in recent years as researchers succeeded in making artificial copies of the human genes that could be manipulated to produce large amounts of specific proteins. Such genes can be introduced into the human body where, in many cases, they substitute for a defective gene.

Like ordinary genes, the artificial gene consists of DNA. It can be delivered to the body in several ways. Suppose the gene encodes for one of the many signaling proteins or hormones that stimulate muscle growth. The direct approach would be to inject the DNA into the muscle. The muscle fibers would then take up the DNA and

MUSCLE AND THE ELDERLY

Everyone knows that when we age, our muscles weaken and our movements become slower. But why is that so?

With aging come a number of changes to the skeletal muscles. Most marked is the loss of mass, which begins as early as 25 years of age. By age 50 the skeletal muscle mass is often reduced by 10 percent, and by age 80 approximately 50 percent of the muscle mass is gone.

This age-related reduction is caused mainly by a loss of muscle fibers. By greatly thickening the individual fibers, weight lifting can stave off the loss of mass from the muscle as a whole, but it appears to have no major effect on the loss of fibers.

Before individual fibers are lost to atrophy, they change shape and appearance. In young people, muscle fibers are distinctively angular, whereas in the elderly they often appear more rounded and in extreme cases banana-shaped. Furthermore, aging seems to induce “type grouping”: in young and middle-aged skeletal muscle the fast and slow fibers are distributed in a chessboard fashion, whereas in aged muscle the fibers cluster in groups of either slow or fast cells (this phe-

age, some of these motor nerves “die.” The nerve’s muscle fibers are then left without any input, so they, too, atrophy and die—unless they are reinnervated by another motor nerve.

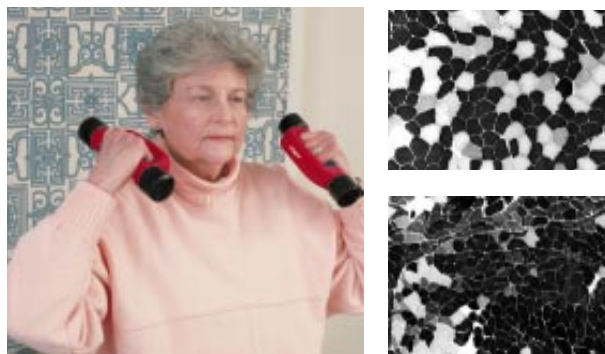
Intriguingly, if a muscle fiber is reinnervated by a nerve from a different motor unit type—for example, if a fast muscle fiber is reinnervated by a nerve from slow fibers—the fiber will be left with conflicting signals. Developmentally it is a fast fiber, but it receives stimulation that leads to an activation pattern that fits a slow fiber. Ultimately, this change in stimulation appears to transform the fast fiber to a slow fiber (or vice versa, in the opposite case).

Aging appears to be harder on the fast fibers, which atrophy at a higher rate than the slow ones do. So some researchers have long suspected that the distribution of fast and slow fibers gradually shifts as we age to favor the slow fibers. This, they reasoned, could help explain why a 10-year-old boy will outrun his 70-year-old grandfather in a 100-meter race, whereas Grandpa might still defeat Junior in a 10K.

The hypothesis is somewhat controversial because it has been difficult to prove that aging leads to an increase in the relative amount of slow fibers. In a recent study, we set out to approach the problem a little differently. We persuaded a group of 12 elderly and frail subjects with an average age of 88 years to submit to a muscle biopsy from their vastus lateralis muscle (which is located on the front side of the thigh and is one of the most well examined of human skeletal muscles). Then, working with thin needles under a microscope, we dissected out single muscle fibers from the tissue samples. We determined the myosin isoform composition of each of 2,300 single fibers.

We know that all humans have not only pure slow and fast fibers but also fibers that contain both the slow and the Ila (fast) myosin isoforms or both fast isoforms (Ila and IIx). In the young vastus lateralis muscle these hybrid fibers are scarce: fewer than 5 percent of the fibers contain both the slow myosin I and fast myosin Ila isoform. In our elderly subjects we found that a third of all the examined fibers contained these two myosin isoforms. Astonishingly, this hybrid fiber was the predominant type in the very aged muscle.

We concluded that the question of whether aging muscle has more slow fibers cannot be answered with a simple yes or no. What seems to happen is not a change in ratio between slow and fast fibers but more an obfuscation of the border between slow and fast fibers, so that in very elderly muscle one third of the fibers are neither strictly slow nor fast but rather somewhere in between. —J.L.A., P.S. and B.S.



WEIGHT LIFTING can prevent some loss of muscle mass. But nothing can prevent changes in the shape and distribution of different types of muscle fiber as we age (young muscle, *top*; elderly muscle, *bottom*).

nomenon also appears in younger people suffering from certain motor nerve-related diseases).

The findings have prompted some researchers to hypothesize that fiber types cluster in elderly muscle as a consequence of a complex process in which the muscle-controlling nerves switch from one muscle fiber to another. Consider the motor unit, defined as all the muscle fibers controlled, or “innervated,” by a single motor nerve originating from the spinal cord. As we

add it to the normal pool of genes.

This method is not very efficient yet, so researchers often use viruses to carry the gene payload into a cell’s nuclei. A virus is essentially a collection of genes packed in a protein capsule that is able to bind to a cell and inject the genes. Scientists replace the virus’s own genes with the artificial gene, which the virus will then efficiently deliver to cells in the body.

Unfortunately, and in contrast to the direct injection of DNA, the artificial gene payload will be delivered not only to the muscle fibers but also to many other cells, such as those of the blood and the liver. Undesirable side effects could very well occur when the artificial gene is expressed in cell types other than the targeted ones. For example, if a gene causing extended muscle hypertrophy

were injected, this would lead to the desired growth of the skeletal muscles. But it would probably also lead to hypertrophy of another kind of muscle, namely that of the heart, giving rise to all the well-known complications of having an enlarged heart. So researchers have explored another approach, which entails removing specific cell types from the patient, adding the artificial gene in the lab-

oratory and reintroducing the cells into the body.

These techniques will be abused by athletes in the future. And sports officials will be hard-pressed to detect the abuse, because the artificial genes will produce proteins that in many cases are identical to the normal proteins. Furthermore, only one injection will be needed, minimizing the risk of disclosure. It is true that officials will be able to detect the DNA of the artificial gene itself, but to do so they would have to know the sequence of the artificial gene, and the testers would have to obtain a sample of the tissue containing the DNA. Athletes, of course, will be quite reluctant to surrender muscle samples before an important competition. Thus, a doping test based on taking pieces of the athletes' muscle is not likely to become routine. For all intents and purposes, gene doping will be undetectable.

Brave New World

What will athletics be like in an age of genetic enhancements? Let us reconsider our opening scenario, at the men's 100-meter final. Only this time it is the year 2012. Prior to these Olympics, it was hard to pick an obvious favorite for the gold medal. After the preliminary heats, that is not so anymore. Already after the semifinals the bookmakers closed the bets for the runner in lane four, John Doeson. He impressed everyone by easing through his 1/8 final in a time only $\frac{3}{100}$ of a second from the now eight-year-old world record. In the quarterfinal he broke the world record by $\frac{15}{100}$ of a second, but the 87,000 spectators did not believe their eyes when in the semifinals he lowered the world record to an unbelievable 8.94 seconds, passing the finish line more than 10 meters ahead of the second-place runner. This performance made several television commentators main-

tain that the viewers had just seen "something from out of this world."

Not quite, but close. What could have led to such an astonishing performance? By 2012 gene therapy will probably be a well-established and widely used medical technology. Let us say that 12 months before the Olympics, a doctor approached Doeson with a proposal likely to sorely tempt any sprinter. What if you could make your muscle cells express the fastest myosin isoform? Under normal conditions, this isoform is not expressed in any of the major human skeletal muscles, but the gene is there and ready to work, like a dusty blueprint that just needs a civil engineer and a construction crew to make it a reality.

This enticing myosin isoform would give muscle fibers functional characteristics that correspond to those of the very fast IIb isoform, found in the rat and in other small mammals that need bursts of speed to elude predators. This IIb isoform has a much higher velocity of contraction and so can generate more power than IIx or IIa fibers. Although Doeson didn't really understand what the doctor was talking about, he fully understood the words "velocity" and "power."

The doctor enthusiastically went on explaining his idea. The gene actually expresses a kind of protein known as a transcription factor, which in turn activates the gene for the very fast myosin IIb isoform. Such a transcription factor was discovered a few years ago and was named Velociphin. Holding a tiny glass vial in front of Doeson's face, he intoned: "This is the DNA for an artificial gene for Velociphin. Just a few injections of this DNA into your quadriceps, hamstring and gluteus, and your muscle fibers will start cranking out Velociphin, which will activate the myosin IIb gene."

Within three months, he added, Doeson's muscles would contain a good portion of IIb fibers, enabling him to break the 100-meter world record with

ease. Moreover, the doctor noted, Doeson's muscles would keep producing Velociphin for years without further injections. And without a muscle biopsy from the quadriceps, hamstring or gluteus, there will be no way for officials to detect the genetic modification.

A year later, as he pulls on his track suit, Doeson recalls the doctor's assurance that there would be no side effects of the genetic treatment. So far, so good. After stretching and warming up, he takes his place on the block in lane four. "On your mark. Get set. BANG!" The runners are away.

A couple of seconds later Doeson is already ahead by two meters. Over the next few seconds, astonishingly, his lead grows. In comparison with those of the other runners, his strides are visibly more powerful and frequent. He feels good as he passes 30, 40 and 50 meters. But then, at 65 meters, far out in front of the field, he feels a sudden twinge in his hamstring. At 80 meters the twinge explodes into overwhelming pain as he pulls his hamstring muscle. A tenth of a second later Doeson's patella tendon gives in, because it is no match for the massive forces generated by his quadriceps muscle. The patella tendon pulls out part of the tibia bone, which then snaps, and the entire quadriceps shoots up along the femur bone. Doeson crumples to the ground, his running career over.

That is not the scenario that generally springs to mind in connection with the words "genetically engineered superathlete." And some athletes will probably manage to exploit engineered genes while avoiding catastrophe. But it is clear that as genetic technologies begin trickling into the mainstream of medicine they will change sports profoundly—and not for the better. As a society, we will have to ask ourselves whether new records and other athletic triumphs really are a simple continuation of the age-old quest to show what our species can do. SA

The Authors

JESPER L. ANDERSEN, PETER SCHJERLING and BENGT SALTIN work together at the Copenhagen Muscle Research Center, which is affiliated with the University of Copenhagen and the city's University Hospital. Andersen is a researcher in the department of molecular muscle biology and a former coach of the sprint team of the Danish national track-and-field team. Schjerling, a geneticist in the same department, recently changed his area of specialty from yeast to a considerably more muscular creature, *Homo sapiens*. Saltin, director of the center, graduated from the Karolinska Institute in Stockholm in 1964 and worked as a professor of human physiology there and at the University of Copenhagen's August Krogh Institute. A former competitive runner, he has also coached the Danish national orienteering team.

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Searching for Shadows of OTHER EARTHS

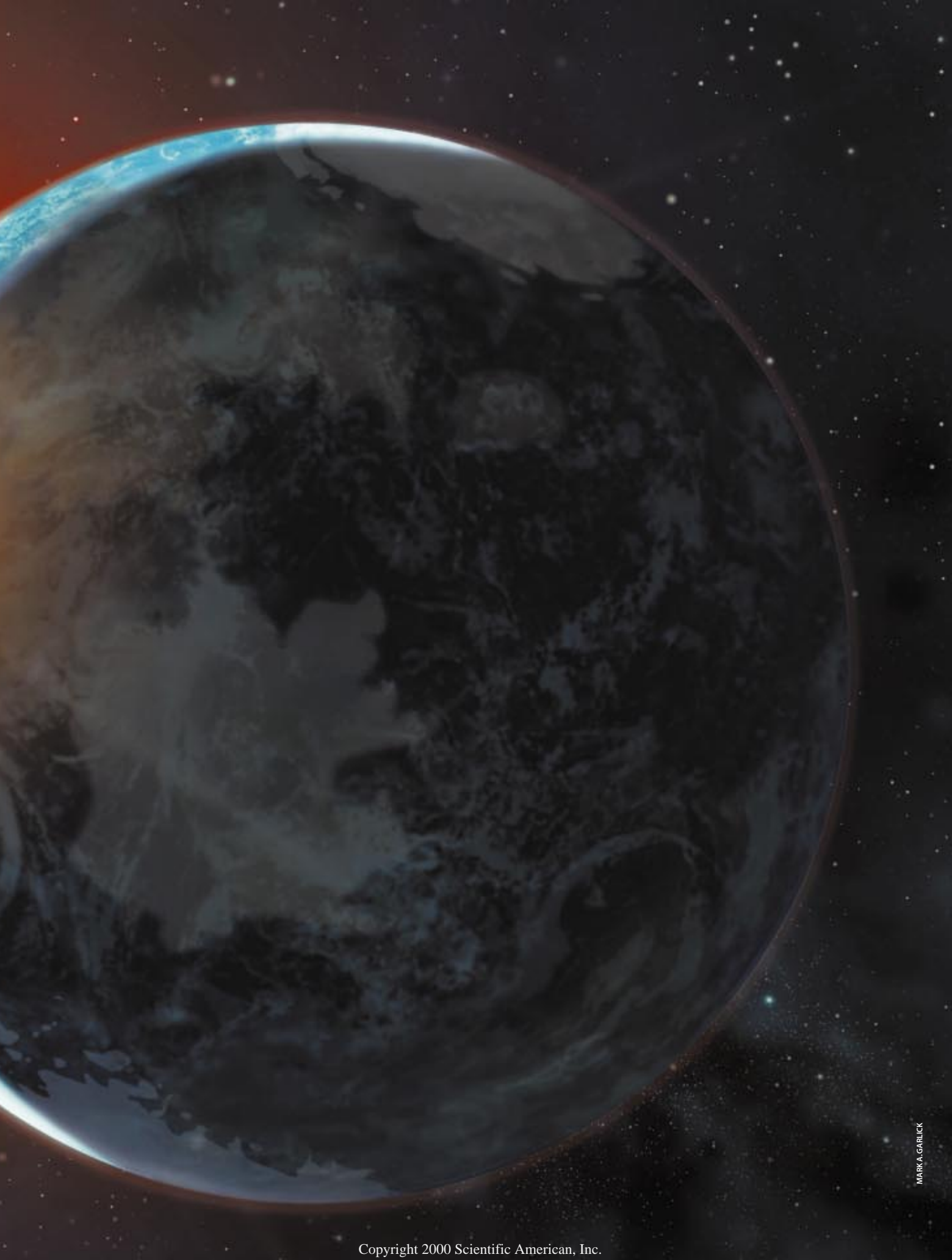
Astronomers have found dozens of giant planets beyond our solar system, but they haven't been capable of bagging an Earth—until now

by Laurance R. Doyle, Hans-Jörg Deeg
and Timothy M. Brown

No one has ever seen a planet outside our solar system. But in November of last year two astronomers saw the next best thing: its shadow. David Charbonneau, a graduate student at Harvard University, was analyzing the brightness of the sunlike star HD 209458 using data taken earlier, when he had been working with one of us (Brown). At nearly the same time, Tennessee State University astronomer Greg Henry was independently observing the same star.

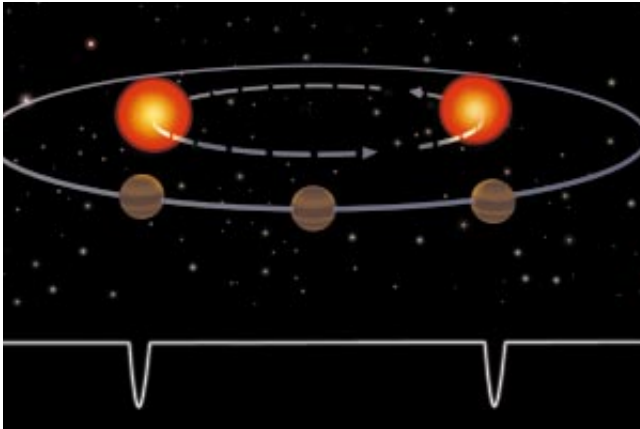
It is an unassuming star, without even a proper name. But it has one claim to fame:

EARTH-LIKE PLANET may have been detected around the binary stars CM Draconis. The authors have observed a slight, rhythmic dimming of the stars' light—perhaps the sign of a planet passing in front. Whether or not that is confirmed, the technique of looking for oscillations in stellar brightness is, for now, astronomers' best hope for finding habitable worlds.

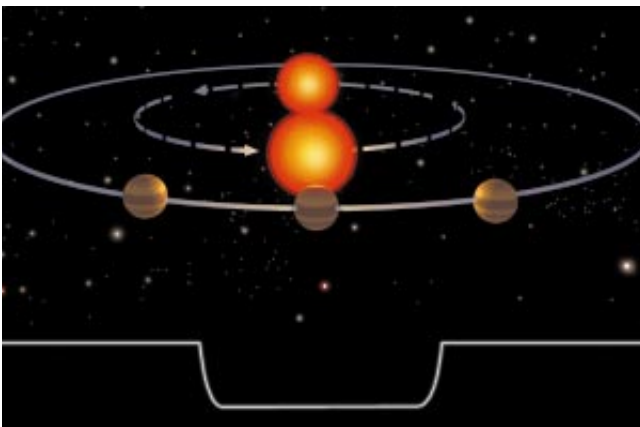


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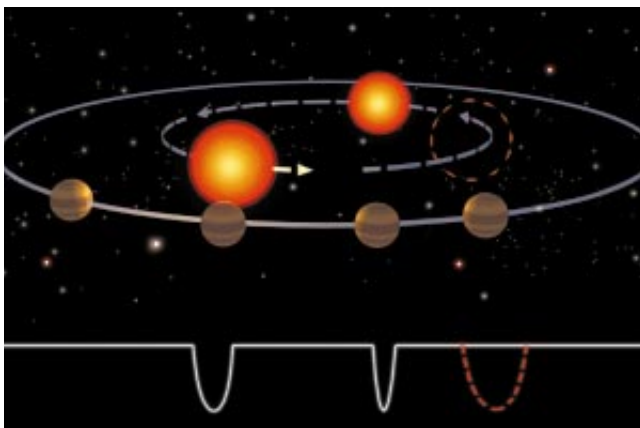
NOW YOU SEE IT, NOW YOU SEE LESS OF IT: That is the idea behind the transit method for the detection of planets. Consider a planet in a binary star system. For these purposes, astronomers do not actually see the two individual stars; the light is lumped together. As the planet passes in front of each star from our perspective, the system dims in a characteristic way. The precise amount and duration of dimming depends on where the stars are in their mutual orbit.



Here the stars are at their greatest apparent separation. The planet makes a double transit: it passes in front of one, then the other.



If the planet passes in front when one of the stars is eclipsing the other, the transit can last for longer and produce a larger relative decrease in brightness.



If the planet passes in front just prior to a stellar eclipse, a triple transit occurs: first across the near star, then across the far one (but for a shorter time because the star and planet are moving in opposite directions) and finally across the far one again.

around it orbits a planet with a mass at least two thirds that of Jupiter. Or so astronomers thought. The planet had only been inferred indirectly by the wobbles it induced in the star. Charbonneau and Henry sought confirmation by a different technique. Might it be possible, they asked, for the planet to pass in front of the star, across our line of sight, and temporarily block some of the starlight?

From our perspective, the star would then dim in a distinctive way. Such an event, known as a transit, requires the planetary orbit to be tilted nearly edge-on, but that is not as improbable as it might seem. For planets that orbit very close to their stars, such as the one around HD 209458, the chance of the correct alignment is one in 10. By the time Charbonneau and Henry looked at it, most of the other accepted extrasolar planets had already been searched for transits, without success. A handful of astronomers had even begun to wonder whether the lack of transits implied a lack of planets. Perhaps the wobble observations had been misinterpreted.

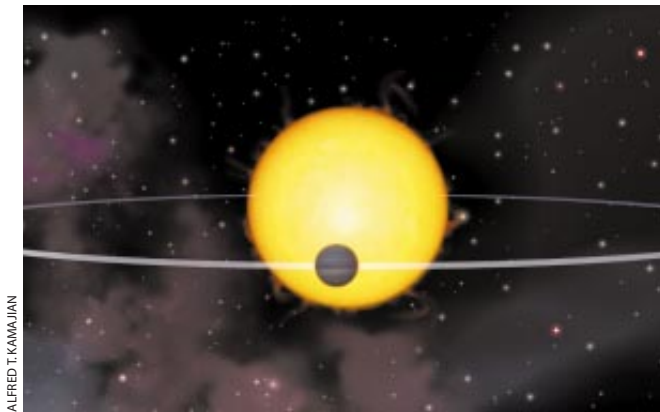
Charbonneau's and Henry's studies dispelled those doubts. At precisely the time the wobble observations indicated that transits might occur, the star dimmed by about 1.8 percent for an interval of three hours. Besides providing clear evidence for a planet, the dimming directly measured its diameter, 1.3 times that of Jupiter—the first size measurement ever made of an extrasolar planet. The size matched theoretical predictions that the planet, located so close to its star, would have puffed up like a roasted marshmallow.

The transit method had made an auspicious debut. Until now, planet hunters had relied mainly on the wobble technique, technically known as the radial-velocity method. That approach looks for subtle periodic shifts in a star's spectrum, which intimate that the star is being tugged to and fro by an unseen companion. Its first success came in 1995 with the discovery of a planet around the sunlike star 51 Pegasi. Since then, more than three dozen such planets have swum into astronomers' ken [see box on pages 62 and 63]. The radial-velocity method can be applied to any star, but it has trouble seeing worlds that are too small or too distant from their stars.

The transit method has its own serious disadvantage—the need for a fortuitous orbital alignment. But when transits do occur, they reveal the planet's size and other properties, even if it is a fairly small world. In fact, the transit method is the only technique currently able to spot planets down to Earth size around sunlike stars. Two of us (Doyle and Deeg) have already used it to search another star system, known as CM Draconis, for Earth-like worlds. We are able to see bodies as diminutive as 2.5 times the diameter of Earth. Thus, the first search for extrasolar planets with the potential of sustaining life as we know it is under way.

A Little Black Spot on the Sun Today

The idea of seeking out transits is not new. After all, a solar eclipse is basically just a transit of the moon across the sun. Johannes Kepler predicted transits of Mercury across the sun in the early 17th century, and Captain James Cook undertook his first voyage to the South Seas in part to witness the transit of Venus in 1769. Astronomers of the day used these events to triangulate Earth's distance from the sun. The idea that transits might be observable across stars other than the sun was first suggested in a small note by Otto Struve of Yerkes Observatory in 1951 and developed by Frank Rosenblatt of Cornell University in 1971 and by William



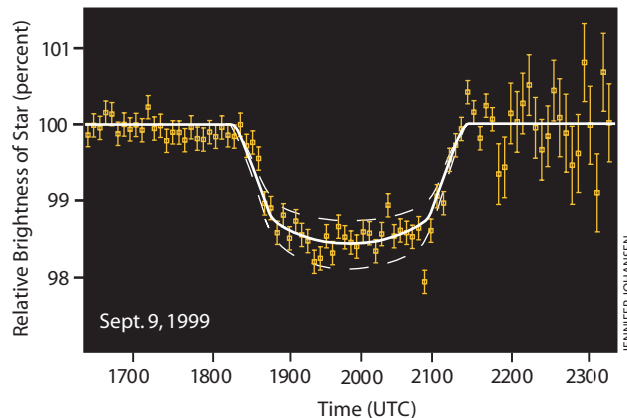
FIRST SUCCESS of the transit method was the confirmation of a planet around the sunlike star HD 209458. The 1.8 percent drop in the star's brightness (*points with error bars*) implies a planet 1.3 times the diameter of Jupiter (*solid line*), although a

Borucki of the National Aeronautics and Space Administration Ames Research Center in the early 1980s.

During a transit of Mercury or Venus, astronomers watch as a small black dot glides across the face of the sun. Transits by extrasolar planets, however, can only be detected indirectly. Observers must monitor the light curve of the star—a plot of how its brightness changes with time—and look for a recurring decrease that is characteristic of a planet crossing in front. The careful measurement of stellar luminosity is an entire subfield of astronomy known as photometry. The unaided human eye can easily tell when a star changes in brightness by a factor of about 2.5. By comparing the brightness of two stars in a procedure known as differential photometry, the trained eye can discern much subtler changes. Small telescopes equipped with modern CCD cameras can achieve a precision of 0.1 percent. Larger telescopes, by collecting more light and averaging out atmospheric irregularities, can do even better.

Photometric transit measurements are potentially far more sensitive to smaller planets than other detection methods are. This sensitivity may be understood in terms of the signal to be measured—namely, the amount of starlight blocked by the planet. This signal is proportional to the cross-sectional area of the planet and hence varies with the ratio of the square of the planet's radius to the square of the star's radius. In contrast, the wobble in the radial velocity of a star is proportional to the ratio of the planet's mass to the star's mass and hence to the ratio of the cubes of their radii. Because planets are much smaller than stars—Jupiter's radius is about 10 percent of the sun's, and Earth's about 1 percent—the ratio of the squares is less than the ratio of the cubes, which acts in favor of transit measurements.

Marginal detection of the transit across HD 209458 took about 40,000 photons of light, whereas measuring its wobble with the same degree of confidence took about 10 million photons. Of course, these photons were used differently: in the transit method, they were counted over time by a photometer; in the wobble method, they were subdivided into narrow wavelength bands by a spectrometer. But the upshot is that the photometric method can use smaller telescopes to find planets of a given size. A Jupiter-size world causes its star to dim by about 1 percent, well within the instrumental precision of a one-meter telescope; an Earth-size world, about



world 10 percent larger or smaller would have much the same effect (*dotted lines*). Recent multicolor observations suggest a diameter 1.6 times Jupiter's. The measurement errors worsened after the transit because the star was approaching the horizon.

0.01 percent, which is beyond the capability of even the largest telescopes currently available. But the requisite precision can still be achieved using special observational tricks and signal detection techniques.

The distance between a planet and its star must also be taken into account. The wobble method falls off in sensitivity as the square root of this distance, because far-off worlds exert a weaker gravitational pull on their stars. This very bias is why most planets found this way have been Jupiter-size bodies in tight orbits. But transit events can be detected as easily for properly aligned distant companions as for nearby ones. It is a purely geometric effect that relies on the relative positions of star, planet and observer. Compared with the light-years that separate the star from Earth, the distance between star and planet is utterly insignificant; it could change by a large fractional amount, and from our perspective the amount of dimming would remain almost the same.

What Other Planets Circle Other Suns

Increasing the distance does, however, reduce the chance that the planet will be on an orbit that lets us see its transits. For example, the probability that Earth in its present orbit would transit across the sun, as seen by a randomly located extraterrestrial astronomer, is only about 0.5 percent. For this reason, the transit method was long neglected. Two developments changed astronomers' minds. The first was the unexpected discovery of those giant extrasolar planets very close to their parent stars, rather than in wide orbits as in our solar system. The close-in orbits increase the probability of transit alignments 10-fold. The second was the introduction of wide-field imaging systems that can monitor tens or hundreds of thousands of stars at once. The reasoning is simple: if one looks at enough stars enough of the time, some of them should show transits. In this way, astronomers can not only rack up lists of planets but also collect statistics on their general prevalence.

Many such searches are now in progress using ground-based telescopes, most looking for giant planets like the one found orbiting close to HD 209458. The STARE project (directed by Brown) and the Vulcan project (directed by Borucki, David Koch of NASA Ames and Jon Jenkins of the nearby SETI Institute in Mountain View, Calif.) look at the disk of the Milky Way, where stars are abundant. Meanwhile An-



WOBBLE WORLDS

The count is now up to 44. That is the number of planets found to date around nearby stars similar to the sun. Telescopes around the world—Hawaii, California, Massachusetts, Chile, Australia, France—are adding to this count almost monthly. Despite the breathtaking pace, the searches are still sensitive only to relatively big planets not too far from their suns. Nevertheless, some surprising trends are already beginning to show. These trends challenge our preconceptions about the origin and the diversity of planetary systems in the cosmos.

All 44 planets have been found by measuring the telltale wobbles of the parent stars as the planets go around. As the star moves toward us in response to the planet's pull, lines in its spectrum shift to bluer, shorter wavelengths. As the star recedes, the lines shift toward the red. By measuring these subtle periodic Doppler shifts, astronomers are able to infer the orbit and minimum mass of the planet or planets.

Subtle is indeed the word. For Jupiter or an analogous world, the effect is only 12.5 meters per second over a 12-year period. The sun's spectral lines in the optical part of the spectrum (around 500 nanometers), for example, shift by just 0.00002 nanometer. For Earth, the velocity undulates by barely one tenth of a meter per second.

For all the limitations of the technique, its findings have stunned astronomers. The very first discovery was a roughly Jupiter-mass planet orbiting extremely close to the star 51 Pegasi; it is a mere 0.05 astronomical unit (the Earth-sun distance) away. No one expected such a tight orbit. Soon after that announcement in 1995 by Michel Mayor and Didier Queloz of the Geneva Observatory, a team led by Geoffrey W. Marcy and R. Paul Butler, then at San Francisco State University, reported massive planets around two more nearby stars. One of them, around 70 Virginis, brought another surprise: its orbit is highly eccentric, or elliptical, unlike that of planets in our solar system.

Now, based on surveys of some 800 stars in the solar neighborhood, it appears that roughly one in 20 sunlike stars has a giant planet circling it. Some are like 51 Pegasi: close-in planets in circular orbits. Others are like 70 Virginis: in wider but elongated orbits. At least one system, Upsilon Andromedae, has multiple planets [see "A Planetary System at Last?" by Renu Malhotra; *SCIENTIFIC AMERICAN*, September 1999]. Several other stars, including 55 Cancri, are also suspected to have full-fledged families.

Thanks to improvements in the precision of radial-velocity measurements, Marcy and Butler's team has discovered two planets with roughly the mass of Saturn, about a third of

Jupiter's mass. Their announcement this past March was quickly followed by a report of a third Saturn-mass planet detected by the Swiss team. These findings strengthen predictions that lower-mass planets are common. On the high end of the scale, however, brown dwarfs—failed stars of 10 to 80 Jupiter-masses—in tight orbits are proving to be rarer than had been thought. This could be telling us that planets and brown dwarfs form through very different processes and that smaller worlds are easier to make than more massive ones.

The elongated orbits remain a mystery. Because planets form in disks of gas and dust around young stars, friction should have circularized their orbits. How did 70 Virginis and similar worlds elude this process? One clue may come from comets in our own solar system. Close encounters with planets are thought to be responsible for kicking comets into elliptical orbits. Perhaps planets themselves engage in such slingshot games. If that is the case, our solar system, with its mostly circular orbits, may be the exception rather than the norm. In some cases, like that of 16 Cygni B, the gravitational influence of a binary companion star might be responsible for distorting the orbits.

Several researchers have noticed an intriguing property among the host stars of exoplanets: they tend to have unusually high concentrations of elements heavier than hydrogen and helium [see "Here Come the Suns," by George Musser; *News and Analysis*, *SCIENTIFIC AMERICAN*, May 1999]. One explanation is that unless a star and its surrounding disk had a critical amount of heavy elements, planets would never form. Another suggestion is that these stars got richer in these elements by devouring some of their newborn planets.

While we ponder these mysteries, more detections of exoplanets will follow as new surveys monitor more stars with higher precision over longer times (so that longer-period planets can be found). State-of-the-art Doppler measurements reach about three meters per second, and even higher precision is in the works. Researchers may soon find planets with masses as low as those of Uranus and Neptune, which are only about 5 percent as heavy as Jupiter. But the Doppler technique could hit a wall at about one meter per second; star spots and other surface blemishes probably will not allow spectral-line shifts to be gauged more accurately than that. The discovery of true Earth analogues may take a brand-new technique.

RAY JAYAWARDHANA is a Miller Research Fellow at the University of California, Berkeley, where he studies the origin of planets.

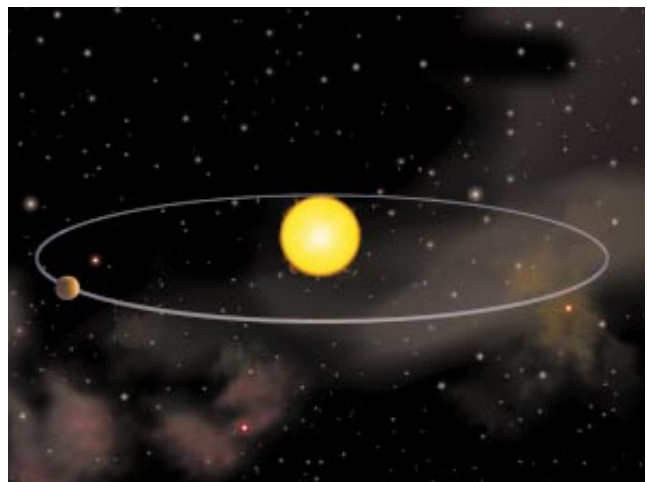
dreas Quirrenbach of the University of California at San Diego is leading a hunt for planets in open star clusters—groups of hundreds or thousands of stars that came into existence at about the same time. It is possible to estimate the age of a star cluster, so if planets are found in one, astronomers will automatically know how old they are.

Another search was recently performed using the Hubble Space Telescope. The team, led by Space Telescope Science Institute astronomer Ron Gilliland, along with Brown, watched the globular cluster 47 Tucanae for eight days. The researchers tracked 34,000 stars and expected statistically to

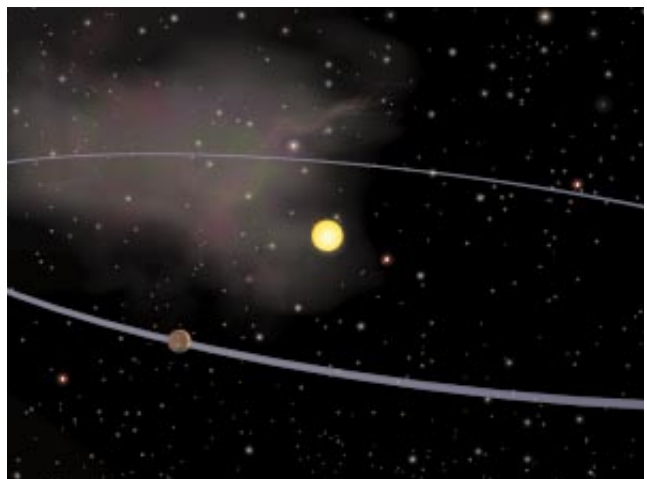
see 17 transits. Yet they found none. Astronomers are still mulling the null result. The cluster may lack planets because its stars are impoverished in the heavy elements that constitute planets or because the proximity of the stars has disrupted planetary orbits over the 10 billion years or so since the cluster formed.

All these efforts provide valuable insight into how planets form and how common they may be. But because they focus on comparatively large stars and observe them for a short time—looking for single transit events rather than a recurring pattern—the searches target gas giants, which cannot sustain

Star Name	Min. Mass (in Jupiters)	Orbital Eccentricity	Semimajor Axis (AU)
HD 16141	0.22	0.28	0.350
HD 168746	0.24	0.00	0.066
HD 46375	0.25	0.00	0.041
HD 108147	0.34	0.56	0.098
HD 83443	0.35	0.00	0.038
HD 75289	0.42	0.05	0.046
51 Peg	0.47	0.00	0.051
BD-10 3166	0.48	0.00	0.046
HD 187123	0.52	0.03	0.042
HD 209458	0.69	0.00	0.045
Ups And b	0.71	0.03	0.059
HD 192263	0.76	0.03	0.150
HD 38529	0.77	0.27	0.129
55 Cnc	0.84	0.05	0.110
HD 37124	1.04	0.19	0.585
HD 130322	1.08	0.05	0.088
Rho CrB	1.1	0.03	0.23
HD 52265	1.13	0.29	0.49
HD 217107	1.28	0.14	0.070
HD 177830	1.28	0.43	1.00
HD 210277	1.28	0.45	1.097
16 Cyg B	1.5	0.67	1.700
HD 134987	1.58	0.25	0.780
GJ 876	2.1	0.27	0.210
Ups And c	2.11	0.18	0.830
HD 92788	2.12	0.44	0.99
HD 82943	2.24	0.61	1.16
Iota Hor (HR 810)	2.26	0.16	0.925
47 UMa	2.41	0.10	2.10
HD 12661	2.8	0.33	0.827
HD 169830	2.96	0.34	0.823
14 Her	3.3	0.35	2.50
HD 1237 (GJ 3021)	3.31	0.51	0.49
HD 195019	3.43	0.05	0.14
Tau Boo	3.87	0.02	0.046
GJ 86	4.23	0.05	0.11
Ups And d	4.61	0.41	2.50
HD 168443	5.04	0.54	0.277
HD 222582	5.4	0.71	1.35
HD 10697	6.59	0.12	2.00
70 Vir	6.6	0.40	0.43
HD 89744	7.2	0.70	0.880
HD 114762	10.93	0.34	0.351
HD 162020	13.73	0.28	0.072



51 PEGASI exemplifies one of the two observed types of planetary orbit (*blue rows in table*): tight and circular.



70 VIRGINIS exemplifies the other type of planetary orbit (*black rows in table*): wider and elliptical.

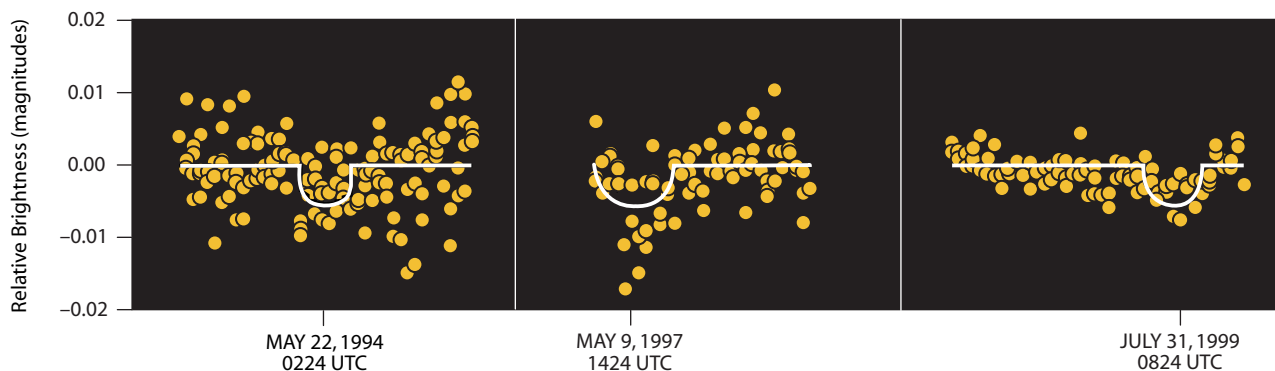
For further information see "Giant Planets Orbiting Faraway Stars," by Geoffrey W. Marcy and R. Paul Butler; SCIENTIFIC AMERICAN PRESENTS: Magnificent Cosmos, Spring 1998.

JENNIFER JOHANSEN (chart); SOURCE: THE WEB SITE www.harvard.edu/planets/catalog.html; ALFRED T. KAMAJIAN (illustrations)

life as we know it. To look for potentially habitable worlds, Doyle and Deeg have taken yet another approach. We are concentrating on stars that are relatively small and are already known to have the proper alignment needed to spot transits. We then watch them for long enough to observe multiple transits, building up a signal that stands out even if each transit is too puny to be detected on its own.

To understand the significance of the first characteristic, consider what it takes to make a home for living things. Terrestrial-style biochemistry requires liquid water, which a planet can possess only if it orbits a certain distance from its

star. If a planet is too close, it suffers a runaway greenhouse effect. According to work by James Kasting of Pennsylvania State University, Dan Whitmire of Southern Louisiana University and Ray Reynolds of NASA Ames, the stratosphere of the planet becomes saturated with water vapor, sunlight breaks the water down into oxygen and hydrogen, and the latter drifts off into space. The ultimate result is a bone-dry, super-hot planet like Venus. Similarly, if a planet is too far from its star, a runaway refrigerator effect takes hold. Greenhouse gases such as carbon dioxide snow out, and because snow reflects more radiation than rock does, it reinforces the



PURE NOISE? Or does a planet lurk somewhere in these brightness measurements for the binary star CM Draconis (*points*)? To distinguish the random flickering caused by Earth's atmosphere

from the dimming caused by a planet, the authors look for repeating patterns. The curved lines represent the dimming expected for a body 2.5 times the diameter of Earth on a 23-day orbit.

cooling trend. The planet goes into a deep freeze, as Mars has.

Stars smaller than the sun are cooler, so their habitable zones are closer in. The proximity, in turn, makes it more likely that we will see transits. Moreover, a planet of a given size yields a bigger transit signal when passing across a small star. Therefore, it is around small stars that potentially life-bearing planets might most easily be detected.

Shades of Other Earths

The second characteristic of the stars in our sample is that they already seem to have the necessary orientation for transit observations. We have picked them from astronomers' catalogue of eclipsing binary systems, double stars whose orbital planes happen to be parallel to our line of sight. Astronomers infer this orientation from the distinctive variation

tem consists of two very small, very cool stars about nine billion years old, located roughly 54 light-years away. Planets within its habitable zone would have orbital periods ranging from about 18 to 35 days. To do a thorough search of this zone for Earth-like planets, the TEP network had to observe the system for a total of more than 1,000 hours. Over the past six years Schneider, Valerij Kozhevnikov of Ural State University in Russia, Brian Oediker of the University of New Mexico, Eduardo Martin of the California Institute of Technology, J. Ellen Blue of SRI International in Menlo Park, Calif., Remington P. S. Stone of Lick Observatory near San Jose, Calif., and Efthimios Paleologou of the University of Crete have contributed data from their respective longitudes.

The problem is to distinguish the transit signal from the noise, which includes variations in Earth's atmosphere, equipment instabilities, intrinsic stellar variability, and so on. Fortunately,

the pattern of transits across eclipsing binaries is distinctive and predictable—so much so that our algorithm, developed with Jenkins, can detect planets even if the amount of dimming they cause is smaller than the

amount of noise. To pluck a planet from the noise, we compare all possible patterns to see which, if any, match the data. A great number of patterns can hide in 1,000 hours of photometric observations. In order not to miss any, we tested more than 400 million candidate patterns against the light curve. This correlation of possible transit models with our observations is known as a "matching filter." Nine possibilities, all involving a planet of about 2.5 Earth radii across, made the cut. The test has been to check whether transits continue to occur on cue. At press date, two possibilities remain—one with a 21-day orbit and another with a 26-day orbit. Meanwhile we have already broadened our search to several hundred other eclipsing binaries.

Clockworld

Eventually, transits could even reveal whether the planets have satellites. By causing a gentle ripple in the orbital motion of their parent planets, satellites would slightly alter the transit timing. For example, if extraterrestrial astronomers were monitoring the sun, they would notice a slight dimming every 365.24 days and thus deduce the presence of Earth. Over the years, however, the transits would occur up to two minutes late or early, implying the presence of a moon (once

If extraterrestrials were monitoring the sun, they would deduce the presence of Earth.

in the brightness of these systems: the two stars wax and wane just as they should if each regularly passes in front of the other. Over the years astronomers, both professional and amateur, have found thousands of eclipsing binaries. Apart from their fortuitous orientation, these systems are run-of-the-mill binary stars. Such systems can have stable planetary orbits as long as the star-planet distance is at least four times larger than the stars' mutual separation. The planet trundles around in the usual way but has two suns in its sky rather than one.

Eclipsing binaries are nature's gift to the planet hunter, as was first pointed out by Jean Schneider and Michel Chevreton of Meudon Observatory in Paris. Theorists believe that if any planets do form in binary systems, they tend to form in the same orbital plane as the two stars. If so, the probability of seeing a transit is 100 percent. When such a planet passes in front of its parent stars, it should cause a telltale double dip as it blocks the light of one star and then the other. The shape of the double dip would depend on the geometric configuration [see illustrations on page 60].

In 1994 we organized a worldwide network of one-meter-class telescopes—the TEP (transit of extrasolar planets) network—to look for Earth-like worlds around CM Draconis, one of the smallest known eclipsing binary systems. This sys-

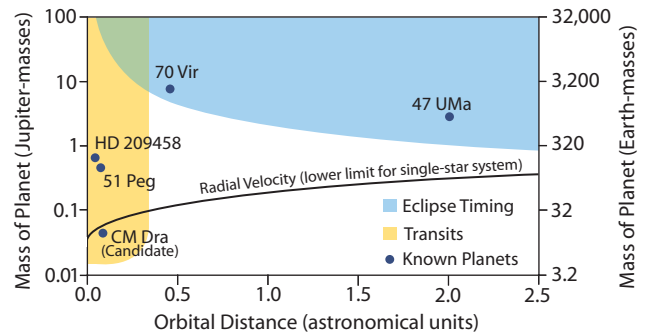


other orbital effects had been accounted for). If the extraterrestrials' photometry was extremely precise, they could directly detect a bit of extra dimming caused by the moon.

Transits are not the only way a planet might make its presence known to a photometer. An eclipsing binary is a kind of clock; stellar eclipses should occur at regular intervals. If the clock is not keeping perfect time, it may mean that an unseen body is tugging at the stars. If a Jupiter-mass planet pulled the binary star away from us, say, the eclipses would seem to occur a few seconds late, because it would take the light from the two stars that much longer to reach Earth. The farther the planet or the greater its mass, the greater the offset would be. A giant planet can therefore be detected without transiting the two stars at all. Using existing data, astronomers have already placed limits on the prevalence of giant planets in certain systems. CM Draconis, for example, does not contain any bodies larger than about three Jupiter-masses and closer than the orbit of Earth.

High photometric precision and years-long observations allow for yet another spinoff: the reflected light of a planet. Planets sufficiently close to their stars should reflect a perceptible amount of starlight. They undergo phase changes similar to those the moon goes through each month, thus producing a cyclic undulation that can be distinguished from other variations in stellar brightness. The technique should pick up bodies with an orbital period of one week or less. It could even probe the nature of the planet itself, because rough-surfaced planets would cause steeper variations in brightness than smoother ones would. A related method looks for reflected planetary light in the spectrum of the star. Last year Andrew Collier Cameron of the University of St. Andrews in Scotland and his colleagues claimed to have seen the reflection of the giant planet around the star Tau Bootis, but this finding has proved controversial.

Because the largest sources of error in measuring stellar light curves come from Earth's atmosphere, watching the stars from space would clearly improve matters. An orbital observatory should be able to achieve a photometric accuracy of 0.002 percent. Several such missions are now in the works. The European spacecraft COROT is set to launch in 2004 and will be sensitive to planets as small as twice the size of Earth. The European Space Agency's Eddington observatory, which one of us (Deeg) has been working on, could spot truly Earth-size ones. The most ambitious mission is the



PROS AND CONS of various methods for planet finding are summarized on this chart, which shows the methods' sensitivity to planets of a given mass (*vertical axis*) and a given distance from their parent star (*horizontal axis*). Even at its theoretical limit, the radial-velocity method (*black line*) misses sub-Saturn worlds unless they are very close in. The transit method can spot Earth-size bodies; practical limitations currently limit it to fairly close planets (*yellow*), but spaceborne missions will cover the entire diagram. The eclipse-timing method (*blue*) picks up distant planets more readily than nearby ones.

NASA Kepler satellite. It would monitor 170,000 stars in the constellation Cygnus and, if the statistical trends hold, should detect the transits of more than 600 terrestrial-size planets, as well as the reflections of an additional 1,700 or so giant inner planets. These worlds would be obvious targets for space-borne nulling interferometers, which should eventually be able to cancel out the stellar glare and take actual pictures of the planets [see "Searching for Life on Other Planets," by J. Roger P. Angel and Neville J. Woolf; *SCIENTIFIC AMERICAN*, April 1996]. During the transits, the planets will be backlit by their stars, which could make it easier to examine them spectroscopically for potential markers of life, such as ozone, water and methane.

All of us in the field feel privileged to live in an age of first discovery. Renaissance astronomer Christiaan Huygens wrote: "What a wonderful and amazing Scheme have we here of the magnificent Vastness of the Universe! So many Suns, so many Earths!" Was Huygens correct? Are there other planets like ours? Are they inhabited? By the end of the decade, we should know.

The Authors

LAURANCE R. DOYLE, HANS-JÖRG DEEG and TIMOTHY M. BROWN are astronomers who have been searching for extrasolar planets using the photometric method since the early 1990s. Doyle is at the SETI Institute in Mountain View, Calif. He has also developed algorithms to analyze marine-mammal vocalizations, such as bottlenose dolphin whistles. Deeg is at the Astrophysical Institute of Andalusia in Granada, Spain. He frequently takes advantage of both the telescopes and the hiking trails on the Canary Islands. Brown is at the National Center for Atmospheric Research in Boulder, Colo. His telescope has a working aperture of just 2.5 inches, which provides a wide field of view.

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One day children may get immunized by munching on foods instead of enduring shots. More important, food vaccines might save millions who now die for lack of access to traditional inoculants

Edible Vaccines

by William H. R. Langridge



Vaccines have accomplished near miracles in the fight against infectious disease. They have consigned smallpox to history and should soon do the same for polio. By the late 1990s an international campaign to immunize all the world's children against six devastating diseases was reportedly reaching 80 percent of infants (up from about 5 percent in the mid-1970s) and was reducing the annual death toll from those infections by roughly three million.

Yet these victories mask tragic gaps in delivery. The 20 percent of infants still missed by the six vaccines—against diphtheria, pertussis (whooping cough), polio, measles, tetanus and tuberculosis—account for about two million unnecessary deaths each year, especially in the most remote and impoverished parts of the globe. Upheavals in many developing nations now threaten to erode the advances of the recent past, and millions still die from infectious diseases for which immunizations are nonexistent, unreliable or too costly.

This situation is worrisome not only for the places that lack health care but for the entire world. Regions harboring infections that have faded from other areas are like bombs ready to explode. When environmental or social disasters undermine sanitation systems or displace communities—bringing people with little immunity into contact with carriers—infections that have been long gone from a population can come roaring back. Further, as international travel and trade make the earth a smaller place, diseases that arise in one locale are increasingly popping up continents away. Until everyone has routine access to vaccines, no one will be entirely safe.

In the early 1990s Charles J. Arntzen, then at Texas A&M University, conceived of a way to solve many of the problems that bar vaccines from reaching all too many children in developing nations. Soon after learning of a World Health Organization call for inexpensive, oral vaccines that needed no refrigeration, Arntzen visited Bangkok, where he saw a mother soothe a crying

FOODS UNDER STUDY as alternatives to injectable vaccines include bananas, potatoes and tomatoes, as well as lettuce, rice, wheat, soybeans and corn.

JOHNSON & FANCHER



BANANA TREES AND TOMATO PLANTS growing at the Boyce Thompson Institute for Plant Research at Cornell University have been genetically engineered to produce vaccines in their fruit. Bananas are particularly appealing as vaccines because they grow widely in many parts of the developing world, can be eaten raw and are liked by most children.



baby by offering a piece of banana. Plant biologists had already devised ways of introducing selected genes (the blueprints for proteins) into plants and inducing the altered, or “transgenic,” plants to manufacture the encoded proteins. Perhaps, he mused, food could be genetically engineered to produce vaccines in their edible parts, which could then be eaten when inoculations were needed.

The advantages would be enormous. The plants could be grown locally, and cheaply, using the standard growing methods of a given region. Because many food plants can be regenerated readily, the crops could potentially be produced indefinitely without the growers having to purchase more seeds or plants year after year. Homegrown vaccines would also avoid the logistical and economic problems posed by having to transport traditional preparations over long distances, keeping them cold en route and at their destination. And, being edible, the vaccines would require no syringes—which, aside from costing something, can lead to infections if they become contaminated.

Efforts to make Arntzen’s inspired vision a reality are still quite preliminary. Yet studies carried out in animals over the past 10 years, and small tests in people, encourage hope that edible vaccines can work. The research has also fueled speculation that certain food vaccines might help suppress autoimmunity—in which the body’s defenses mistakenly attack normal, uninfected tissues. Among the autoimmune disorders that might be prevented or eased are type I diabetes (the kind that commonly arises during childhood), multiple sclerosis and rheumatoid arthritis.

By Any Other Name ...

Regardless of how vaccines for infectious diseases are delivered, they all have the same aim: priming the immune system to swiftly destroy specific disease-causing agents, or pathogens, before the agents can multiply enough to cause symptoms. Classically, this priming has been achieved by presenting the immune system with whole viruses or bacteria that have been killed or made too weak to proliferate much.

On detecting the presence of a foreign organism in a vaccine, the immune system behaves as if the body were under attack by a fully potent antagonist. It mobilizes its various forces to root out and destroy the apparent invader—targeting the campaign to specific antigens (proteins recognized as foreign). The acute response soon abates, but it leaves behind sentries, known as “memory” cells, that remain on alert, ready to unleash whole armies of defenders if the real pathogen ever finds its way into the body. Some vaccines

provide lifelong protection; others (such as those for cholera and tetanus) must be readministered periodically.

Classic vaccines pose a small but troubling risk that the vaccine microorganisms will somehow spring back to life, causing the diseases they were meant to forestall. For that reason, vaccine makers today favor so-called subunit preparations, composed primarily of antigenic proteins divorced from a pathogen’s genes. On their own, the proteins have no way of establishing an infection. Subunit vaccines, however, are expensive, in part because they are produced in cultures of bacteria or animal cells and have to be purified out; they also need to be refrigerated.

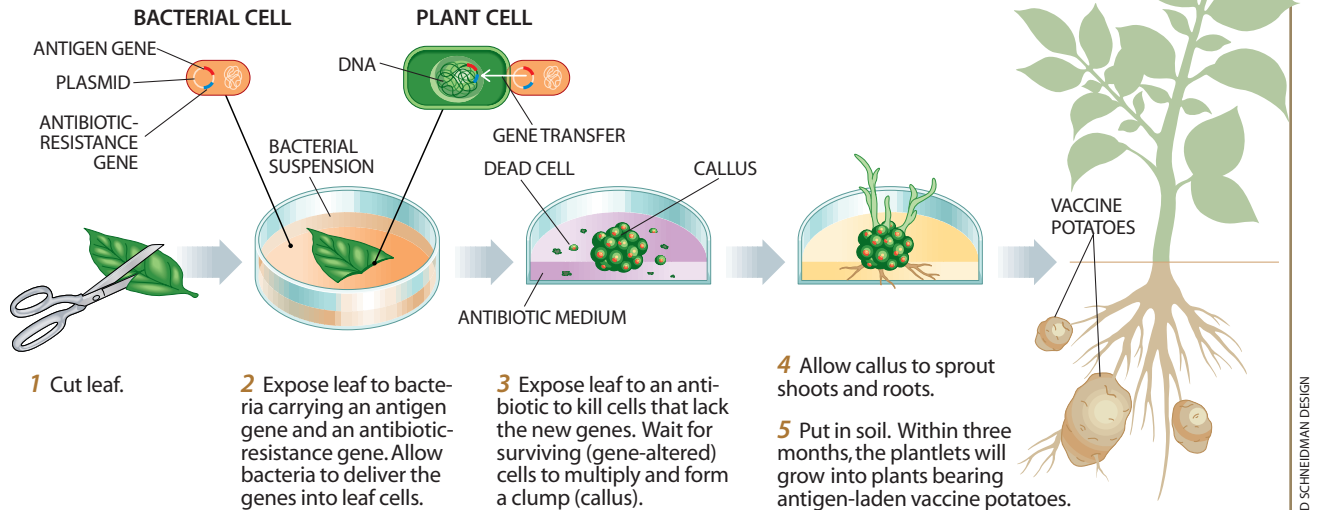
Food vaccines are like subunit preparations in that they are engineered to contain antigens but bear no genes that would enable whole pathogens to form. Ten years ago Arntzen understood that edible vaccines would therefore be as safe as subunit preparations while sidestepping their costs and demands for purification and refrigeration. But before he and others could study the effects of food vaccines in people, they had to obtain positive answers to a number of questions. Would plants engineered to carry antigen genes produce functional copies of the specified proteins? When the food plants were fed to test animals, would the antigens be degraded in the stomach before having a chance to act? (Typical subunit vaccines have to be delivered by injection precisely because of such degradation.) If the antigens did survive, would they, in fact, attract the immune system’s attention? And would the response be strong enough to defend the animals against infection?

Additionally, researchers wanted to know whether edible vaccines would elicit what is known as mucosal immunity. Many pathogens enter the body through the nose, mouth or other openings. Hence, the first defenses they encounter are those in the mucous membranes that line the airways, the digestive tract and the reproductive tract; these membranes constitute the biggest pathogen-detering surface in the body. When the mucosal immune response is effective, it generates molecules known as secretory antibodies that dash into the

HOW TO MAKE AN EDIBLE VACCINE

One way of generating edible vaccines relies on the bacterium *Agrobacterium tumefaciens* to deliver into plant cells the genetic blueprints for viral or bacterial

“antigens”—proteins that elicit a targeted immune response in the recipient. The diagram illustrates the production of vaccine potatoes.



JARED SCHNEIDMAN DESIGN

cavities of those passageways, neutralizing any pathogens they find. An effective reaction also activates a systemic response, in which circulating cells of the immune system help to destroy invaders at distant sites.

Injected vaccines initially bypass mucous membranes and typically do a poor job of stimulating mucosal immune responses. But edible vaccines come into contact with the lining of the digestive tract. In theory, then, they would activate both mucosal and systemic immunity. That dual effect should, in turn, help improve protection against many dangerous microorganisms, including, importantly, the kinds that cause diarrhea.

Those of us attempting to develop food vaccines place a high priority on combating diarrhea. Together the main causes—the Norwalk virus, rotavirus, *Vibrio cholerae* (the cause of cholera) and enterotoxigenic *Escherichia coli* (a toxin-producing source of “traveler’s diarrhea”)—account for some three million infant deaths a year, mainly in developing nations. These pathogens disrupt cells of the small intestine in ways that cause water to flow from the blood and tissues into the intestine. The resulting dehydration may be combated by delivering an intravenous or oral solution of electrolytes, but it often turns deadly when rehydration therapy is not an option. No vaccine practical for wide distribution in the developing na-

tions is yet available to prevent these ills.

By 1995 researchers attempting to answer the many questions before them had established that plants could indeed manufacture foreign antigens in their proper conformations. For instance, Arntzen and his colleagues had introduced into tobacco plants the gene for a protein derived from the hepatitis B virus and had gotten the plants to synthesize the protein. When they injected the antigen into mice, it activated the same immune system components that are activated by the virus itself. (Hepatitis B can damage the liver and contribute to liver cancer.)

Green Lights on Many Fronts

But injection is not the aim; feeding is. In the past five years experiments conducted by Arntzen (who moved to the Boyce Thompson Institute for Plant Research at Cornell University in 1995) and his collaborators and by my group at Loma Linda University have demonstrated that tomato or potato plants can synthesize antigens from the Norwalk virus, enterotoxigenic *E. coli*, *V. cholerae* and the hepatitis B virus. Moreover, feeding antigen-laced tubers or fruits to test animals can evoke mucosal and systemic immune responses that fully or partly protect animals from subsequent exposure to the real pathogens or, in the case of *V. cholerae* and enterotox-

igenic *E. coli*, to microbial toxins. Edible vaccines have also provided laboratory animals with some protection against challenge by the rabies virus, *Helicobacter pylori* (a bacterial cause of ulcers) and the mink enteric virus (which does not affect humans).

It is not entirely surprising that antigens delivered in plant foods survive the trip through the stomach well enough to reach and activate the immune system. The tough outer wall of plant cells apparently serves as temporary armor for the antigens, keeping them relatively safe from gastric secretions. When the wall finally begins to break up in the intestines, the cells gradually release their antigenic cargo.

Of course, the key question is whether food vaccines can be useful in people. The era of clinical trials for this technology is just beginning. Nevertheless, Arntzen and his collaborators obtained reassuring results in the first published human trial, involving about a dozen subjects. In 1997 volunteers who ate pieces of peeled, raw potatoes containing a benign segment of the *E. coli* toxin (the part called the B subunit) displayed both mucosal and systemic immune responses. Since then, the group has also seen immune reactivity in 19 of 20 people who ate a potato vaccine aimed at the Norwalk virus. Similarly, after Hilary Koprowski of Thomas Jefferson University fed transgenic lettuce carrying

a hepatitis B antigen to three volunteers, two of the subjects displayed a good systemic response. Whether edible vaccines can actually protect against human disease remains to be determined, however.

Still to Be Accomplished

In short, the studies completed so far in animals and people have provided a proof of principle; they indicate that the strategy is feasible. Yet many issues must still be addressed. For one, the amount of vaccine made by a plant is low. Production can be increased in different ways—for instance, by linking antigen genes with regulatory elements known to help switch on the genes more readily. As researchers solve that challenge, they will also have to ensure that any given amount of a vaccine food provides a predictable dose of antigen.

Additionally, workers could try to enhance the odds that antigens will activate the immune system instead of passing out of the body unused. General stimulants (adjuvants) and better targeting to the immune system might compensate in part for low antigen production.

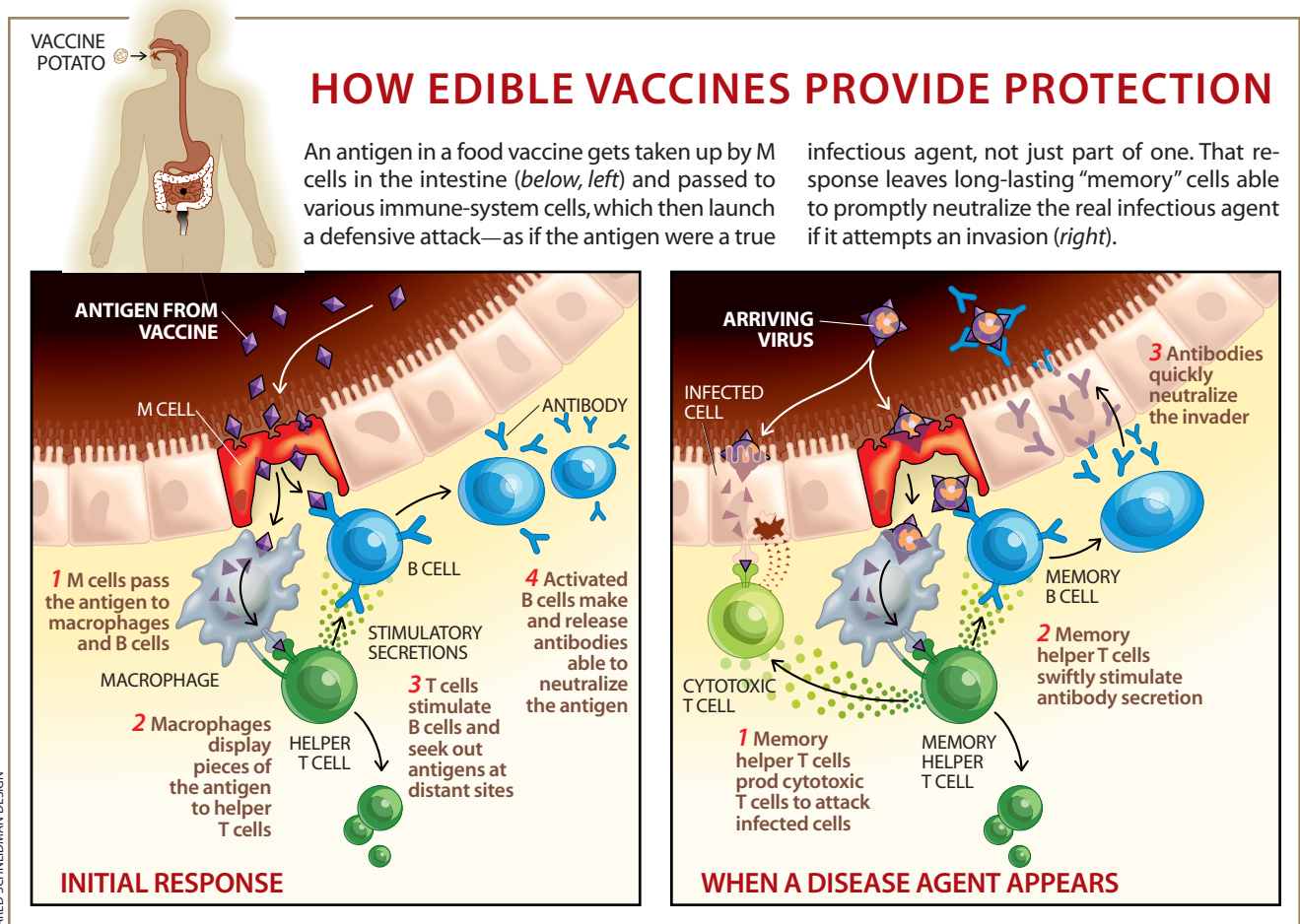
One targeting strategy involves linking antigens to molecules that bind well to immune system components known as M cells in the intestinal lining. M cells take in samples of materials that have entered the small intestine (including pathogens) and pass them to other cells of the immune system, such as antigen-presenting cells. Macrophages and other antigen-presenting cells chop up their acquisitions and display the resulting protein fragments on the cell surface. If white blood cells called helper T lymphocytes recognize the fragments as foreign, they may induce B lymphocytes (B cells) to secrete neutralizing antibodies and may also help initiate a broader attack on the perceived enemy.

It turns out that an innocuous segment of the *V. cholerae* toxin—the B subunit—binds readily to a molecule on M cells that ushers foreign material into those cells. By fusing antigens from other pathogens to this subunit, it should be possible to improve the uptake of antigens by M cells and to enhance immune responses to the added antigens. The B subunit also tends to associate with copies of itself, forming a dough-

nut-shaped, five-membered ring with a hole in the middle. These features raise the prospect of producing a vaccine that brings several different antigens to M cells at once—thus potentially fulfilling an urgent need for a single vaccine that can protect against multiple diseases simultaneously.

Researchers are also grappling with the reality that plants sometimes grow poorly when they start producing large amounts of a foreign protein. One solution would be to equip plants with regulatory elements that cause antigen genes to turn on—that is, give rise to the encoded antigens—only at selected times (such as after a plant is nearly fully grown or is exposed to some outside activator molecule) or only in its edible regions. This work is progressing.

Further, each type of plant poses its own challenges. Potatoes are ideal in many ways because they can be propagated from “eyes” and can be stored for long periods without refrigeration. But potatoes usually have to be cooked to be palatable, and heating can denature proteins. Indeed, as is true of tobacco plants, potatoes were not initially intended to be



used as vaccine vehicles; they were studied because they were easy to manipulate. Surprisingly, though, some kinds of potatoes are actually eaten raw in South America. Also, contrary to expectations, cooking of potatoes does not always destroy the full complement of antigen. So potatoes may have more practical merit than most of us expected.

Bananas need no cooking and are grown widely in developing nations, but banana trees take a few years to mature, and the fruit spoils fairly rapidly after ripening. Tomatoes grow more quickly and are cultivated broadly, but they too may rot readily. Inexpensive methods of preserving these foods—such as drying—might overcome the spoilage prob-

lem. Among the other foods under consideration are lettuce, carrots, peanuts, rice, wheat, corn and soybeans.

In another concern, scientists need to be sure that vaccines meant to enhance immune responses do not backfire and suppress immunity instead. Research into a phenomenon called oral tolerance has shown that ingesting certain proteins can at times cause the body to shut down its responses to those proteins. To determine safe, effective doses and feeding schedules for edible vaccines, manufacturers will need to gain a better handle on the manipulations that influence whether an orally delivered antigen will stimulate or depress immunity.

A final issue worth studying is whether food vaccines ingested by mothers can indirectly vaccinate their babies. In theory, a mother could eat a banana or two and thus trigger production of antibodies that would travel to her fetus via the placenta or to her infant via breast milk.

Nonscientific challenges accompany the technical ones. Not many pharmaceutical manufacturers are eager to support research for products targeted primarily to markets outside the lucrative West. International aid organizations and some national governments and philanthropies are striving to fill the gap, but the effort to develop edible vaccines remains underfunded.

In addition, edible vaccines fall under the increasingly unpopular rubric of “genetically modified” plants. Recently a British company (Axis Genetics) that was supporting studies of edible vaccines failed; one of its leaders lays at least part of the blame on investor worry about companies involved with genetically engineered foods. I hope, however, that these vaccines will avoid serious controversy, because they are intended to save lives and would probably be planted over much less acreage than other food plants (if they are raised outside of greenhouses at all). Also, as drugs, they would be subjected to closer scrutiny by regulatory bodies.

Fighting Autoimmunity

Consideration of one of the challenges detailed here—the risk of inducing oral tolerance—has recently led my group and others to pursue edible vaccines as tools for quashing autoimmunity. Although oral delivery of antigens derived from infectious agents often stimulates the immune system, oral delivery of “autoantigens” (proteins de-

Moving against Malnutrition

As research into edible vaccines is progressing, so too are efforts to make foods more nutritious. A much publicized example, “golden rice,” takes aim at vitamin A deficiency, rampant in many parts of Asia, Africa and Latin America. This condition can lead to blindness and to immune impairment, which contributes to the death of more than a million children each year.

Rice would be a convenient way to deliver the needed vitamin, because the grain is a daily staple for a third or more of all people on the earth. But natural varieties do not supply vitamin A. Golden rice, though, has been genetically altered to make beta-carotene, a pigment the body converts to vitamin A.

A team led by Ingo Potrykus of the Swiss Federal Institute of Technology and Peter Beyer of the University of Freiburg in Germany formally reported its creation this past January in *Science*. In May an agribusiness—Zeneca—bought the rights and agreed to allow the rice to be donated to facilities that will cross the beta-carotene trait into rice species popular in impoverished areas and will distribute the resulting products to farmers at no charge. (Zeneca is hoping to make its money from sales of the improved rice in richer countries, where beta-carotene’s antioxidant properties are likely to have appeal.)

Golden rice is not yet ready to be commercialized, however. Much testing still lies ahead, including analyses of whether the human body can efficiently absorb the beta-carotene in the rice. Testing is expected to last at least until 2003.

Meanwhile scientists are trying to enrich rice with still more beta-carotene, with other vitamins and with minerals. At a conference last year Potrykus announced success with iron; more than two billion people worldwide are iron deficient.

Investigators are attempting to enhance other foods as well. In June, for instance, a group of British and Japanese investigators reported the creation of a tomato containing a gene able to supply three times the usual amount of beta-carotene. Conventional breeding methods are being used, too, such as in an international project focused on increasing the vitamin and mineral content of rice and four other staples—wheat, corn, beans and cassava.

Not everyone is thrilled by the recent genetic coups. Genetically modified (GM) foods in general remain controversial. Some opponents contend that malnutrition can be combated right now in other ways—say, by constructing supply roads. And they fear that companies will tout the benefits of the new foods to deflect attention from worries over other GM crops, most of which (such as plants designed to resist damage from pesticides) offer fewer clear advantages for consumers. High on the list of concerns are risk to the environment and to people. Supporters of the nutritionally improved foods hope, however, that the rice won’t be thrown out with the rinse water.

—Ricki Rusting, staff writer



COURTESY OF PETER BEYER, University of Freiburg

“GOLDEN RICE” contains beta-carotene, which adds color as well as nutrition to the grain.

constructing supply roads. And they fear that companies will tout the benefits of the new foods to deflect attention from worries over other GM crops, most of which (such as plants designed to resist damage from pesticides) offer fewer clear advantages for consumers. High on the list of concerns are risk to the environment and to people. Supporters of the nutritionally improved foods hope, however, that the rice won’t be thrown out with the rinse water.

rived from uninfected tissue in a treated individual) can sometimes suppress immune activity—a phenomenon seen frequently in test animals. No one fully understands the reasons for this difference.

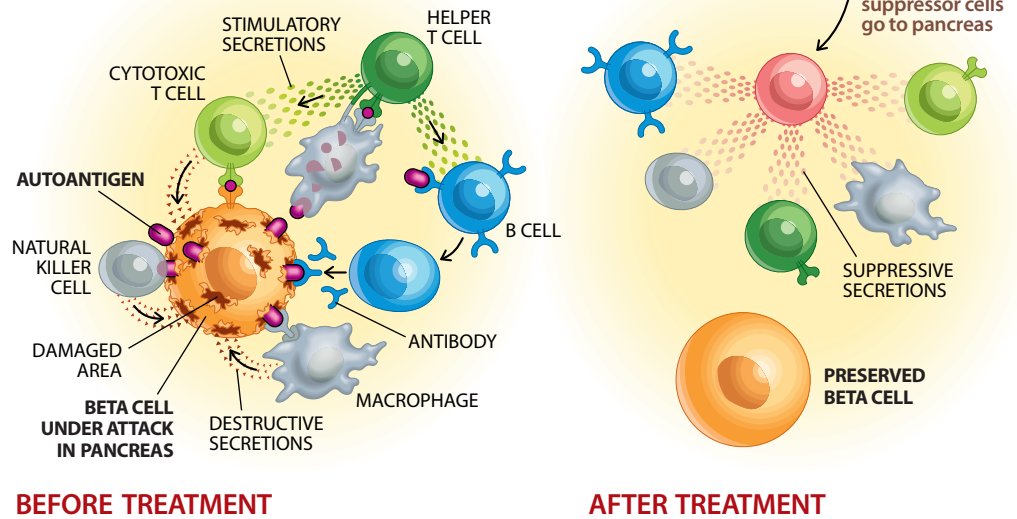
Some of the evidence that ingesting autoantigens, or “self-antigens,” might suppress autoimmunity comes from studies of type I diabetes, which results from autoimmune destruction of the insulin-producing cells (beta cells) of the pancreas. This destruction progresses silently for a time. Eventually, though, the loss of beta cells leads to a drastic shortage of insulin, a hormone needed to help cells take up sugar for energy. The loss results in high blood sugar levels. Insulin injections help to control diabetes, but they are by no means a cure; diabetics face an elevated risk of severe complications.

In the past 15 years, investigators have identified several beta cell proteins that can elicit autoimmunity in people predisposed to type I diabetes. The main culprits, however, are insulin and a protein called GAD (glutamic acid decarboxylase). Researchers have also made progress in detecting when diabetes is “brewing.” The next step, then, is to find ways of stopping the underground process before any symptoms arise.

To that end, my colleagues and I, as well as other groups, have developed

STOPPING AUTOIMMUNITY

The autoimmune reaction responsible for type I diabetes arises when the immune system mistakes proteins that are made by pancreatic beta cells (the insulin producers) for foreign invaders. The resulting attack, targeted to the offending proteins, or “autoantigens,” destroys the beta cells (*below, left*). Eating small amounts of autoantigens quiets the process in diabetic mice, for unclear reasons. The autoantigens might act in part by switching on “suppressor” cells of the immune system (*inset*), which then block the destructive activities of their cousins (*below, right*).



plant-based diabetes vaccines, such as potatoes containing insulin or GAD linked to the innocuous B subunit of the *V. cholerae* toxin (to enhance uptake of the antigens by M cells). Feeding of the vaccines to a mouse strain that becomes diabetic helped to suppress the immune attack and to prevent or delay the onset of high blood sugar.

Transgenic plants cannot yet produce the amounts of self-antigens that would be needed for a viable vaccine against human diabetes or other autoimmune

diseases. But, as is true for infectious diseases, investigators are exploring a number of promising schemes to overcome that and other challenges.

Edible vaccines for combating autoimmunity and infectious diseases have a long way to go before they will be ready for large-scale testing in people. The technical obstacles, though, all seem surmountable. Nothing would be more satisfying than to protect the health of many millions of now defenseless children around the globe.

The Author

WILLIAM H. R. LANGRIDGE, a leader in the effort to develop edible vaccines for infectious and autoimmune diseases, is professor in the department of biochemistry and at the Center for Molecular Biology and Gene Therapy at the Loma Linda University School of Medicine. After receiving his Ph.D. in biochemistry from the University of Massachusetts at Amherst in 1973, he conducted genetic research on insect viruses and plants at the Boyce Thompson Institute for Plant Research at Cornell University. In 1987 he moved to the Plant Biotechnology Center of the University of Alberta in Edmonton, and he joined Loma Linda in 1993.

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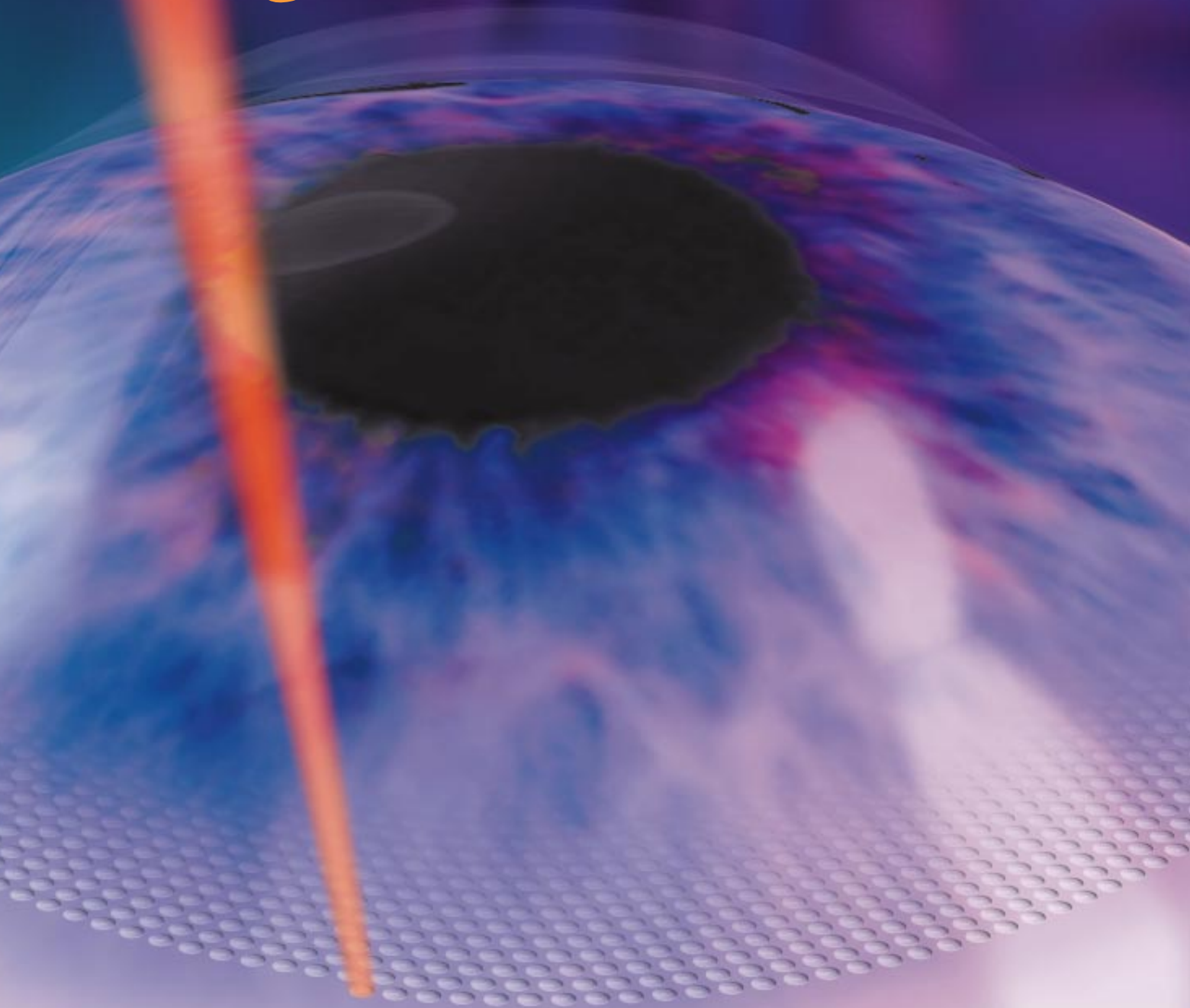
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by John-Mark Hopkins and Wilson Sibbett

Ultrashort-Pulse Lasers:



Big Payoffs in a Flash

The briefest man-made events, pulses of laser light lasting millionths of a nanosecond, can be used for delicate eye surgery, high-bandwidth communications and stop-motion studies of molecules reacting

How long did it take you to read this sentence? Just recognizing the first letter took only milliseconds. Around 0.05 millisecond, or 50 microseconds, passes each time chemicals diffuse across a synapse, carrying a signal from one neuron to another in your brain. Are you holding the magazine at a comfortable reading distance? It takes light one or two nanoseconds to travel from the page to your eye and about 20 picoseconds to pass through the lens in your eye. And yet these brief natural events are epically long compared with the shortest man-made events, which proceed 1,000-fold more swiftly: pulses of laser light that last for only a few femtoseconds (quadrillionths of a second).

It is hard to comprehend the brevity of a femtosecond (10^{-15} second). One femtosecond is to one second as one second is to 32 million years. Put another way, more than 10 times as many femtoseconds elapse every second than hours have passed since the big bang! Some of the most fundamental processes in the universe—for example, electrons moving between atoms and molecular bonds breaking or forming—occur on timescales of hundreds of femtoseconds or less. Scientists have used femtosecond pulses to record and study such fast events in detail, much as Harold E. Edgerton of the Massachusetts Institute of Technology used microsecond flashes of light to produce unforgettable photographs of splashing droplets and flying bullets. The pioneering work of Ahmed H. Zewail of the California Institute of Technology enabled chemists to see how reactions proceed on timescales of a few hundred femtoseconds, earning him the Nobel Prize in Chemistry [see “The Nobel Prizes for 1999,” *SCIENTIFIC AMERICAN*, January]. Researchers have also effectively “freeze-framed” the dynamics of electrons within semiconductor materials to enable them to design better optoelectronic devices to achieve the ever faster signal processing demanded by the computer and telecommunications industries.

The science and technology of ultrashort-pulse lasers have enjoyed much exciting progress since they were developed in the mid-1960s. In particular, the past decade has seen pulses shorter than 10 femtoseconds and the emergence of a new

ULTRASHORT LASER PULSES can slice a flap of the cornea for LASIK eye surgery by producing a layer of perforations at a constant depth. The holes would be smaller and the beam more tightly focused than in this artist's depiction.

generation of versatile, compact ultrashort-pulse lasers—a revolutionary change from their large, temperamental, power-hungry ancestors. Such laser designs, which make use of sophisticated nonlinear optical phenomena and concurrent advances in diode lasers, increasingly meet the stringent specifications and reliability necessary for many industrial and medical applications. As we enter the 21st century, ultrashort-pulse lasers are becoming more impressive in scope and intensity, producing beams that span the electromagnetic spectrum from x-rays to T-rays (terahertz radiation, beyond infrared) and generating optical peak powers as colossal as petawatts (billions of megawatts). As a result, many new applications in physics, chemistry, biology, medicine, and digital optical technology are emerging and attracting worldwide interest in science and industry.

Sharpest of Scalpels

Many applications of ultrashort-pulse lasers make use of the very high power that each pulse momentarily provides. Although the average power from the laser may be quite moderate and the total energy within a pulse small, the extremely short duration of each pulse guarantees that the peak instantaneous power is large. In a typical system the interval between pulses is 100,000 times longer than the pulses themselves, and so the peak power is about 100,000 times the average power. For example, a 100-femtosecond pulse with a moderate energy of three microjoules (not enough energy to heat a drop of water by a millionth of a degree Celsius) delivers a peak power of 30 megawatts.

When focused on a tiny spot, such high powers ablate many materials, making ultrashort pulses a tool for micromachining, drilling, cutting and welding. Precision can exceed the beam focus if the pulse intensity is carefully set so that only the brightest central part of the beam rises above the material's ablation threshold. The pulse deposits the energy at the focus too rapidly for the heat to diffuse into the surrounding unirradiated areas, ensuring smooth and precise features [see top illustration on page 75]. Researchers have demonstrated this technique by accurately machining diamond, titanium carbide and tooth enamel. Amazingly, the lasers can even slice safely through high explosives—they vaporize what is at the cutting point without detonating the adjoining material. This procedure may prove practical in the decommissioning of weapons.

Surgical applications also abound. For example, in microvascular surgery an ultrashort-pulse laser can drill small holes in the walls of the heart to supply oxygenated blood to cardiac muscles with irreparably blocked blood vessels. Ul-

The Basics

Electromagnetic radiation has a thousand faces. Most familiar is visible light. All the colors of the rainbow are distinguished by one property, the light's wavelength, ranging from about 380 nanometers (nm) for the deepest perceivable violet to about 750 nm for the reddest of reds. Most of the colors we see around us, particularly the browns, grays and pastels not found in a rainbow, involve a mixture of many different wavelengths. The electromagnetic spectrum extends far beyond visible light, to gamma rays at the short-wavelength and high-frequency extreme, and radio waves at the other. The mild waves emitted by 60-hertz household wiring would lie about seven divisions below the lowest mark on the chart at the right.

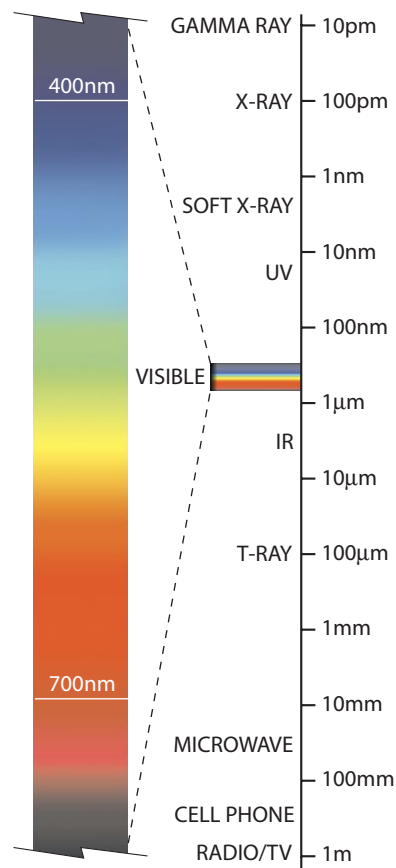
Distinctions of wavelength are just the beginning of how light can be packaged. Most light is incoherent, analogous to a stadium crowd roaring. Lasers produce coherent light—the crowd sings a song in unison. Light can come in continuous waves, like breakers endlessly arriving at the beach, and also as a pulse, like a tsunami. Compressing light into the shortest of coherent pulses—the record stands at around four femtoseconds—creates an extraordinarily versatile tool with a remarkable combination of power and delicacy.

News stories on other gymnastics and mysteries of electromagnetic radiation appear on pages 20 and 26 of this issue.

—Graham P. Collins, staff writer

Small and Large

Prefix	Factor	Name (U.S.)	Prefix	Factor	Name (U.S.)
milli (m)	10^{-3}	thousandth	kilo (k)	10^3	thousand
micro (μ)	10^{-6}	millionth	mega (M)	10^6	million
nano (n)	10^{-9}	billionth	giga (G)	10^9	billion
pico (p)	10^{-12}	trillionth	tera (T)	10^{12}	trillion
femto (f)	10^{-15}	quadrillionth	peta (P)	10^{15}	quadrillion
atto (a)	10^{-18}	quintillionth	exa (E)	10^{18}	quintillion
zepto (z)	10^{-21}	sextillionth	zetta (Z)	10^{21}	sextillion
yocto (y)	10^{-24}	septillionth	yotta (Y)	10^{24}	septillion



LAURIE GRACE

trashort pulses are especially effective because their low average power reduces the collateral tissue damage. Scientists at Lawrence Livermore National Laboratory have used ultrashort pulses, with a clever monitoring system, to remove bony intrusions into the spinal column without damaging the adjacent nerve tissue. And researchers at the University of Michigan and the University of Heidelberg in Germany have demonstrated a remarkable form of eye surgery: a beam of ultrashort pulses focused to an exact depth in the cornea create a small mesh of interconnecting bubbles, or cavitations [see illustration below]. A flap of the cornea can then be peeled back, exposing a disk of the

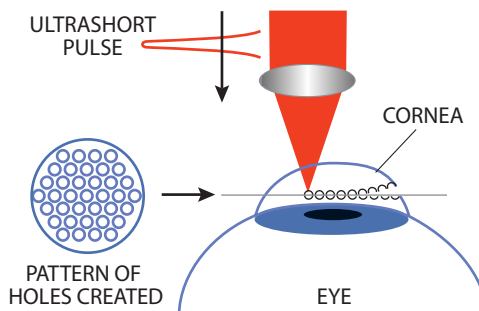
lower tissue for removal. The top layer is then put back, smooth surface intact, and the resultant flattening of the cornea corrects myopia, or nearsightedness. The laser cuts a smoother flap than the standard knife-based technique and provides more control over the cut's shape and location.

Imaging

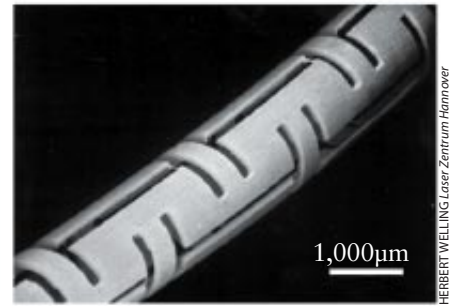
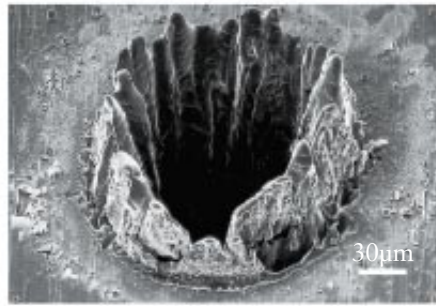
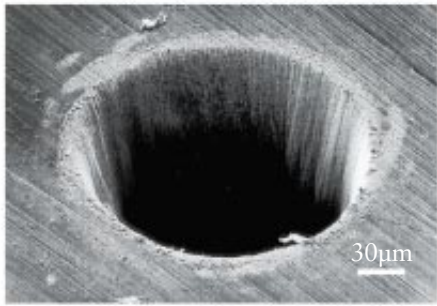
An obvious use for any new source of light is to produce images in novel ways. In biology and medicine, imaging often relies on special dyes or natural molecules in tissues fluorescing in response to short-wavelength light, such as violet light. Usually this proceeds by a

molecule absorbing a single quantum of light, or photon, and subsequently emitting another photon. Using light of longer wavelength would have many advantages, but such photons carry less energy, so two or more photons must act in synchrony to excite each molecule. This multiphoton excitation becomes significant only at very high intensities. Ultrashort pulses provide the required intensities while delivering sufficiently low average power to avoid tissue damage. In addition, longer-wavelength light penetrates tissues more efficiently and causes less damage to cells than the shorter wavelengths. The intensity can be adjusted so that fluorescence occurs predominantly at the focus of the beam,

EXPERIMENTAL laser eye treatment detaches a flap of the cornea by punching tiny holes at the focus of the laser (left). Further such cuts detach a subsurface disk of the cornea (right). When the flap is laid back, the cornea is flattened, correcting myopia. In conventional LASIK surgery, the flap is cut with a blade—a riskier procedure that produces a rougher cut.



LAURIE GRACE (left); GERARD A. MOUROU University of Michigan (right)



HERBERT WELLING/Laser Zentrum Hannover

LASER MICROMACHINING benefits from the properties of the shortest pulses. A 200-femtosecond pulse produces a very smooth hole in steel by ablation (*left*). Pulses of half the power and lasting 16 times longer melt the surrounding areas (*center*) unless special techniques are used. Laser micromachining can produce smooth tantalum stents (*right*) used to treat cardiovascular problems.

resulting in a much higher resolution [see illustration below]. This technique, introduced by Watt W. Webb of Cornell University, produces three-dimensional images of living tissue with better clarity and definition than were possible before. A related method images silicon microchips through their plastic packaging by detecting electric currents induced by multiphoton excitations.

Another new form of imaging is T-ray imaging, which uses radiation from the terahertz part of the electromagnetic spectrum. This region, corresponding to wavelengths from 15 microns to one millimeter, lies on the long-wavelength side of the infrared. T-rays can penetrate deeply through many materials that are opaque to shorter wavelengths, such as visible light. In fact, many common materials are relatively transparent to terahertz radiation. Conversely, T-rays can achieve images with finer resolution than is possible with microwaves, which have wavelengths of about a centimeter and up.

In the 1980s David Auston and his co-workers at Columbia University managed to create T-rays by firing ultrashort pulses at specially tailored semiconductor structures. The pulses induce flows of electrons that in turn generate the T-rays. T-rays produced by laser pulses are easier to separate from background radiation and noise and can distinguish layers of very similar material, such as those of different types of soft tissue. For example, T-ray imaging can clearly distinguish between burned and healthy tissues. First demonstrated by Martin Nuss and his colleagues at AT&T Bell Laborato-

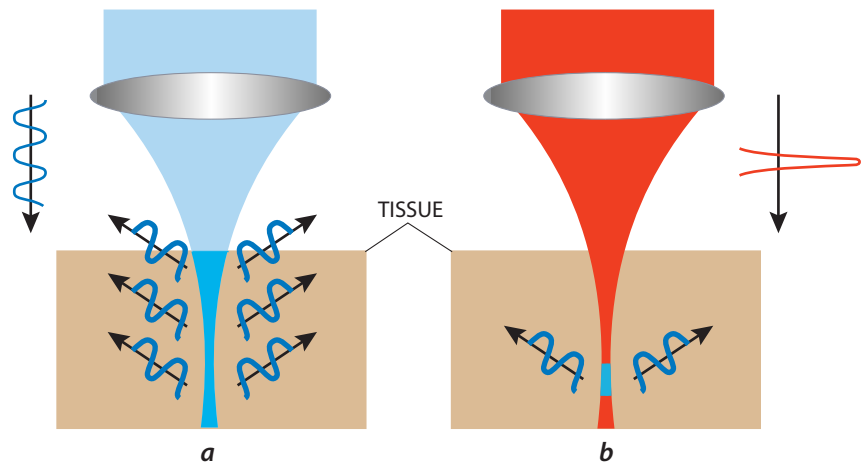
ries (now Lucent Technologies) in 1995, terahertz-pulse imaging is still in its infancy, but researchers have applied it to inspect electronic components and to detect the earliest stages of tooth decay and other diseased tissues. At airports, T-rays might be an effective way to detect ceramic weapons, which are difficult to identify using standard x-ray equipment.

In industry, ultrashort-pulse lasers are proving invaluable for making accurate measurements during the manufacture of highly complex microchips. They monitor the thickness of metal and semiconductor layers without interrupting production, resulting in more efficient fabrication [see “Picosecond Ultrasonics,” by Humphrey Maris; SCIENTIFIC AMERICAN, January 1998]. Another possible commercial application is in telecommunications: in 1997 Nuss and his co-workers at Lucent showed how to use femtosecond pulses to transmit more than 200 data channels through an optical fiber.

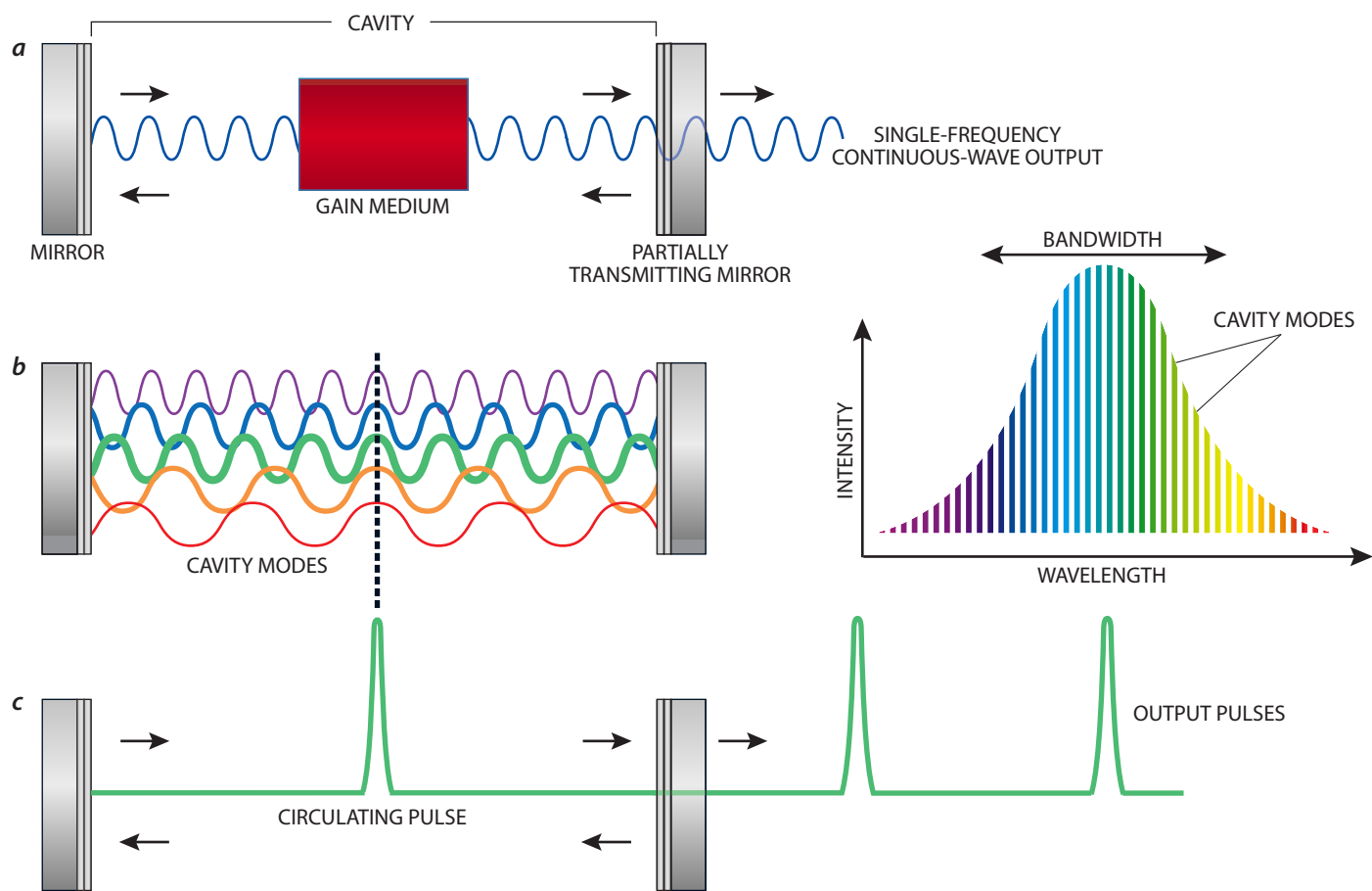
Such applications were out of the question only a decade ago, when femtosecond-pulse lasers were bulky, inefficient and unreliable. Today revolutionary advances have led to dependable, compact femtosecond lasers that can be integrated as an internal component in portable imaging or diagnostic equipment. This revolution in the design of femtosecond-pulse lasers is a story in itself.

The keys to any laser operation are optical amplification and feedback. In the late 1960s rock musician Jimi Hendrix amazed audiences by placing his Stratocaster guitar in front of an amplifier to invoke a wail of sustained acoustic feedback. Earlier in the same decade Theodore H. Maiman of Hughes Research Laboratories in Malibu, Calif., had done something similar with light: he demonstrated that an excited ruby rod placed in a cavity to provide optical feedback could produce an intense beam of laser light. The cavity is nothing more than the space between a pair of mirrors; the rod acts as the gain medium, or optical amplifier [see illustration on next page]. Light bounces back and forth in the cavity, building in intensity. Usually one of the mirrors is partially transmissive, allowing a portion of the light to escape and form the familiar laser beam. The cavity can support only light of certain wavelengths, or modes, that fit a whole number of times between the mirrors. Modes are the optical equivalent of the harmonic notes on each string of Hendrix’s guitar.

LASER-INDUCED FLUORESCENCE for imaging conventionally produces light along all of the beam (*a*). Ultrashort pulses of longer wavelength can improve the image quality by producing fluorescence mainly at the focus of the laser (*b*).



LAURIE GRACE



FEEDBACK AND AMPLIFICATION drive the “lasing” process. Light reflecting back and forth between two mirrors (a) is amplified each time it passes through an excited gain medium. A continuous beam emerges through a partially transmitting mirror at one end. When many different wavelengths, or modes, of light oscillate in the cavity in precise synchrony (b), they add up to produce an intense pulse (c). A periodic sequence of pulses emerges through the partially transmitting mirror.

A well-controlled continuous-wave laser emits a constant beam of light of a color that corresponds to the frequency of one of these modes. A short laser pulse, however, must contain a large range of frequencies, like a chord made up of many notes. (This requirement is related to Heisenberg’s uncertainty principle; shorter pulses must have broader bandwidth, just as a particle confined to a precise location must have a wide spread of possible velocities.) A 10-femtosecond light pulse, for example, has an associated spectrum spanning roughly 100 nanometers. This is a huge range—in visual terms, it would span one third of the wavelengths of light we can see, all the colors from cyan to orange. The red beam of a typical continuous-wave diode laser, in contrast, has a bandwidth of less than a nanometer.

To generate an ultrashort pulse, these many thousands of modes must be locked together in phase. Imagine a row of bells, each of different tone, swinging

in a bell tower. When the bells swing randomly, the result is a steady cacophony. In contrast, when swinging in synchrony at regular intervals, they produce a sequence of loud, equally spaced chords. Similarly, in so-called mode-locked operation, all the light within a laser’s optical cavity is confined to a discrete ultrashort pulse that circulates between the mirrors [see illustration above]. The laser emits a periodic sequence of light pulses through its partially transmissive mirror.

Broadband Gain Crystals

Amplifying a wide range of frequencies requires special broadband gain media. The earliest generation of tunable ultrashort-pulse lasers (ones in which the output frequencies can be varied) used jets of colorful organic dyes dissolved in viscous solvents. These dye lasers tended to be large, complicated and high-maintenance. They typically produced an average output of only a

few milliwatts, despite needing high electrical powers to be run. For producing the shortest pulses (20 to 30 femtoseconds), the performance of dye lasers proved too limited and unreliable for many applications. Also, the dye-solvent combinations were not without their hazards, especially when circulated at high pressure through small nozzles. (The dyes are optically exhausted by each pulse and so must be rapidly refreshed.) Some laser scientists still talk wistfully of their quite literal baptism into the field of ultrashort-pulse research and like to show off the range of dye stains on their lab floor and ceiling!

The first major step toward more user-friendly femtosecond lasers was the discovery of modern broadband crystals that can emit and amplify wavelengths ranging from the visible to the mid-infrared (about 3,000 nanometers). The most popular such material, titanium-doped sapphire, or Ti:sapphire, was developed by Peter Moulton of M.I.T.’s Lincoln Laboratory. Ti:sapphire can amplify wavelengths from about 700 to 1,100 nanometers and can support pulses shorter than four femtoseconds.

A major challenge with these new broadband materials was encouraging the laser to produce a periodic sequence

of pulses, instead of continuous-wave light, by successfully locking the many millions of modes in phase. One of the early techniques for generating ultrashort laser pulses from Ti:sapphire used two optical cavities that were coupled together and precisely matched in length. But while optimizing such a mode-locked laser in 1989, researchers at the University of St. Andrews in Scotland were astonished to see pulses being produced with only one cavity.

Those researchers and several other groups concluded that this self-mode-locking relies on the optical Kerr effect occurring inside the Ti:sapphire crystal. This phenomenon arises because in a transparent material such as glass or Ti:sapphire, light of sufficiently high intensity travels slower than low-intensity light. A laser beam is most intense at its center, so light at the edges of the beam travels faster. The result is equivalent to passing the beam through a convex lens and is called self-focusing, or Kerr lensing, of the laser beam [see illustration below]. This effect can self-mode-lock, or Kerr lens mode-lock, a laser by degrading the amplification of a continuous beam relative to that of a circulating light pulse. The weakened continuous beam is spread over the entire cavity length, and its intensity remains too low to trigger Kerr focusing. A pulse evolves when a momentary large fluctuation of light intensity, part of the optical noise in the cavity, is Kerr focused and therefore highly amplified. The resulting pulse appropriates essentially all the available amplifier energy. In essence, the laser

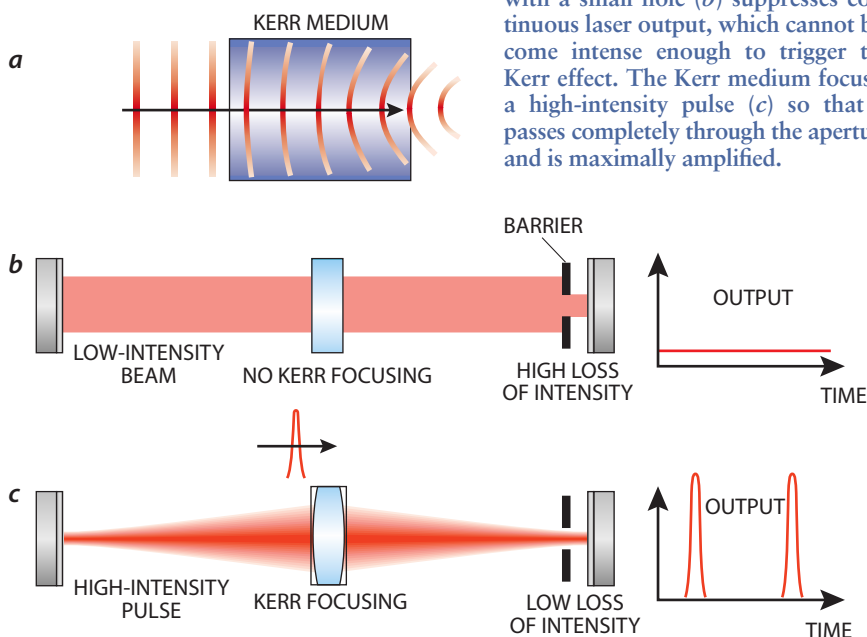
“prefers” to concentrate its energy into such a pulse and promptly locks the modes in phase to achieve it. For the first demonstrations of Kerr lens mode-locking at St. Andrews, the researchers started the pulse evolution process by tapping on one of the cavity mirrors to induce an initial burst of (optical) noise.

The Kerr effect also extends the bandwidth of an evolving pulse, which can be further exploited [see illustration on page 79]. Kerr lens mode-locking produced, for the first time, ultrashort pulses that could be tuned over a broad frequency range, at unprecedented power levels [see top illustration on next page]. The technique has proved to be the simplest, most elegant way to produce femtosecond pulses yet reported. Modern ultrashort-pulse lasers incorporate several refinements but retain the basic simplicity of the mode-locking process.

New Mirrors and Pumps

One significant innovation has been an ingenious type of absorbing mirror made from semiconductors. An absorbing component of these mirrors spoils their reflectivity for low levels of light, but at sufficiently high intensities, the absorber becomes saturated, and the mirror’s reflectivity increases. By reflecting higher intensities more efficient-

OPTICAL KERR EFFECT causes light of sufficiently high intensity to travel slower than low-intensity light. A Kerr medium thus acts like a focusing lens on a beam that has very high intensity at its center (a). A barrier with a small hole (b) suppresses continuous laser output, which cannot become intense enough to trigger the Kerr effect. The Kerr medium focuses a high-intensity pulse (c) so that it passes completely through the aperture and is maximally amplified.



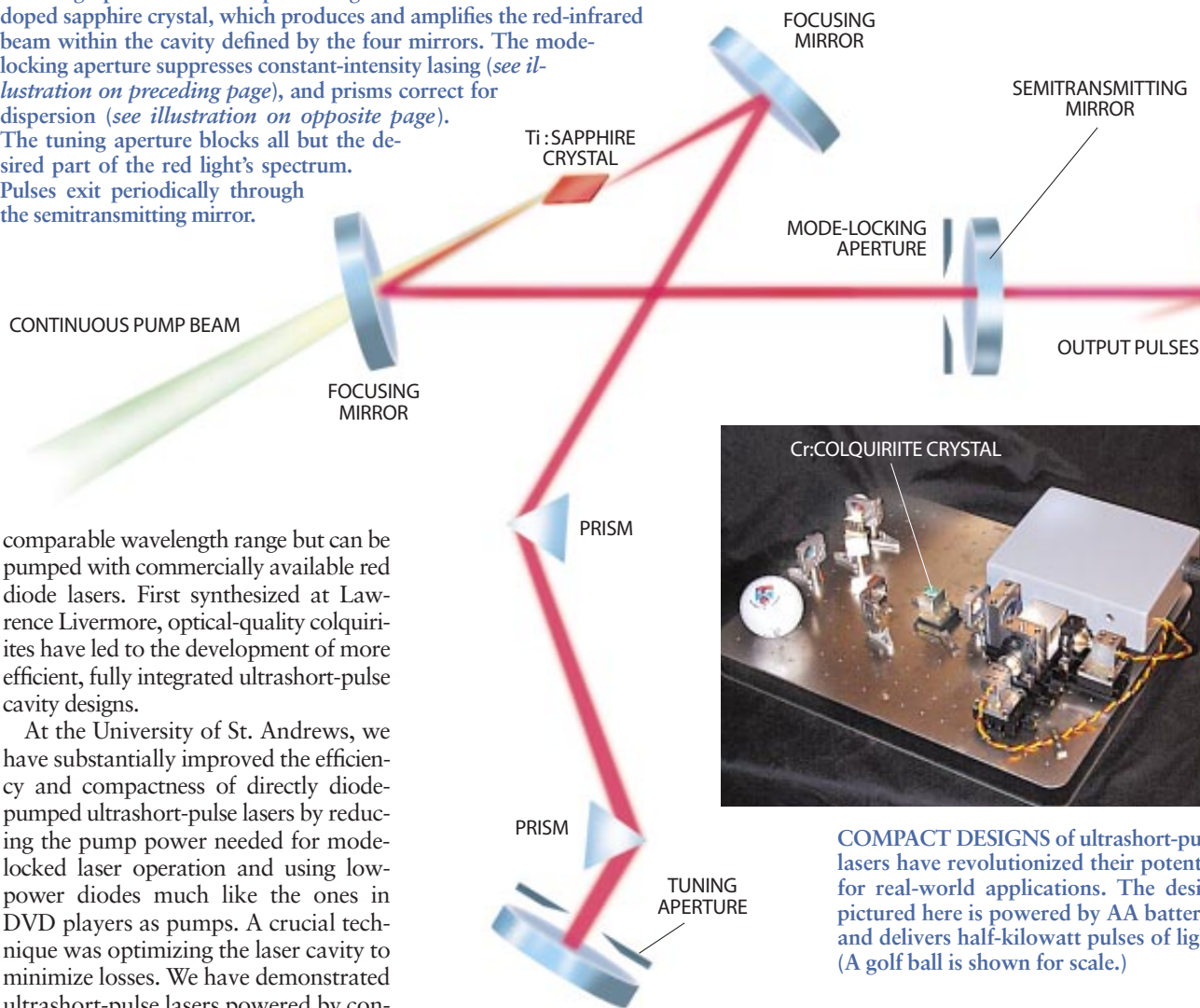
ly, the mirrors favor pulse generation in the cavity over continuous-wave output, much as with Kerr lens mode-locking. The devices have the added advantage that they can initiate the evolution of a pulse from very low levels of background noise within the cavity. In 1991 researchers at AT&T Bell Laboratories first demonstrated such lasers.

The discovery of these modern mode-locking mechanisms made ultrashort-pulse lasers much easier to operate and brought immediate commercial success to femtosecond Ti:sapphire lasers. A number of key improvements still had to be made, however—most notably in the excitation sources, or pumps, for these laser systems. Just as a guitar amplifier needs electrical power, so a laser needs power to amplify the light of its beam. In the case of Ti:sapphire crystals, a continuous-wave pump laser provides this drive power: the pump beam shines into the crystal, exciting atoms that subsequently relax by contributing more light to the pulsed laser beam. Early Ti:sapphire lasers were pumped by argon-ion lasers—big devices that consume tens of kilowatts of electrical power to produce 10 to 20 watts of blue-green light. The expense of operating and maintaining such lasers added to their unattractiveness.

Nowadays we can pump Ti:sapphire and kindred materials with efficient solid-state lasers (which are in turn pumped by compact, high-power diode lasers). These diode-pumped solid-state lasers outclass their argon-ion predecessors in almost every respect: supplying up to 10 watts of green light in a higher-quality beam, occupying less than one tenth of the space, operating off a standard power plug and costing much less to run.

The next step is obvious: remove the intermediate solid-state laser and directly pump an ultrashort-pulse laser with a diode laser. This reduction from three stages to two will reduce device size and further enhance efficiency. Unfortunately, direct pumping of Ti:sapphire is not likely in the near future, because diode lasers with the required wavelengths and output power have not yet been developed. But diodes have pumped a number of other laser crystals, producing output pulses that compare favorably with some Ti:sapphire lasers. A lower-power example is the colquirites, named after the Colquiri tin mine in Bolivia where they were discovered. Chromium-doped colquirites make an excellent alternative to Ti:sapphire, because they oscillate over a

KERR LENS MODE-LOCKED LASER similar to the first one developed produces high-power ultrashort pulses. A green laser beam excites the titanium-doped sapphire crystal, which produces and amplifies the red-infrared beam within the cavity defined by the four mirrors. The mode-locking aperture suppresses constant-intensity lasing (see illustration on preceding page), and prisms correct for dispersion (see illustration on opposite page). The tuning aperture blocks all but the desired part of the red light's spectrum. Pulses exit periodically through the semitransmitting mirror.



comparable wavelength range but can be pumped with commercially available red diode lasers. First synthesized at Lawrence Livermore, optical-quality colquirites have led to the development of more efficient, fully integrated ultrashort-pulse cavity designs.

At the University of St. Andrews, we have substantially improved the efficiency and compactness of directly diode-pumped ultrashort-pulse lasers by reducing the pump power needed for mode-locked laser operation and using low-power diodes much like the ones in DVD players as pumps. A crucial technique was optimizing the laser cavity to minimize losses. We have demonstrated ultrashort-pulse lasers powered by conventional AA-size batteries in which the laser occupied an area smaller than a page of this article [see photograph at right]. A laser of this design produces 100-femtosecond pulses at average powers of around 10 milliwatts. The total power consumption, one watt, is a substantial improvement on the 100 kilowatts used by mode-locked dye lasers that had similar output powers.

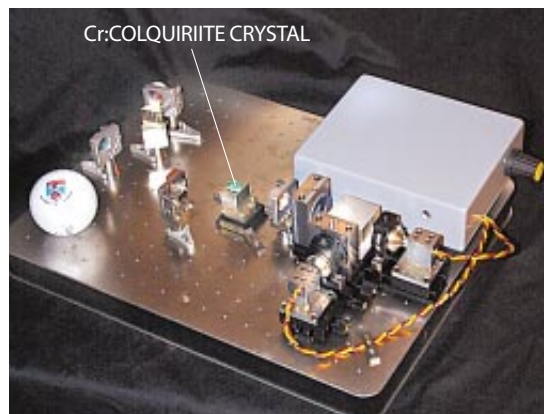
Small fiber lasers can also generate femtosecond pulses if tunability is not required. Fiber lasers use short lengths of doped optical fiber as the gain media. This type of laser provides compact, efficient sources of femtosecond pulses and is ideal for emerging industrial applications. Earlier this year researchers at IMRA America in Ann Arbor, Mich., reported average output powers greater than 10 watts from a femtosecond-pulse fiber laser.

The ultimate in compactness will come when femtosecond pulses are available directly from special laser diodes. For

now, however, the current generation of all-solid-state ultrashort-pulse lasers has permitted these lasers to graduate from specialist laboratories to real-world applications of the type discussed earlier.

Highest Powers

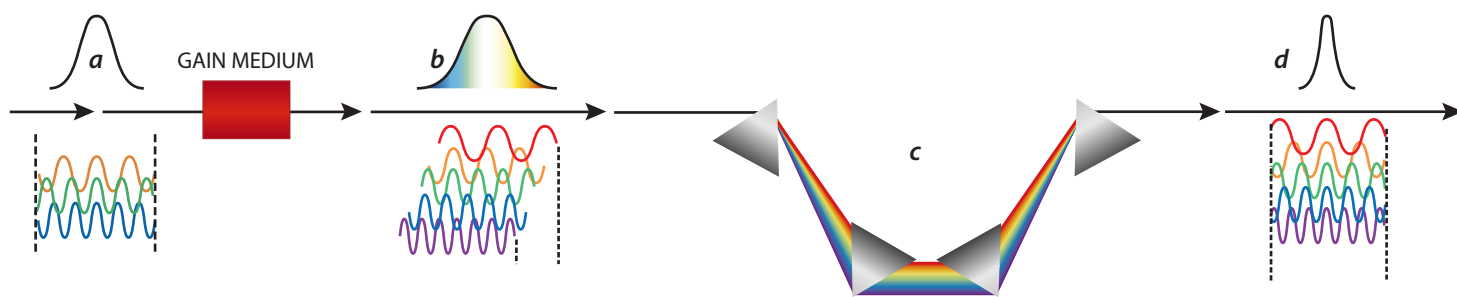
At higher energies the peak intensity of an ultrashort pulse can damage conventional laser optics, changing the properties of the medium and even breaking it down. (In fact, a proposed application of high-power ultrashort pulses is to discharge thunderclouds by ionizing a conducting path in the air.) For a long time, these problems limited focused laser intensities to about 10^{15} watts per square centimeter. In 1985 Gérard A. Mourou and Donna Strickland, then at the University of Rochester, developed a technique, known as chirped-pulse amplification, that overcomes these difficulties. The pulses are



COMPACT DESIGNS of ultrashort-pulse lasers have revolutionized their potential for real-world applications. The design pictured here is powered by AA batteries and delivers half-kilowatt pulses of light. (A golf ball is shown for scale.)

stretched out by a process known as chirping, which lowers their intensity and lets them be amplified by a conventional gain medium. The amplified stretched pulses are then recompressed using sturdy diffraction gratings in a vacuum.

Early designs required many stages of amplification and were confined to large laboratory installations. Today we have benchtop terawatt (10^{12} watts) lasers with output beams that can be focused to extremely high intensities (10^{18} watts per square centimeter). They have been used to create plasmas that in turn produce ultrashort pulses of coherent soft x-rays, which are useful for microscopy and lithography. In the very high electric fields in these plasmas, electrons can start behaving relativistically, opening up new avenues of research in special relativity and quantum mechanics. Nuclear fusion of deuterium has recently been demonstrated at the focus of a tabletop system that pro-



vides 35-femtosecond terawatt pulses.

Large laser facilities have achieved on-target intensities as high as 2×10^{21} watts per square centimeter and peak pulse powers of petawatts (10^{15} watts), 1,000 times greater than the power that is dissipated in a lightning strike. By radiation pressure and other effects, such lasers can accelerate matter at rates of 10^{22} times the earth's gravity—an acceleration much greater than that near a solar-mass black hole! They can provide temperatures and pressures comparable to those inside stars, permitting studies of stellar dynamics. Working with focused intensities of 10^{30} watts per square centimeter, physicists will be able to create matter-antimatter pairs of particles. Such feats will further investigations of quantum electrodynamics, which describes the quantum behavior of charged particles and electromagnetism in the most exacting and intricate detail.

The other frontier is that of shortest pulses. Researchers have used the huge bandwidth of pulses shorter than 10 femtoseconds for precise measurements of optical frequencies. The modes of a mode-locked laser are uniformly spaced in frequency like the teeth of a comb [see illustration on page 76]. Such a “comb” can be used as a standard for measuring frequencies that are hard to evaluate directly. Researchers have used this technique to measure optical atomic energy transitions with precision

INTENSE PULSES EVOLVE under the influence of several effects during each passage through a laser cavity. When an intense pulse (a) passes through a gain medium, the Kerr effect generates waves of shorter and longer wavelengths, and dispersion separates the component waves, lengthening the pulse (b). A system of prisms (c) can undo the dispersion to produce an optimally short pulse after many round-trips (d).

1,000 times greater than ever before. This result provides a new and independent way to determine the fine structure constant, which dictates the strength of the electromagnetic force.

The record for well-characterized short pulses stands at 4.5 femtoseconds, produced from Ti:sapphire lasers. Until now, ultrashort pulses have been understood using a theory in which the envelope of the pulse varies slowly compared with the optical oscillations of the light. Pulses shorter than five femtoseconds have only a few optical cycles in their envelope and push the theory to its limit. Soon we will enter a new regime of physics: pulses with durations comparable to a single optical cycle.

The Future

Ultrashort-pulse lasers spanning a range of powers—more than 17 orders of magnitude—are driving forward many areas of scientific research and industrial applications. From the deep imaging of living tissue to answering fundamental questions about the universe, the shortest man-made events are proving their worth. Just as femtosecond pulses have provided the ability to ob-

serve molecular processes and motions of atoms, so attosecond (one thousandth of a femtosecond) pulses will provide new insights as the motions of electrons, protons and neutrons become directly observable.

The field of ultrafast science and technology will progressively influence all our lives, particularly as biological imaging and laser-based medical procedures continue to develop. The lasers should also produce major new pharmaceutical discoveries, such as how certain drugs function at the chemical level. Other upcoming roles include the coherent control of electric currents in semiconductor devices and in femtosecond networks for digital optical communications.

When the laser was invented, some called it a solution in search of a problem. Today lasers are ubiquitous in consumer technology, from CD players to supermarket checkout scanners. Since their emergence in the mid-1960s, ultrashort-pulse lasers have embarked on a similar journey from the esoteric to the truly practical. Already they provide the preferred solution to an impressive variety of real-world tasks, and in the future they will enhance quality of life and contribute wealth to the world economy. SA

The Authors

JOHN-MARK HOPKINS and WILSON SIBBETT work in the School of Physics and Astronomy at the University of St. Andrews in Scotland. Hopkins won a thesis prize for his work on compact, low-threshold femtosecond lasers in the ultrashort-pulse laser research group that is headed by Sibbett. He received his Ph.D. in 1999 and is now a research assistant in the semiconductor physics group. Sibbett received his Ph.D. from Queen's University in Belfast in 1974 and has been Professor of Natural Philosophy at St. Andrews since 1985. In addition to his groundbreaking laser research, he is active in science policy as a member of the U.K. Engineering and Physical Sciences Research Council. St. Andrews, Scotland's oldest university, was founded 1.86×10^{25} femtoseconds ago, in the year 1410.

Further Information

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ULTRASHORT LIGHT PULSES: LIFE IN THE FAST LANE. Henry Kapteyn and Margaret Murnane in *Physics World*, Vol. 12, No. 1, pages 31–35; January 1999.

TERAHERTZ IMAGING COMES INTO VIEW. Don Arnone, Craig Ciesla and Michael Pepper in *Physics World*, Vol. 13, No. 4, pages 35–40; April 2000.

Who Were the

If your answer was fur-clad mammoth hunters,



The leaf-shaped spearpoint I'm holding is surprisingly dainty—for a deadly weapon. I let my mind wander, trying to imagine life some 14,700 years ago in the marshes of southern Chile, where this relic was found. The 30 or so people who lived there then, at the creekside campsite now known as Monte Verde, were some of the earliest inhabitants of South America—most likely descendants of people who reached North America by crossing the Bering land bridge from Asia at least 15,000 years ago, perhaps more. Did this roving crew realize they were such pioneers? Or are such musings reserved for people who don't have to worry about where to find their next meal?

My thoughts are interrupted by Tom Dillehay, professor of anthropology at the University of Kentucky and the man who in the 1970s uncovered Monte Verde, the oldest known site of human habitation in the Americas. In a basement classroom on the university's campus, Dillehay has spread out a gallery of artifacts from Monte Verde on the table before me. He directs my attention to a fragment of another spearpoint, which, were it still intact, would be virtually identical to the one I'm holding. "These were probably made by the same person," he says.

The misty images of primitive explorers evaporate, and I suddenly picture a single artisan spending hours, perhaps days, crafting these stone tools, each less than four inches long and half an inch wide. The workmanship is exquisite, even to my untrained eye: the series of tiny notches that form the sharp edges are flawlessly symmetrical. Whoever made these tools was clearly a perfectionist.

The question of when people first reached the Americas has been an ongoing discussion in anthropology and archaeology circles for years. Yet how the first Americans actually lived—how my diligent toolmaker spent his (or her?) days—is only now receiving significant attention. The findings at Monte Verde shattered the previously accepted entry date into the Americas, which had been considered to be around 14,000 years ago. (Because of the significance of this shift in thinking, acceptance of the Monte Verde site was a slow process; the archaeological community did not endorse Dillehay's analysis until 1997, when a paper on the site was published in the journal *Science*. A handful of scholars still have reservations about the age of the site.)

First Americans?

guess again. The first people to settle the New World may have been fisherfolk and basket weavers

by Sasha Nemecek, *staff writer*

Excavations under way in the eastern U.S. and throughout South America hint that humans' arrival date may have to be pushed back to as far as 20,000 or even 40,000 years ago. Such discoveries may very well do more than just alter our understanding of how long people have lived in the Americas. With every new artifact, researchers like Dillehay are slowly piecing together more about the day-to-day lives of the early Americans: how they hunted, what plants they ate, how they moved across vast stretches of land—in short, what life was *really* like for those men, women and children who originally settled in the New World.

The canonical view of how humans first reached the Americas can be traced back to 1589, when José de Acosta, a Jesuit missionary to South America, suggested that the original Americans had somehow migrated from Siberia many thousands of years ago. The theory persisted, and by the early part of the 20th century archaeologists had agreed on the identity of the very first Americans. The evidence seemed irrefutable. Archaeological sites dating to approximately 13,000 years ago had turned up all across the landscape; nothing older had yet been found. Moreover, the tools from these sites shared striking similarities, as though the people who created them had a common cultural background and had all moved onto the continent together. Researchers termed these people and their culture “Clovis” (after Clovis, N.M., where the first such artifact was found). Clovis spearpoints, for instance, can be found in Canada, across the U.S. and into Central America.

In certain parts of the U.S., particularly the desert Southwest, these Clovis points are nearly as common as cacti. Why would the Clovis people have needed so many weapons?

MAMMOTH HUNTER OR FISH CATCHER? Archaeologists had concluded that the first inhabitants of the New World were fur-clad big-game hunters who swept across the Bering land bridge in pursuit of their prey. But recent evidence suggests that the first settlers may have been just as likely to hunt small game, catch fish or gather plants as they moved through more temperate environments. One of the oldest human artifacts found in the Americas—a small spearpoint from a 14,700-year-old campsite in Chile—is pictured above.



Again, the answer seemed clear. They must have been voracious hunters, following their prey—big game animals like the woolly mammoth—across the Bering land bridge around 14,000 or 15,000 years ago, when the ice sheets extending from the North Pole had melted just enough to open a land passageway through Canada. The hunters pursued the animals relentlessly, taking around 1,000 years to spread through North and South America. The emphasis on hunting made sense—this was the Ice Age, after all, and meat from a mammoth or bison provided lots of much needed fat and protein for the entire family. And the fur hides could be fashioned into warm clothes.

Thomas Lynch, an expert on Clovis culture and director of the Brazos Valley Museum of Natural History in Bryan, Tex., points out another advantage: “The easiest way to get food is by hunting big game, in particular herding animals. And at first, the animals would not be afraid of humans.” A quick sweep across the continent fits the pattern as well, Lynch argues, remarking that the hunters would have had to move fast “as the animals got spooked by humans.”

The idea that the first Americans were Ice Age hunters has been accepted for decades, filling pages in both textbooks and scientific journals. But researchers have increasingly pointed to holes in the theory. David Meltzer, a professor of anthropology at Southern Methodist University who has studied Clovis culture extensively, suggests that this view of the first settlers is too simplistic, relying as it does on a stereotype that “people worked their way through the continent gnawing on mammoth bones.” With closer scrutiny, he says, “this just doesn’t hold up.”

Meltzer contends that the small bands of 15 to 30 people, typical of nomadic tribes, were essentially always at risk of dying out, either from inbreeding or some sort of catastrophe. Hunting a mammoth was, of course, extremely dangerous, possibly even too perilous for these groups to have relied on it as their sole source of food. So they must have turned to other sources, particularly small game, nuts and berries, and maybe even fish and turtles. Indeed, a few archaeologists have discovered the remains of smaller animals, including deer, rabbits and snakes, at Clovis sites. Unfortunately, though, the technology associated with small-game hunting, fish-

EARLY SITES IN THE AMERICAS

BERING LAND BRIDGE THEORY

Migrants from northeastern Asia crossed the land bridge between Siberia and North America, which existed during the last Ice Age, when sea levels were much lower. The settlers moved into Canada through an ice-free corridor between the two glaciers that covered the northern half of the continent at the time. This route funneled them into the U.S.; they advanced quickly through Central and South America. For the past several decades this has been the prevailing theory of how people reached the New World.

PACIFIC COASTAL ROUTE THEORY

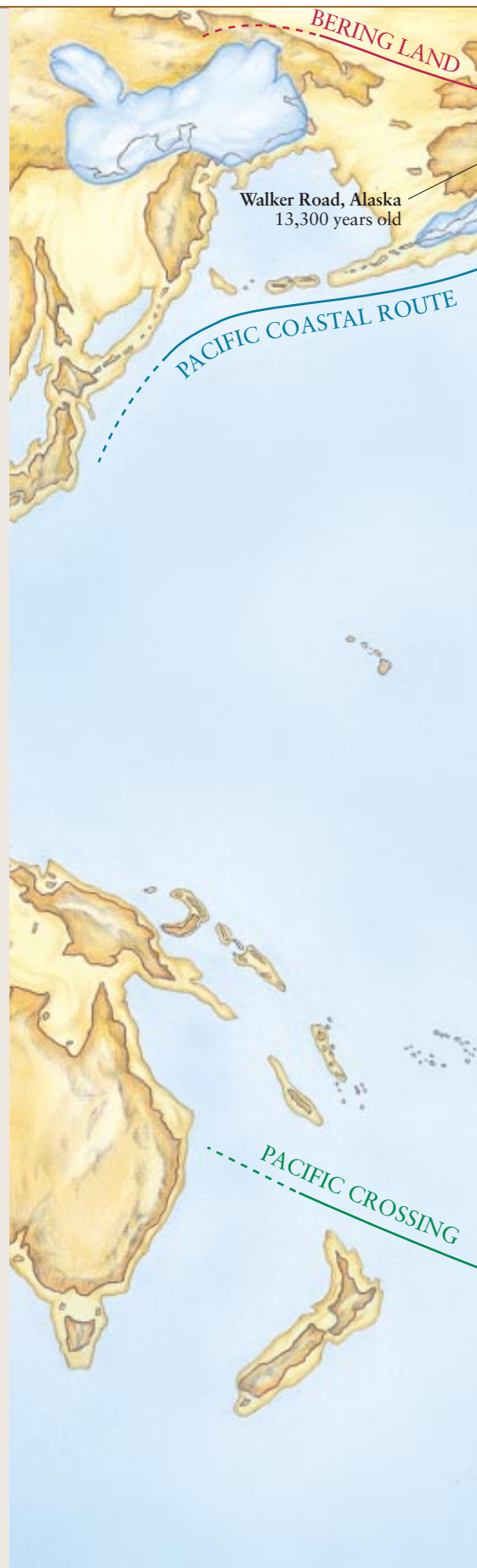
As an alternative to the Bering land bridge theory, many researchers have begun to consider the idea that explorers from southeastern Asia followed the coastline in small boats. Scientists believe this mode of travel could have enabled the early settlers to reach the tip of South America in as little as 100 years.

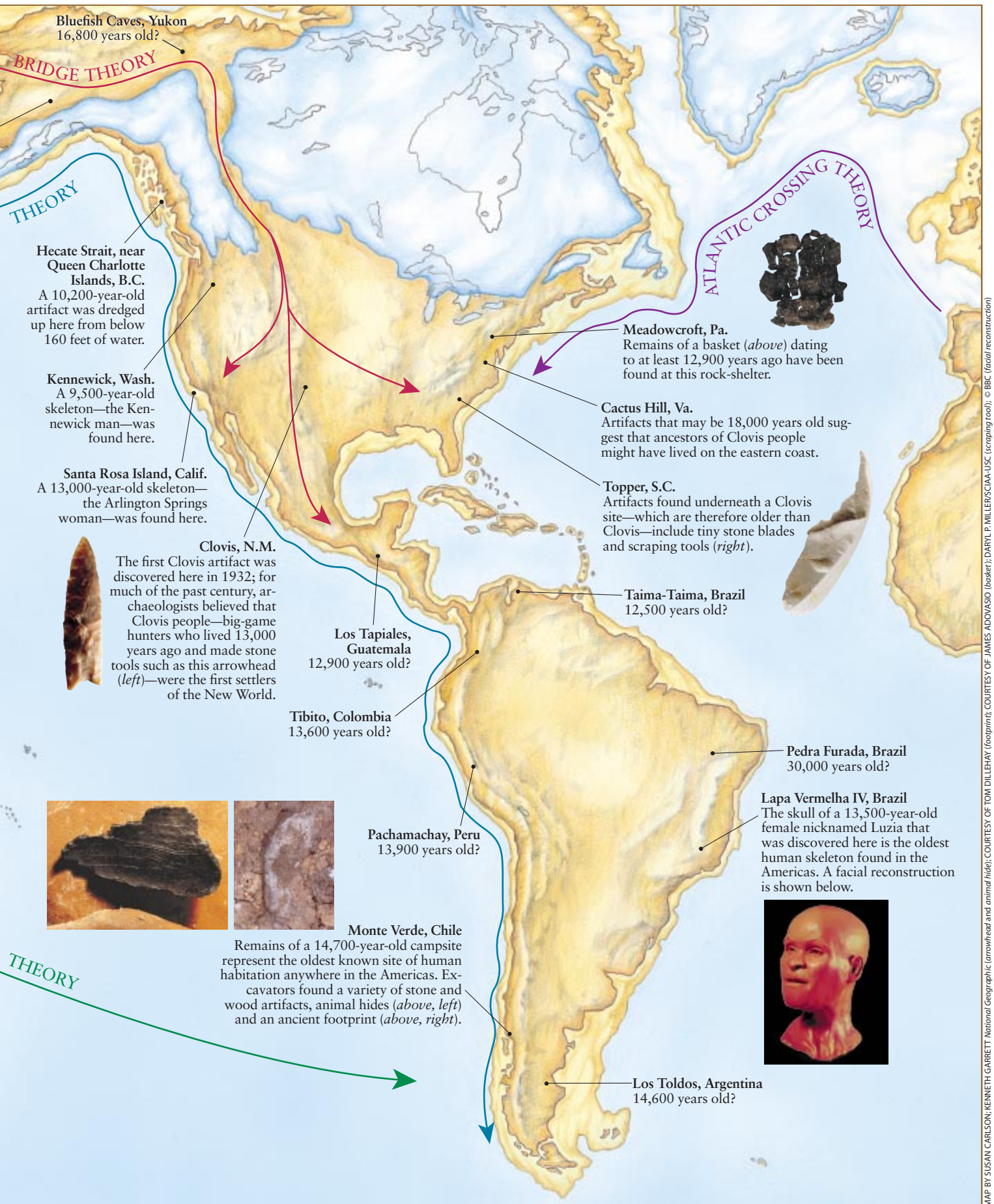
PACIFIC CROSSING THEORY

Inhabitants of Australia and the islands of the South Pacific might have continued traveling east, eventually reaching South America. Evidence for this scenario is scarce.

ATLANTIC CROSSING THEORY

Residents of the Iberian peninsula may have ventured into the Atlantic in boats, following the edge of the glaciers that then covered the North Sea. This theory remains tentative, relying on an observed similarity between Clovis spearpoints and European Solutrean technology from between 16,000 and 24,000 years ago.





MAP BY SUSAN CARLSON; KENNETH GARRITT, National Geographic (arrowhead and animal hide); COURTESY OF TOM DILLEHAY (footprints); COURTESY OF JAMES ADOVASIO (basket); DARYL P. MILLER/SCIAA-USC (scraping tool); © BBC (facial reconstruction)

ing and gathering—the wooden tools, nets and baskets—generally don't survive as well as stone artifacts do.

One site in Pennsylvania, however, has yielded just these kinds of remains. James Adovasio, an archaeologist at Mercyhurst College, has spent almost 30 years excavating Meadowcroft Rockshelter southwest of Pittsburgh, where early settlers set up camp at least 12,900 years ago. He has found baskets that he believes would have been used to carry plants or even mussels from the nearby Ohio River. Adovasio has also uncovered parts of snares for catching

small game, and bone awls for working textiles and hides.

For much of the past three decades, other archaeologists have disputed Adovasio's interpretation of these finds; even today some question the antiquity of the site, although a recent analysis of the site by an outside researcher may help resolve the issue. "We have found bone needles, and people would say, 'Oh, they used them to sew hides.' But you and I know they would snap!" Adovasio insists. Instead, he argues, these needles must have been for weaving lightweight fabrics made from plant material. "People make the mistake of thinking

the Ice Age was cold all the time. They remember the 40,000 Januarys but forget the 40,000 Julys," he laughs.

And just who was sewing clothes for the warmer weather? Adovasio complains that the official mammoth-centric picture of early Americans completely neglects the role of women, children and grandparents. He points to the icon of the Ice Age hunter with his stone spears: "By focusing only on stones, we are ignoring 95 percent of what these people made and what they did." Look at more recent hunter-gatherer societies, he says. Women, children and older people of both sexes supply the vast majority of the food and carry out vital tasks such as making clothes, nets and baskets. Why would the earliest Americans have been any different?

Margaret Jodry, an archaeologist at the Smithsonian Institution, also cautions against overlooking the issue of how families traveled through the New World. Conventional wisdom has the Clovis people walking the entire way. But, Jodry asks, what about Clovis sites that have been found on both sides of a river? "Unless we're suggesting they would swim across" the river every day just to get home, she says incredulously, they must have relied on boats for transportation. "How are you going to swim the Missouri River with Grandma, your wife who's eight months pregnant, your kids and dogs?" Furthermore, she points out, humans had developed watercraft by at least 40,000 years ago, because by then they were in Australia.

Early American boats would have been constructed from animal skins or wood—again, fairly ephemeral substances. But Jodry thinks that archaeologists might be able to find distinct signatures of the boatbuilding process. Based on her observations of construction techniques used by modern indigenous groups of North America, she has proposed archaeological markers—a certain configuration of post holes encircled by stones, for instance—that might represent an ancient workshop for assembling boats.

In response to these novel lines of reasoning, archaeologists are beginning to change how and where they dig. Jodry reports that some colleagues have told her they plan to revisit previously excavated sites, looking for evidence of boats. And finds at Meadowcroft and elsewhere have prompted archaeologists to hunt for more than just stones and bones. (At Monte Verde, Dillehay found

ARCHAEOLOGY'S DATING GAME

MATCHING RADIOCARBON DATES TO THE CALENDAR

The complex question of when people first reached the Americas is further complicated by a problem with dates. Archaeologists generally rely on radiocarbon dating to determine the age of such artifacts as bones, charcoal or wood. But one radiocarbon year isn't always the same as one calendar year.

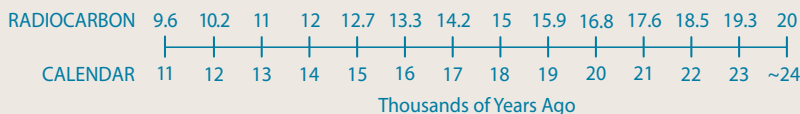
Radiocarbon dating works because all living things absorb carbon. Specifically, they take up two isotopes: carbon 14 and carbon 12. (Isotopes of an element have the same number of protons inside the atomic nucleus but different numbers of neutrons.) While an animal or plant is alive, the ratio of carbon 14 to carbon 12 in its tissues reflects the ratio present in the atmosphere. Once it dies, the ratio changes.

Carbon 14 is radioactive (but not dangerous) and undergoes radioactive decay; carbon 12 is stable. During a creature's lifetime, processes such as breathing replenish carbon 14. After death, however, the amount drops, and the ratio between carbon 14 and carbon 12 falls as well. Scientists know the rate at which carbon 14 decays, and by assessing how much has been lost compared with carbon 12, they can determine the age of an object.

Notably, the ratio of carbon 14 to carbon 12 in the atmosphere is not constant, which alters the baseline for calibrating dates. To match radiocarbon years to calendar years, researchers have turned to independent timescales based on tree rings, ice cores and uranium-thorium dating.

Unfortunately for scientists studying the peopling of the Americas, the period between 10,000 and 20,000 years ago has been difficult to calibrate. For many years archaeologists simply presented their results in uncorrected radiocarbon years. Recent findings, however, make it easier to adjust dates from this era. All the dates in this article have been calibrated to calendar years (for information on the calibration program, go on-line at www.rlaha.ox.ac.uk/orau/).

The distinction between radiocarbon years and calendar years is important. A report earlier this year described a 13,000-year-old skeleton found in California and compared it to 12,500-year-old Monte Verde, without mentioning that the former date was in calendar years and the latter, radiocarbon years. Some readers understandably thought that the California skeleton was older than the campsite at Monte Verde. But in calendar years, Monte Verde is 14,700 years old. —S.N.



RADIOCARBON YEARS before the present (*top*) must be translated into calendar years before the present (*bottom*). For example, an artifact that is 11,000 radiocarbon years old is actually 13,000 calendar years old.

JENNIFER JOHANSEN

knotted cords that he thinks were used to secure tents made of animal hides; remains of the tents turned up as well.)

But they'll have to change the types of sites they look for, according to Dillehay. "People concentrate on caves and open-air sites," he explains, where preservation of delicate artifacts is unlikely. "If you want to find another Monte Verde"—where a layer of peat from the nearby swamp covered the campsite and prevented oxygen from reaching the remains—"you've got to look where wet sites are preserved," he says.

This newfound emphasis on softer artifacts should help to substantiate the emerging picture of the first Americans as people with an intricate knowledge of their environment, who could not only spear a mammoth once in a while but who also knew how to catch fish, pick the right berries, weave plant fibers into clothes and baskets, and build boats for local travel.

And as researchers cast a wider net for artifacts, they may have to consider a range of explanations for what they find. Texas A&M University archaeologist and Clovis specialist Mike Waters notes that when the archaeological community accepted the 14,700-year-old date for Monte Verde just three years ago, the recognition "jump-started the whole debate about Clovis being first." As scholars digest the evidence from Monte Verde, they have been rethinking many long-held ideas on who populated the Americas and when and how they got here [see map on pages 82 and 83]. For his part, Waters maintains three working hypotheses: that the Clovis people were in fact the first in the Americas, that there was a smattering of people in North America before Clovis but they left almost no trace or that there was a large pre-Clovis occupation we have yet to identify.

Transportation to the New World is a big topic for debate. If the early Americans did cruise around the continent in canoes and kayaks, might the first settlers have arrived by boat as well? For decades the archaeological community rejected this notion (Ice Age hunters could never have carried all their weapons and leftover mammoth meat in such tiny boats!), but in recent years the idea has gathered more support. One reason for the shift: the nagging problem of just how fast people can make the journey from Alaska to Tierra del Fuego.



MONTE VERDE in Chile—home to around 30 people some 12,500 years ago—is the oldest known site of human habitation in the Americas. Archaeologist Tom Dillehay (*standing*) and his colleagues have uncovered a variety of human artifacts from this ancient camp, which is not far from the Andes and the Pacific Ocean.

Consider Dillehay's 14,700-year-old Monte Verde site. According to the previously accepted timeline, people could have made the journey from Asia on foot no earlier than 15,700 years ago (before this time, the ice sheets extending from the North Pole covered Alaska and Canada completely, making a land passage impossible). If this entry date is correct, the Monte Verde find would indicate that the first settlers had to make the 12,000-mile trip through two continents in only 1,000 years. In archaeolog-

won't be easy to prove. Rising sea levels from the melting Ice Age glaciers inundated thousands of square miles along the Pacific coasts of both continents. Any early sites near the ocean that were inhabited before 13,000 years ago would now be deep underwater.

Recently a few enterprising researchers have attempted to dredge up artifacts from below the Pacific. In 1997, for example, Daryl Fedje, an archaeologist with Parks Canada (which runs that country's national parks system), led a

"People make the mistake of thinking the Ice Age was cold all the time."

ical time, that's as fast as Marion Jones.

One way to achieve this pace, however, would be by traveling along the Pacific coastlines of North and South America in boats. Knut Fladmark, a professor of archaeology at Simon Fraser University in Burnaby, B.C., first suggested this possibility in the 1970s and remains an advocate of a coastal entry into the Americas. If people had a reason to keep moving, he says, they could have traversed both continents in 100 years. Fladmark estimates that traveling at a rate of 200 miles a month would have been quite reasonable; the settlers no doubt stopped during winter months and probably stayed in some spots for a generation or so if the local resources were particularly tempting.

Fladmark's theory, though enticing,

team that pulled up a small stone tool from 160 feet underwater just off the coast of British Columbia. The single tool, which Fedje estimates to be around 10,200 years old, does establish that people once lived on the now submerged land but reveals little about the culture there.

Excavating underwater sites might turn out to be the only way to prove when humans first arrived on this continent. And for many researchers this is still a very open question, with answers ranging from 15,000 years ago to as far back as 50,000 years ago. When Fladmark first proposed the idea of a coastal migration, the entry date of 14,000 or 15,000 years ago was orthodox. But many researchers have since speculated that humans must have been

in the Americas for much, much longer.

Which brings me back to my skilled spearpoint designer from Monte Verde. Although his ancestors theoretically could have made it to the southern tip of Chile in just 100 years if they traveled in watercraft, practically speaking, the group wouldn't then have had much time to adapt to the new surroundings.

And for Dillehay, this distinction between theory and reality is crucial: The people living at Monte Verde 14,700 years ago, he says, "knew exactly where

probably requires several generations at least. Precisely how long the folks at Monte Verde would have needed to gain such an understanding, though, is difficult to estimate. The arrival of modern humans into an unpopulated continent has happened only twice—in Australia and in the Americas—so we have little by way of reference. But Dillehay looks at the issue in a broader context. In places like the Indus Valley and China, it took tens of thousands of years for complex civilizations to arise. He re-

mate that the ancestors of the former left Siberia for the New World at least 30,000 years ago.

These ancient dates—if they are correct—would have important implications. Experts on human origins believe that behaviorally modern humans left Africa for Europe and Asia around 50,000 or 60,000 years ago. So as archaeologists push back the arrival date of humans in the Americas, they move the peopling of the New World into the larger story of human evolution. As

Robson Bonnicksen, director of the Center for the Study of the First Americans at Oregon State University, has written, the occupation of the Americas should be "understood in respect to

the process that led to the global expansion of modern humans."

Some evidence links the settling of the Americas to the migration of modern humans out of Africa. In perhaps one of the most startling finds of recent years, Walter Neves of the University of São Paulo determined that the oldest skeleton ever found in the Americas—a 13,500-year-old adult female from southeastern Brazil—resembles Africans and Australian aborigines more than modern Asians or Native Americans. Neves interprets this result (and similar ones from some 50 skulls dated to between 8,900 and 11,600 years old) to mean that non-Mongoloid migrants were among the first in the Americas.

Neves is quick to point out, though, that he does not think these people came directly from Africa or Australia but that they splintered off from the band moving slowly through Asia that eventually went south to Australia. According to the fossil record, Mongoloid groups arrived in South America around 9,000 years ago, where they appear to have replaced the previous population. "I don't have an answer for [what happened]," Neves says. "Maybe war, maybe killing, maybe they were absorbed" by all the intermixing that was surely going on, he suggests.

So it seems the New World has been a smelting pot for millennia. Those famous Ice Age hunters no doubt did cross the Bering land bridge at some point and head onto the continent. But they probably were not the first ones to do so, and they most certainly were not the only ones. Thanks to recent archaeological finds, researchers are beginning

Some evidence links the settling of the Americas to the migration of modern humans out of Africa.

they were positioning themselves." They had been in the region long enough to set up camp on prime real estate, within an hour's walk of nearby wetlands, lush with edible plants. The ocean and the Andean foothills were both about a day's walk away. The group had carefully situated itself close to three different environments, all of which provided them with food and supplies.

Dillehay has found desiccated cakes, or "quids," of seaweed that the people sucked on, probably for the high iodine content in the plants (the quids are almost perfect molds of the top of a person's mouth—down to the impressions of molars). And based on the mastodon bones found at the site, Dillehay believes that the Monte Verdeans either killed or scavenged animals trapped in the nearby bogs. He also suspects they used rib bones from the animals as digging sticks to unearth tubers and rhizomes from the surrounding marshes.

Such elaborate knowledge of one's environment does not come quickly; it

marks that unless Americans were "the most remarkable people in the world"—setting up the beginnings of civilization in only a couple thousand years—they must have been here for much longer. Dillehay suggests that an arrival time of around 20,000 years ago would have given the first Americans ample time to put down the roots of civilization.

Such an early entry date is bolstered by two other lines of evidence. Linguist Johanna Nichols of the University of California at Berkeley argues that the amazing diversity of languages among Native Americans could have arisen only after humans had been in the New World for at least 20,000 years—possibly even 30,000. Geneticists, including Theodore Schurr of the Southwest Foundation for Biomedical Research in San Antonio, Tex., and Douglas Wallace of Emory University, present a related argument based on genetic diversity. By comparing several DNA markers found in modern Native Americans and modern Siberians, Schurr and Wallace esti-



HUMAN ARTIFACTS found at Monte Verde, Chile, include a wooden digging stick (left) and remnants of logs that helped anchor the tents where the 30 or so residents lived (above).



to figure out what life was like for some of the other people here—the fisherfolk boating along the Pacific coast, the hunter-gatherers living in the temperate forests of North and South America.

In the meantime, investigators can't dig fast enough to keep pace with the rapid shifts in our knowledge of who the first Americans were. Archaeologists are scouring Alaska for remains of early inhabitants; geologists are trying to determine exactly when the glaciers melted enough for settlers to start moving into central Canada and the U.S. Others continue hunting for even earlier signs of Clovis in the U.S. The eastern U.S. is home to several important ongoing excavations: Cactus Hill in Virginia and Topper Site in South Carolina. Preliminary finds at Cactus Hill suggest that a group possibly related to the Clovis people may have lived in the area around 18,000 years ago.

Al Goodyear, an archaeologist at the University of South Carolina, went back to a Clovis site at Topper, near the Savannah River, to see what was underneath (and thus older). The results surprised him: artifacts in the deeper layers at Topper are completely unlike Clovis technology. He has found no Clovis-type

EARLY MIGRANTS to the New World may have traveled in small boats, which were probably made from animal skin or wood. Archaeologists know that humans had developed watercraft by 40,000 years ago because by then they were in Australia.

spearpoints, only tiny stone blades and scraping tools thought to be associated with the use of wood, bone and antlers.

Goodyear recounts how he “went into a mild state of shock” when he realized just how difficult it would be to explain who these people were. This summer he brought in two experts on determining the age of archaeological sites, Waters of Texas A&M and Tom Stafford of Stafford Research Laboratories in Boulder, Colo., the leading carbon-14 dating facility in the country. The team is still unsure of how old the tools are—as Stafford says, they could be from just 100 years before Clovis—but the analysis continues. Goodyear hopes eventually to excavate in a nearby marshy area, where conditions should be more suited to the preservation of delicate items such as wooden tools or clothing fibers.

Other investigators working at sites in South America, including Dillehay, have described camps that could be as old as 30,000 years. Dillehay himself, however, is cautious about these dates, saying more spots must be found from this era before researchers can be certain these

highly contested numbers are correct.

But he has little doubt on another point: that the individuals who lived at Monte Verde and throughout the New World—whenever it was truly new—were part of “one of the most intricate, thrilling and inspiring episodes of the human adventure.” In his book *The Settlement of the Americas* (Basic Books, 2000), he describes the expansion into new environments as the “high adventure that gave people a strong sense of mission”—analogous to having our space program continue for thousands of years.

But isn't this sort of self-awareness rather too modern? Wasn't the main adventure for these people trying to stay alive? Dillehay thinks perhaps they had more on their minds. “People pick the same good campsites over and over—rock-shelters, overlooks,” he says, so it wouldn't have been strange to see the remains of previous inhabitants. “But there must have been some point when people realized that no one had been there before,” he adds. “When they realized, ‘We are the first.’”

A firsthand account
by renowned engineer

Robert Silman

Perched on a hillside in southwestern Pennsylvania, about 72 miles from Pittsburgh, is one of the world's most famous houses. Fallingwater, the stunning creation of architect Frank Lloyd Wright, has been an American icon since its construction in 1937. More than two million tourists have visited the site and stared in awe at the building's concrete terraces hanging over a clear, swift-running stream. Architecture critics have extolled Fallingwater as Wright's greatest achievement. In fact, in 1991 the American Institute of Architects voted it the best work ever produced by an American architect.

Yet this incomparable structure has a critical flaw. Wright's design did not provide enough support for the portion of the house that hangs over the stream. As a result, Fallingwater's famed terraces began to droop as soon as they were built, causing large cracks to appear in the concrete. What is more, the sagging gradually increased over the next six decades. In 1995 the Western Pennsylvania Conservancy, which owns Fallingwater, was concerned enough to hire our engineering firm, Robert Silman Associates in New York City, to examine the house's structural problems. The results of our investigation indicated that the beams supporting the house were continuing to bend and that the building would eventually collapse into the stream below if nothing was done.

In 1996 the conservancy prudently decided to shore up Fallingwater with temporary steel beams and columns. At the same time, our office began to draw up a plan to permanently repair the house. We had previously worked on two other buildings designed by Wright—the Darwin D. Martin House in Buffalo, N.Y., and Wingspread in Racine, Wis.—but Fallingwater posed a unique challenge. To determine how to relieve the stresses that were threatening the house, our engineers probed the building with radar and ultrasonic pulses, then performed a rigorous structural analysis. Along the way we also tried to retrace the thinking of Wright and his apprentices. We now have a plausible theory to explain how the design of Fallingwater went awry.

The story of Fallingwater begins with Edgar Kaufmann, Sr., who owned a successful department store in Pittsburgh in the 1930s. His son, Edgar Kaufmann, jr. (he always spelled “junior” with a lowercase “j”), spent a short time as an apprentice in Wright's studio at Taliesin, the architect's estate in Spring Green, Wis. Kaufmann, jr., convinced his father to retain Wright to do some work at the store and later to design a weekend house for the family on a site that had formerly been

The Plan to Save Fallingwater

*This breathtaking house designed by
Frank Lloyd Wright was in danger of
collapse until an engineering firm found
a way to stop it from falling down*





a summer recreation camp for the store's employees.

The wooded property features a small stream known as Bear Run that cascades over a series of rocky ledges. The Kaufmanns had always assumed that their house would be located downstream from the ledges, at a point where the waterfalls could be viewed from below. But it was Wright's genius to site the house *above* the falls, on top of a large sandstone ledge that overlooks the stream. The building was designed in 1935, and construction started in 1936. The design work was conducted at the Taliesin studio, with Wright's apprentices Bob Mosher and Edgar Tafel participating significantly. The structural calculations for Fallingwater were done in the same studio by engineers Mendel Glickman and William Wesley Peters.

Wright and his apprentices designed

the house so that the section over Bear Run acts as a cantilever. Like a diving board, it has a fixed end and a free end. The fixed end consists of four large bolsters, three of reinforced concrete (that is, concrete with steel bars embedded in it) and one of stone masonry. These bolsters rise from the sandstone ledge to the building's first floor [see *illustration on pages 92 and 93*]. Each one supports a horizontal reinforced-concrete beam that extends some 4.42 meters (14.5 feet) beyond the bolster, jutting southward over the stream. The beams are connected to one another by concrete joists, each 100 millimeters (four inches) wide. Together the beams and joists create a rectilinear grid. Above this grid are wooden two-by-fours and planking, which support the stone floor of the house's living room and the first-floor terraces.

Beneath the joists and cantilever beams

is a concrete slab that serves as the finished underside of the structure. Wright chose this design to give the house's exterior a monolithic look, but it also had a structural purpose. In engineering terms, a cantilever has a negative bending moment—the load at the free end of the horizontal beam is resisted by tension in the beam's upper side and by compression in the lower side. (In contrast, a bookshelf has a positive bending moment—the weight of the books is resisted by compression in the shelf's upper side and by tension in the lower side.) Wright's decision to put the concrete slab under the cantilever beams turned them into inverted tee beams—each shaped like an upside-down T—thereby raising their resistance to compression and enabling them to support a greater load.

Fallingwater has more than one cantilever, though. Terraces extend from



INTERIOR VIEW of Fallingwater's living room shows the stone floor that rests on the house's cantilever beams. The windows at the south end of the room are divided by four steel mullions that help support the weight of the second floor.

out than the first floor does, extending an additional 1.83 meters (six feet) southward [see left illustration below]. Four T-shaped window mullions rise from the south edge of the living room to the terrace above. At first glance these steel mullions appear to be merely decorative, but we would eventually learn that they, too, play a key role in Fallingwater's structure.

Concerns about the soundness of Wright's design arose even before construction started. Metzger-Richardson, the Pittsburgh engineering firm that supplied the steel bars for the reinforced concrete, insisted that there were not enough bars in the cantilever beams below the living room. To make the beams strong enough to resist bending under their load, the firm doubled the number of one-inch-square bars in each beam from eight to 16. Wright was furious when he learned about the change. He believed that the additional steel bars would increase the weight of the beams too much and thus weaken the structure. In an angry letter to Kaufmann, Sr., he wrote: "I have put so much more into this house than you or any other client has a right to expect, that if I don't have your confidence—to hell with the whole thing."

Kaufmann, Sr., appeased his architect by asserting his confidence in him. But Wright was clearly wrong about the cantilever beams: if Metzger-Richardson had not slipped in the extra steel bars, the beams surely would have failed. Even the greater amount of reinforce-

the east and west sides of the first floor, supported by concrete joists under their floors and by edge beams in their parapets. And on the building's second floor, directly above the living room, the master bedroom terrace juts farther

ment was not enough, as the builders discovered during Fallingwater's construction. When workers removed the wooden formwork from beneath the concrete of the first floor, they recorded an instantaneous downward movement of 44.5 millimeters. It is not unusual for a small amount of deflection to occur when the scaffolding is removed from a concrete structure, but in this case the bending was especially pronounced. Mosher, the apprentice on site, telephoned Glickman at the studio in Taliesin. After a quick check of his calculations Glickman is reported to have exclaimed, "Oh my God, I forgot the negative reinforcement!"

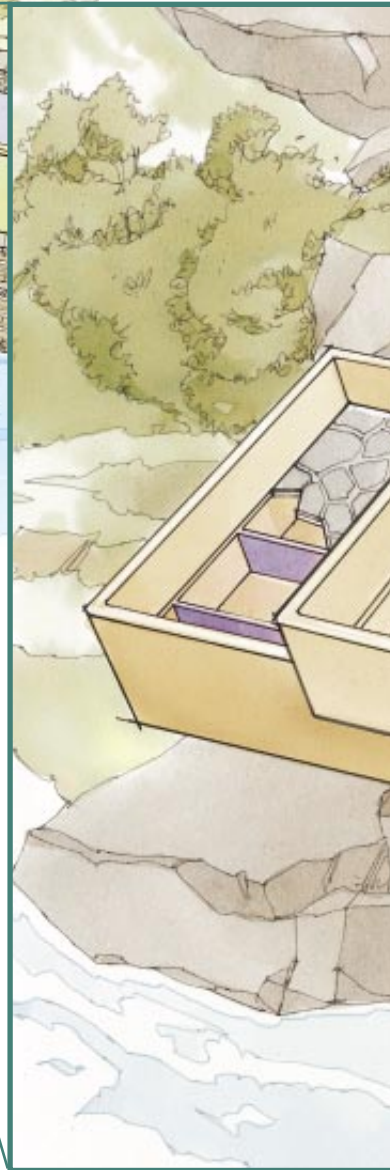
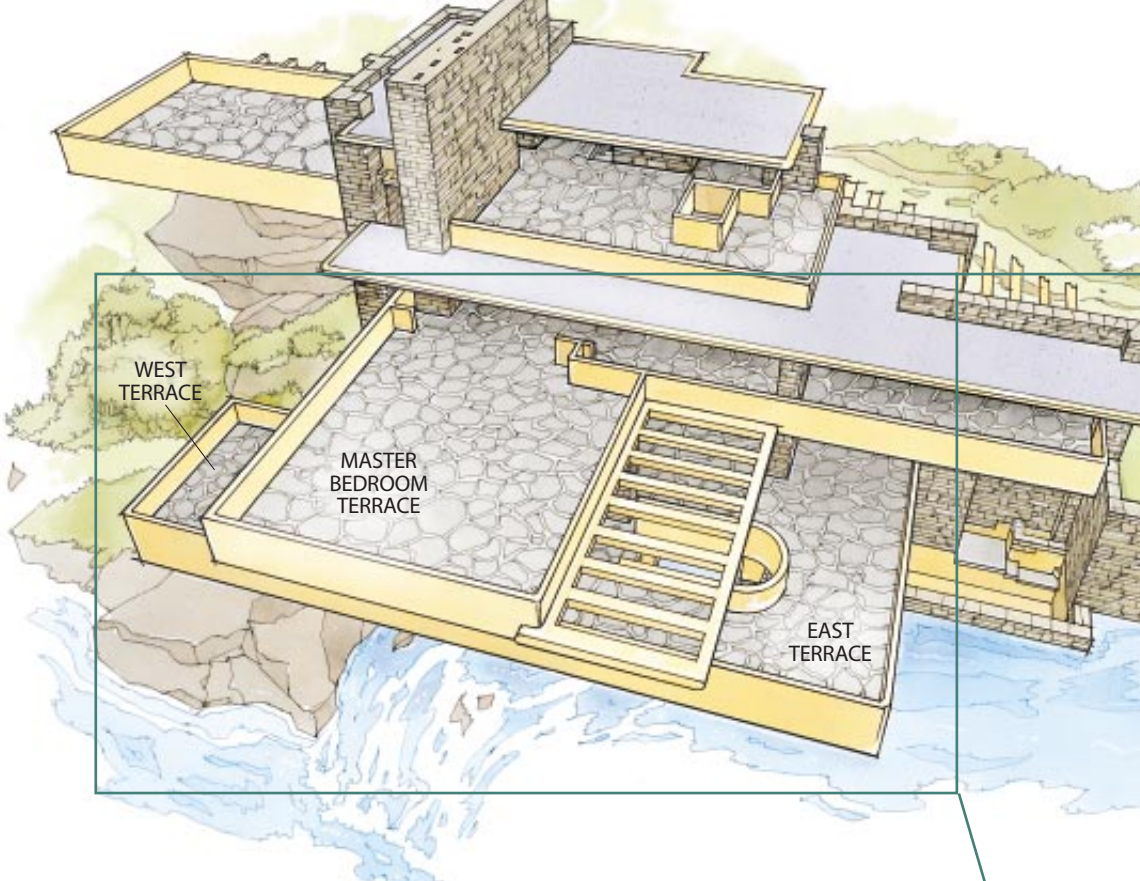
Glickman was referring to the reinforcement needed to balance the negative bending moment, which causes compression in the lower part of each cantilever beam and tension in the upper part. In any beam made of reinforced concrete, the concrete resists the compression on the beam and the steel bars in the concrete resist the tension. Fallingwater's cantilever beams could handle the compression caused by the negative moment, but there were not enough steel bars in the upper parts of the beams to balance the tension.

The problem became even more apparent after the completion of the second floor. Soon after workers removed the formwork from the concrete of the master bedroom terrace, two cracks appeared in the terrace's parapets. In 1937 Metzger-Richardson conducted load tests of the structure and calculated that the stresses in the cantilever beams were near or even exceeded the margins of safety. The engineering firm recommended placing permanent props in the streambed to support the first floor and thus reduce the length of the cantilevers. But Wright stubbornly defend-



CRACKS IN THE PARAPETS of the second-floor terrace appeared as a result of the stresses in the concrete structure (left). Electronic monitors attached to the parapets measured changes in the width of the cracks over 18 months and confirmed that they were growing (below).





ed his design. Once again he forced Kaufmann, Sr., to choose between him and Metzger-Richardson. Kaufmann, Sr., decided to go ahead with the house as originally planned.

Still, the house's owner remained concerned about the tilting of the terraces, so he commissioned a surveyor to measure the deflections on a regular basis by recording the elevations of the tops of the parapet walls. This was done from 1941 until 1955, when Kaufmann, Sr., died. In 1963 Kaufmann, jr., presented the house to the Western Pennsylvania Conservancy. Between 1955 and the time our firm was retained in 1995, only one or two random measurements of the terraces' deflections were recorded.

Engineers as Detectives

The conservancy initially asked our office to evaluate the structural adequacy of the master bedroom terrace, the part of the house that historically had the most severe visible cracks. Work was ongoing to repair Fallingwater's facade, including the terrace's cracks, and the conservancy wished to know whether it was wise to continue repairing these cracks cosmetically without first performing a structural review and, if necessary, repairs. We soon realized that we had to broaden our investigation to include the living room be-

low, because the two floors are structurally interdependent.

Our first question was, "Have the deflections stopped, or are they still growing?" Using an instrument called a water level, we took height readings at more than 30 locations and attempted to relate them to the survey readings done earlier. Our measurements showed that the edge of the west terrace had sagged by as much as 146 millimeters and the edge of the east terrace by as much as 184 millimeters. The deflection of the south end of the master bedroom terrace was about 114 millimeters. We then installed electronic monitors to measure very small movements of the terraces and changes in the width of the cracks in the terrace's parapets. The results over more than one and a half years, corrected for daily and seasonal temperature variations, confirmed that the cracks were still growing and the terraces sagging ever lower.

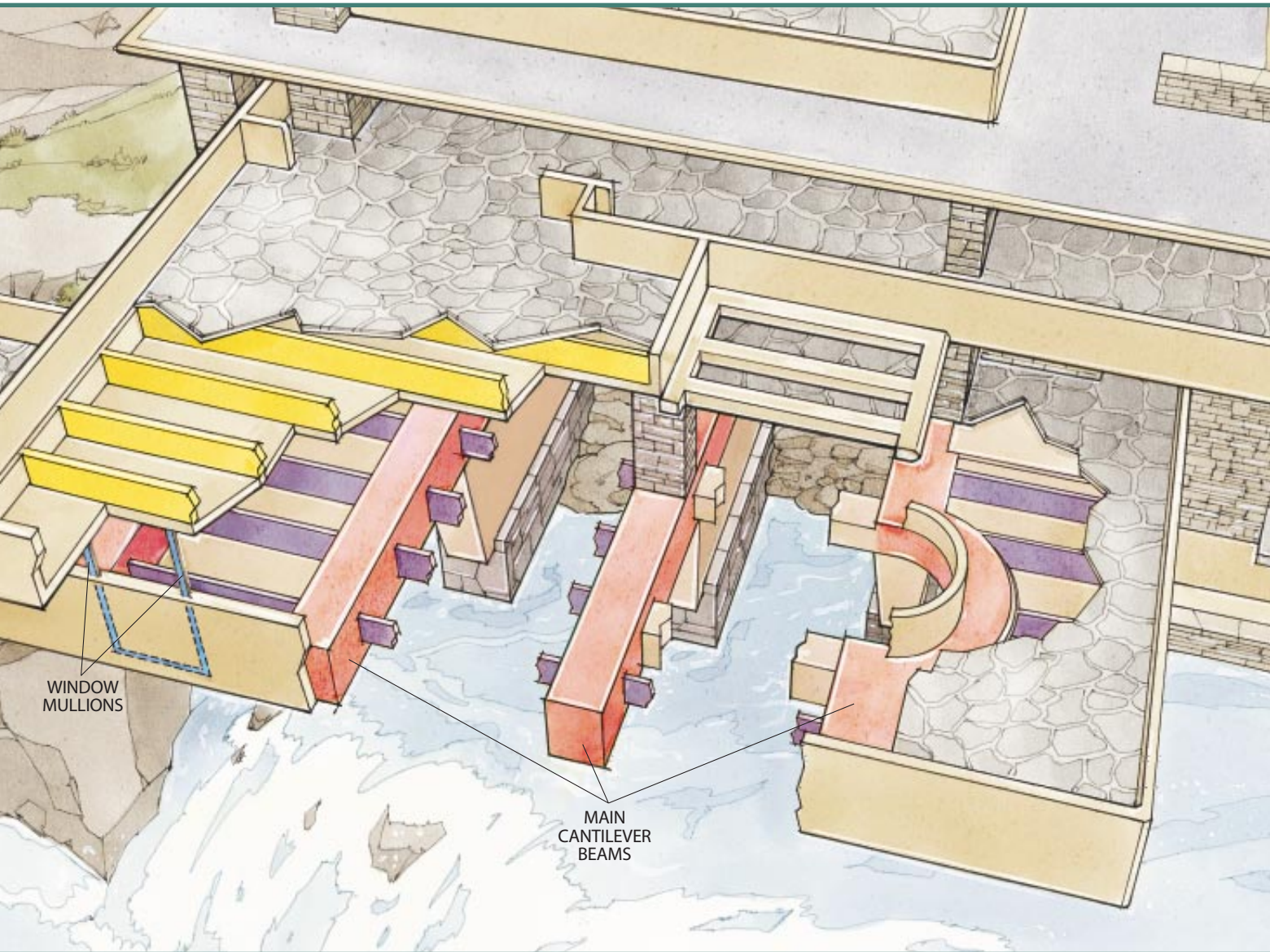
The next step was to examine the structure's as-built condition to see how closely it conformed to Wright's plans. In particular, we needed to verify the actual number, size and location of the reinforcing bars in the cantilever beams and other structural elements. We organized a program of nondestructive evaluation, employing instruments that used impulse radar, ultrasonic pulses and high-resolution magnetic detection to plumb the interiors of the beams,

floors and parapets. The tests also provided data on the quality of the house's concrete. The work was performed by GB Geotechnics of Cambridge, England. To investigate the main cantilever beams, the technicians had to remove several paving stones from the living room floor so that they could gain access to the hollow space below.

Our engineers then conducted an independent structural analysis of the house. Metzger-Richardson had done such an analysis in 1936 and 1937, but we wanted to make our own determination of how the structure functioned.

FRANK LLOYD WRIGHT'S DESIGN for Fallingwater combined beams and parapets made of reinforced concrete with floors and walls made of sandstone (opposite page). A cutaway of the portion of the house overhanging Bear Run (below) shows the concrete bolsters that rise

from the ground and support the horizontal cantilever beams (red). The beams are connected to one another by concrete joists (purple). The steel window mullions (blue) embedded in the first-floor parapet help support the concrete joists (yellow) of the second-floor terrace.



Using a computer model of Fallingwater, we tested three hypotheses: that the master bedroom terrace can support itself through cantilever action; that the living room is a self-supporting cantilever; and that the living room supports both itself and the master bedroom terrace. For each scenario we calculated the bending moments that would be caused by the dead load of the house. Then we calculated the resulting stresses in the steel and concrete of the supporting beams, as well as the amount of deflection that these loads would induce.

If our computer model predicted stresses that were significantly higher than the yield strength of the steel or concrete, we knew that some of our assumptions had to be incorrect, because such overstressing would have resulted in the immediate collapse of Fallingwater. Tests of the house's concrete indicated an in situ strength of about 34 megapascals (5,000 pounds per square inch). We also recovered a small piece of reinforcing steel from the building and sent it to a metallurgical laboratory; the results of the mechanical analysis showed a yield strength of slightly

more than 283 megapascals (41,000 pounds per square inch).

First, we tested the hypothesis that the master bedroom terrace could support itself through cantilever action. If this were the case, our calculations revealed that the stress in the reinforcing bars in the terrace's parapet would be 1,195 megapascals, or more than four times the steel's yield strength. This scenario is therefore not possible. Next, we examined whether the living room is a self-supporting cantilever. Our analysis indicated that the weight of the living room alone would induce tolera-



TEMPORARY SHORING installed in 1997 ensures that Fallingwater will not collapse before permanent repairs can be made to the structure. A line of steel columns and girders rising from the streambed of Bear Run supports the concrete underside of the house's cantilevered first floor.

Thus, in 1997 workers installed a relatively unobtrusive line of steel columns and girders rising from the streambed of Bear Run to the underside of the first floor [see illustration at left]. In addition, they also shored a portion of the streambed itself, the jutting sandstone ledge over which Bear Run cascades. The ledge was braced with pipe struts in a cave behind the waterfall. The temporary shoring, which ensures the safety of the tourists who continue to visit the house, will remain in place until the permanent repairs are completed.

From the analysis of existing stresses, we determined that three of the four cantilever beams below the living room need reinforcing. (The fourth beam, the easternmost one, does not require intervention because it is already propped up by a steel strut that is part of the railing for the stairway that goes down to the stream.) Practically, there is only one method that can provide sufficient reinforcement without altering Fallingwater's outward appearance. This method involves post-tensioning the main beams—that is, connecting them to steel cables and using the tension in the cables to relieve the stress in the beams.

The repair scheme calls for the stone floor of the living room to be removed temporarily. This will allow access to the three main cantilever beams from above. At the south end of each beam—the end jutting over Bear Run—we will attach concrete blocks to both sides of the beam [see left illustration on opposite page]. Into each block we will insert a hollow duct with an inside diameter of 6.35 millimeters. The ducts will run alongside the beams, angling upward and extending through holes drilled in the concrete joists. We will also drill holes in the exterior of the south parapet so that high-strength post-tensioning cable can be threaded through the ducts.

The cables will be anchored at the north end of each beam. At the south end, we will tighten the cables from the outside using a hydraulic jack. The tightened cables will be rigged in such a way that they exert a positive bending moment on each cantilever beam. This positive moment will essentially coun-

ble stresses: a maximum of 152 megapascals in the steel of the main cantilever beams and 16 megapascals in the concrete. We knew, however, from the failure of the first hypothesis, that the living room does not stand alone—it has to support the master bedroom terrace as well. If we assume that the living room is propping up the terrace by means of the T-shaped window mullions at its south end, the calculations predict stresses of 288 megapascals in the steel of the main cantilever beams and 30 megapascals in the concrete. These stresses are at critical levels—they are just about equal to the yield strengths of the materials.

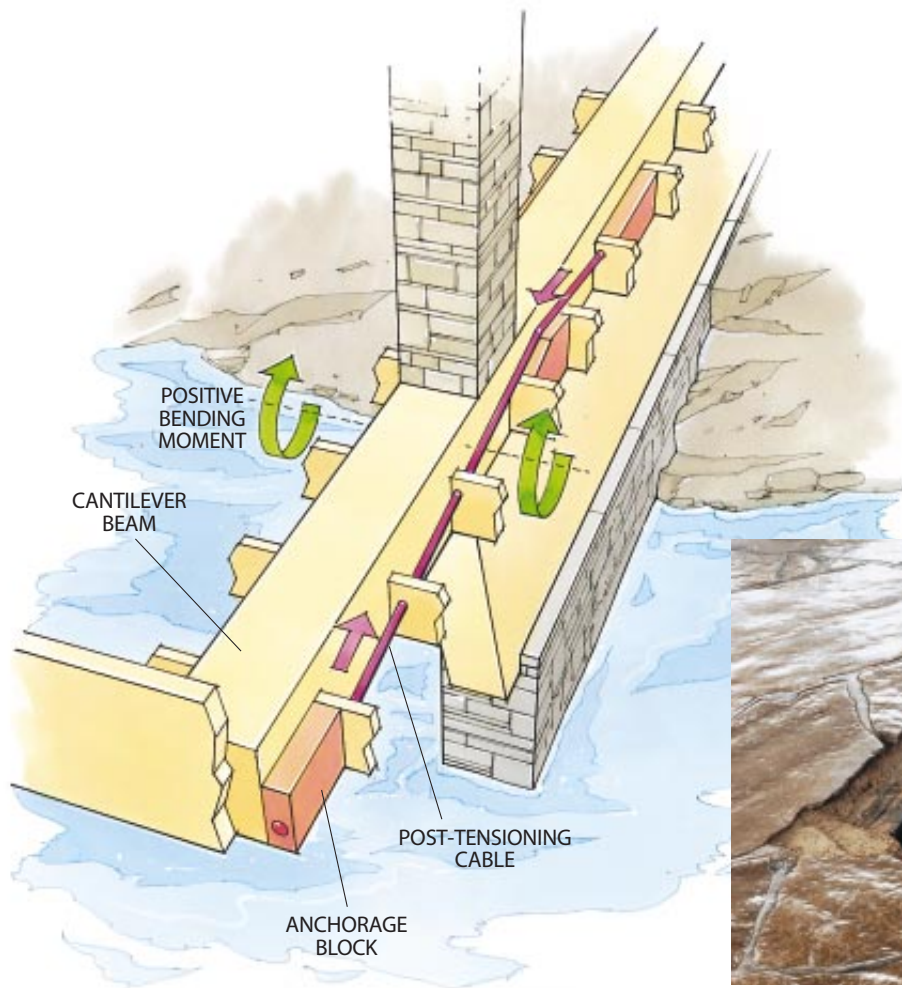
Furthermore, the deflections that would be caused by these stresses closely match the observed tilting of Fallingwater's terraces. Our computer results yielded only the initial deflections and did not allow for the subsequent shrinkage and creep of the concrete in the main cantilever beams. Shrinkage occurs as concrete hardens; creep is the continuing contraction that takes place as concrete is subjected to a constant compression load over time. The amounts of shrinkage and creep depend on many factors, including the quantity of the reinforcing steel and the quality of the concrete. When we added these factors into our calculations, the expected deflections of the east and west terraces turned out to be surprisingly close to the actual conditions.

The logical conclusion is that the T-shaped window mullions do, indeed, support the weight of the master bedroom terrace. Our engineers confirmed that the mullions could handle the load:

the maximum stress induced in them would be 64 megapascals, which is well below their allowable strength of 112 megapascals (assuming that they are braced by the concrete of the living room parapet). What is more, it is this extra weight supported by the mullions that has raised the stresses on the main cantilever beams to critical levels. Although we cannot know for certain what led to this design flaw, the structural evidence suggests a possible chain of events. According to this scenario, when Wright's engineers realized that the master bedroom terrace could not support itself, they redesigned the window mullions to carry some of the load. The engineers failed, however, to redesign the main cantilever beams to support the extra weight.

Fixing Fallingwater

When the conservancy's trustees received the results of our analysis in May 1996, they were naturally concerned. Our study indicated that the stresses in Fallingwater's main cantilever beams were great enough to raise questions about the house's safety. The trustees decided to commence the design of permanent repairs. We advised them that during the construction phase it would be necessary to shore the ends of the main beams while repairs were under way. Because the house would ultimately have to be shored, the trustees wisely chose to do it immediately and thereby eliminate the fear that the building might collapse or that some structural element might fail before repairs could be made.



PLANNED REPAIRS involve relieving the stresses in the cantilever beams through the creative use of post-tensioning. Steel cables will be rigged on both sides of each beam, anchored in concrete blocks attached to the beam's ends (left). The cables will then be tightened from the outside using a hydraulic jack. The tension in the cables will exert a positive bending moment on the beam, counteracting the negative moment caused by cantilever action. A section of one cantilever beam beneath the living room floor (below) has already been exposed to allow engineers to inspect it.



teract the negative moment caused by cantilever action, lowering the tension in the upper part of the beam and the compression in the lower part. We will also connect post-tensioning cables to the parapet edge beams in the east and west terraces to relieve the stresses in those beams. On the second floor, we plan to reinforce the overstressed concrete joist just above the steel window mullions, either by bolting steel channels to each side of the joist or by bonding carbon-fiber plates to it. At the conclusion of the project, we will patch and paint the holes in the parapet, replace the stone floor and remove the temporary shoring.

We anticipate that the structure will lift slightly off the temporary shoring when the post-tensioning forces are applied, but we do not intend to restore the cantilever beams to their original horizontal level. We will fill the cracks in the tops of the beams prior to jacking to limit the amount of upward movement. When the repairs are completed, the terraces will still be tilted, but they will not sag any further. The deflected structure will illustrate the history of the building and the problems that it has encountered over its lifetime.

The repairs are scheduled to take place during the winter of 2001–02 as part of a larger restoration project that

also includes the waterproofing of the entire house. This work will be supervised by Wank Adams Slavin Architects of New York City. The conservancy is also upgrading the water supply and sanitary facilities at the property.

The strengthening of Fallingwater's cantilever beams will guarantee the structural stability of the house for years to come. Moreover, the plan stabilizes the house without the need for permanent props rising from Bear Run. Thanks to state-of-the-art technology, we can preserve the most striking architectural element of Fallingwater, its cantilevered terraces stretching gracefully over the rushing stream.

The Author

ROBERT SILMAN is president of Robert Silman Associates, P.C., Consulting Engineers, a structural engineering firm with offices in New York City and Washington, D.C. Since its founding in 1966, the firm has worked on more than 7,300 projects, including the renovation of 300 designated landmark buildings. Among these are the U.S. Supreme Court Building, Carnegie Hall, George Washington's mansion at Mount Vernon and six other Frank Lloyd Wright buildings. Silman received a bachelor's degree in government from Cornell University and bachelor's and master's degrees in civil engineering from New York University. He is a fellow of the American Society of Civil Engineers.

Further Information

FALLINGWATER: A FRANK LLOYD WRIGHT COUNTRY HOUSE. Edgar Kaufmann, jr. Abbeville Press, 1986.
FRANK LLOYD WRIGHT'S FALLINGWATER: THE HOUSE AND ITS HISTORY. Second edition. Donald Hoffmann. Dover Publications, 1993.
Models of Fallingwater are available at www.greatbuildings.com/buildings/Fallingwater.html on the World Wide Web. Information on visiting Fallingwater is available at www.paconserve.org on the World Wide Web.

A Better Black Box

In the tragic wake of an airline crash, one of the highest priorities of the accident investigators is to retrieve the aircraft's black boxes. The Federal Aviation Administration requires all large commercial aircraft to be equipped with two such devices: the cockpit voice recorder, which records the flight crew's voices and other sounds in the cockpit, and the flight data recorder, which monitors the plane's altitude, airspeed, heading and other instrument readings. Because this information can be vital to the investigation of an air disaster, the recorders must be designed so that the stored data can survive virtually any crash.

The first flight recorders were introduced in the late 1950s. The devices became known as black boxes, and the name endured even after the government required airlines to paint the boxes bright orange to make them easier to locate after a crash. The newest recorders employ flash-memory chips, which can store data for several years without the need for power. The best solid-state recorders can hold about 80 megabytes—much less than the memory of most personal computers but enough to store two hours of voice recordings from the cockpit or a full day's worth of readings from the plane's instruments. These recorders also contain circuit boards that process and compress the data, but only the memory chips are enclosed in the crash-survivable unit inside the box. This unit is covered with thick steel armor so that it can withstand a crushing impact shock. Beneath the steel is a layer of thermal insulation designed to protect the memory chips from the high-temperature fires that often ignite after a jet accident.

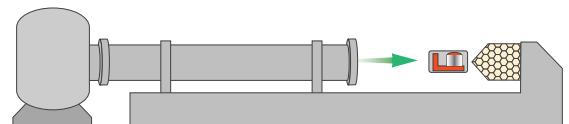
Today's black boxes are far more capable and crash-worthy than earlier models, but the FAA is still seeking improvements. It recently expanded the list of instrument readings that must be stored in flight data recorders. The agency has also proposed that each cockpit voice recorder be equipped with a backup power supply so that it can continue recording even if the aircraft's electrical systems fail.

—Mark Alpert, staff writer

CERTIFICATION TESTS ensure that flight recorders are crashworthy by simulating the extreme conditions of an aviation catastrophe. In the crash impact test (a), a gas gun shoots the recorder into an aluminum target, producing a maximum force of 3,400 g's. In the penetration resistance test (b), a 500-pound weight with a hardened steel spike is dropped on the recorder from a height of 10 feet. In the static crush test (c), an actuator applies 5,000 pounds of pressure. In the deep-sea submersion test (d), the recorder must survive 24 hours in a chamber filled with pressurized seawater. In the fire protection test (e), it is subjected to flames of 1,100 degrees Celsius.

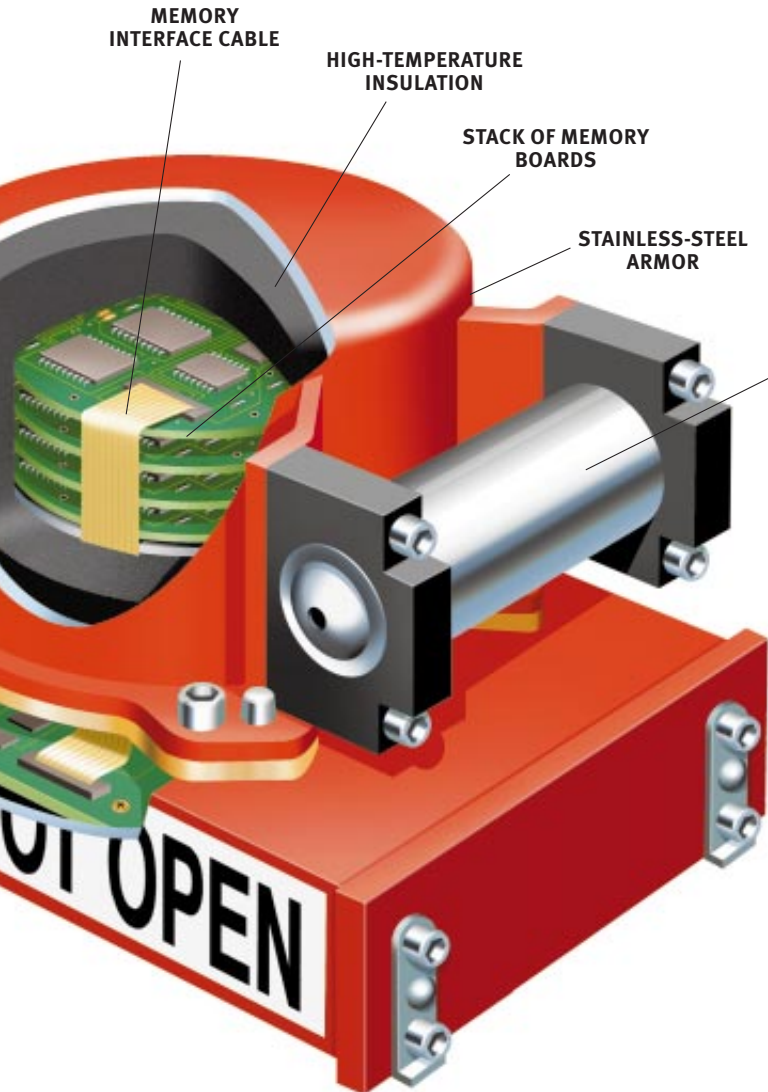
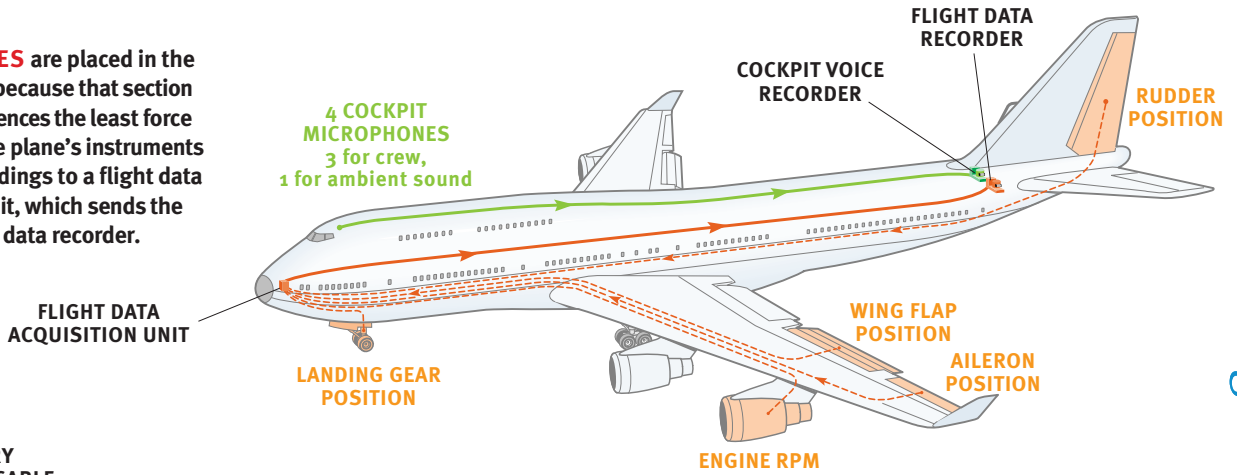


SOLID-STATE RECORDERS are more rugged than earlier devices because they contain no moving parts. In the model shown here, the flash-memory chips are arrayed in a stack of memory boards at the center of a cylindrical crash-survivable unit.



a) CRASH IMPACT

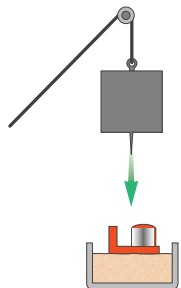
BLACK BOXES are placed in the aircraft's tail because that section usually experiences the least force in a crash. The plane's instruments relay their readings to a flight data acquisition unit, which sends the signals to the data recorder.



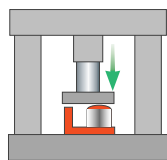
UNDERWATER LOCATOR BEACON, which is bolted to the crash-survivable unit, is activated if the recorder is submerged in water. Also known as a pinger, the device can transmit an acoustic signal from depths as great as 14,000 feet.

DID YOU KNOW ...

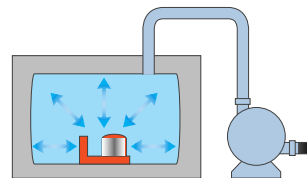
- The earliest flight data recorders used steel foil as their storage medium. The crude devices made marks on a moving roll of foil that was housed in a crash-survivable box. Unfortunately, the foil could be embossed only once, which limited the amount of data it could hold. In 1965 airlines were required to install cockpit voice recorders that used magnetic tape for storage, and this medium soon became the predominant one for flight data recorders as well. Solid-state recorders using memory chips became prevalent in the 1990s.
- Nearly 100,000 flight recorders have been installed in commercial aircraft over the past four decades. The prices of the latest models generally range from \$10,000 to \$20,000. Their survival rate has greatly improved in recent years as the FAA has raised the certification requirements. Although older recorders using magnetic tape were susceptible to fire damage, no solid-state device has been destroyed in an accident to date.



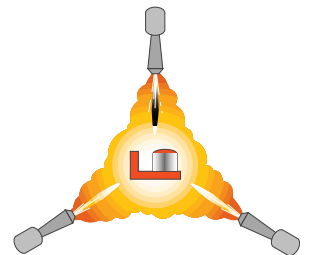
b) PENETRATION RESISTANCE



c) STATIC CRUSH



d) DEEP-SEA SUBMERSION



e) FIRE PROTECTION

ILLUSTRATIONS BY GEORGE RETSECK, BASED ON INFORMATION FROM FAIRCHILD AVIATION RECORDERS

Using a Kite as an Experimental Platform

Shawn Carlson describes how to get instruments airborne without leaving the ground yourself



DELTA-WING KITE, named for its resemblance to the Greek letter delta (Δ), easily lifts a small instrument package high into the sky. Using such a kite for aerial photography requires an ingenious rigging that keeps the camera platform horizontal no matter what the angle of the kite string.

as she let the wind carry the kite skyward. Six years later we still talk about the magic of that moment.

And so began a family tradition. Just last month we took our two-year-old daughter to that same beach for her first taste of handheld aeronautics. When she begged me to send her teddy bear aloft, she reminded me of how kites have for centuries provided amateur scientists with inexpensive access to high altitudes—recall Ben Franklin’s famous investigation of lightning. That experiment has come to symbolize an ordinary person’s ability to carry out scientific research. Indeed, this column sported a logo featuring Franklin’s kite for many years. So it’s embarrassing to admit just how little about kites has been published here, a deficiency that this month’s offering should help to rectify.

Kites are wonderfully inexpensive platforms for aerial photography, something countless scientists, from archaeologists to geologists, use in their research. The view obtained from easy kite height—say, 1,000 feet (300 meters) up—is perfect for monitoring all kinds of environmental changes. But picture taking is not all that’s possible: new lightweight data loggers and sensors of all kinds should make for an explosion of kite-based research of other types. Aspiring meteorologists could, for example, determine temperature as a function of altitude using a thermocouple and a simple pressure sensor. And lifting a hot-ball anemometer (see the November 1995 column) would reveal the speed of the wind aloft. Al-

though I describe here only kite-borne aerial photography—a technique called KAP by its practitioners—I’m certainly looking for clever research projects of other kinds using kites. If you’ve done such work, please let me know so that I can share your inventiveness with this column’s many interested readers.

What’s the best kind of kite for carrying scientific equipment? That’s a hard one to answer. Franklin was limited to the basic diamond-shaped flyer, but kites are now available in a wide variety of designs. For gentle zephyrs not exceeding about 10 miles (16 kilometers) per hour, the “Rokkaku” type is a good lifter. A large one covering 30 square feet sells for around \$130 at your local kite store, or you can contact Into the Wind (800-541-0314). For moderate to stiff breezes (about 10 to 20 miles per hour) KAPers often prefer the “flow-form” or “parafoil” designs. There are no rigid supports in these lightweight wind catchers, which resemble puffy parachutes and fold up for easy transport. Such kites will fly well in a moderate autumn breeze and will pull like tractors in strong wind. A flow-form kite with an area of roughly 30 square feet sells for about \$120.

My favorite variety is the delta wing. This kite also proves stable in moderate winds, and one measuring a dozen feet across (about \$160) can deliver approximately 130 pounds (579 newtons) of pull in a stiff blow. That’s enough to loft some 30 pounds. To lift heavier loads, KAPers sometimes connect two kites in tan-

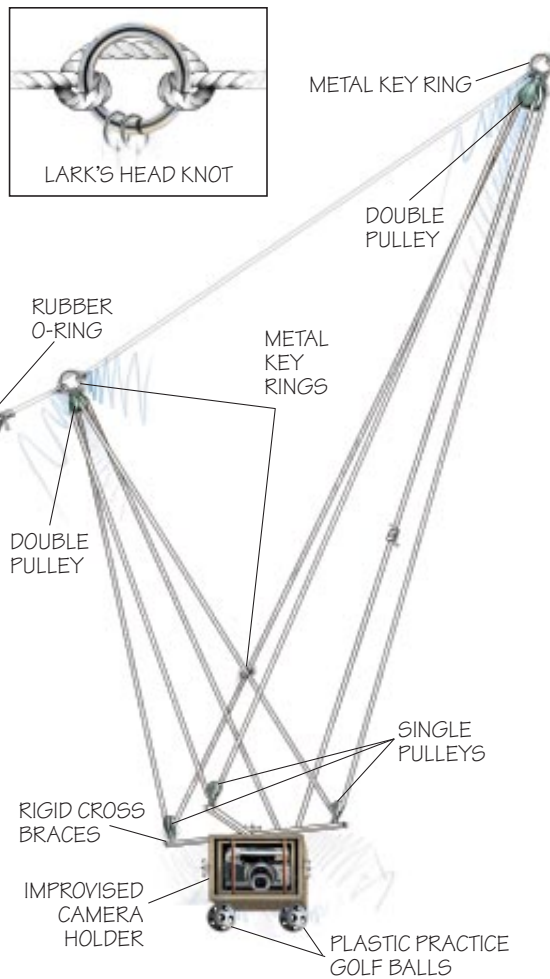
Just weeks before we were married, my wife, Michelle, confessed that she had never flown a kite. I was stunned. Flying kites was such a wonderful part of my own childhood that I couldn’t imagine growing up without it. So I figured it was my responsibility to show her how. And this seemed an opportune time, because I wanted to demonstrate that getting married didn’t mean we had to settle down into a stodgy adulthood; instead we could play together for the rest of our lives.

I thus concocted a plan. As soon as we escaped our wedding reception, I drove my new bride to the beach and unfurled my best kite, a large triangular beauty with a thousand feet of string. I picked a favorite local spot for flying kites, just in front of the cliffs at Torrey Pines State Reserve, near La Jolla, Calif., where I knew I could count on the steady onshore breeze to form an updraft. It all worked. Still in her wedding gown, Michelle stood ankle-deep in wet sand, acting giddy as a schoolgirl

dem, spaced roughly 100 feet apart.

But be prepared. Even a single large kite in a strong wind exerts enough force to pull an adult over. So don't wrestle with a monster kite unless you have the right equipment to control it. Leather gloves are a must. And your line should be rated at least two and a half times the largest tug your kite is likely to deliver. Experienced flyers often wear leather tool belts to which they attach carabiners and other types of rock-climbing equipment to control the line. Another tip: I cut a notch to weaken the crossbar on each of my deltas to ensure that the kite will fail before my string does.

Getting a suitable kite up in the air should be straightforward, but doing photography with it is a bit tricky. Fortunately, one can learn from the experience of others: amateur scientists have been hoisting cameras with kites since the beginning of the 20th century. The earliest pioneers had only limited success because they lacked a platform that would remain level and stable no matter what. An ingenious Frenchman named Pierre Picavet solved that problem in 1912. His suspension system, which now bears his name, is shown above. The instrument package hangs below two perpendicular rods, which are each about one foot long. This large cross is attached to the kite string by threading approximately 50 feet of cord through eight small pulleys. The tiny pulleys sold at hobby stores for radio-controlled model sailboats are ideal (lacking a local source, you can try Proctor Enterprises; 503-678-1300). The Picavet assembly is free to slide about as



PICAVET SUSPENSION levels the camera holder using 50 feet of cord, eight small pulleys, two crossed braces and three metal rings. A lark's head knot (inset) attaches the upper metal rings to the kite string, and two large rubber O-rings prevent vibrations on this line from shaking the camera and thus blurring the pictures.

the kite changes altitude, which keeps the instrument platform level.

To isolate the Picavet from the large side-to-side swaying that kites often execute in high winds, attach the assembly about 100 feet below the kite. Use a metal

ring, such as a large key ring, and a lark's head knot [see inset at left] to attach the Picavet at two points on the kite string about six feet apart.

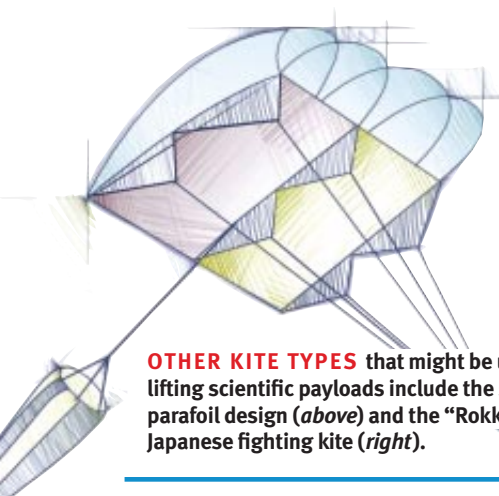
With the wind rushing over it, any taut kite string will develop high-frequency vibrations, which can propagate through the Picavet and blur your images. Large rubber O-rings attached to the kite line help reduce this annoyance [see illustration at left]. The rubber rings used to hang mufflers, available from your local auto supply store, are inexpensive and quite effective at damping vibration.

Although almost any camera will do, KAPers have a few favorites. One is the Samsung Maxima Zoom 145 (\$220 from B&H Photo-Video; 800-606-6969 or, in New York City, 212-444-6615), which can take an entire roll of pictures automatically. Setting its interval timer for a minute or two between shots allows you to adjust the height of the kite and shift its position between frames.

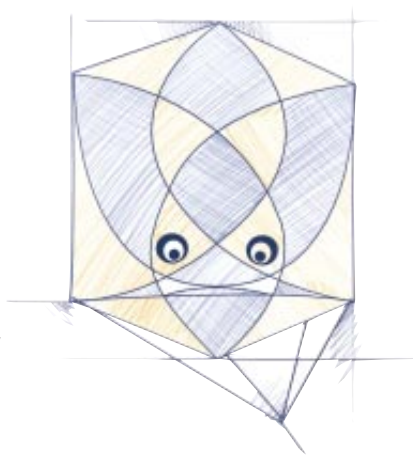
Other point-and-shoot cameras would work, too. But the more limited self-timers on most other models require you to reset them after each photo. Although it is tedious to have to reel in your kite that often, thousands of breathtaking aerial photos have been taken in this way. With any camera, use a film speed of at least ASA 400 and set the shutter to the shortest possible exposure for the light conditions to avoid motion blur.

Advanced practitioners adapt equipment intended for radio-controlled model airplanes. These "servos" can both rotate and tilt the camera, and also trigger the shutter on command. Consult the Web site of the Society for Amateur Scientists to learn more about such options. Whatever strategy you adopt, it's a good idea to affix "landing gear" made of practice golf balls to the camera housing as shown. They make for a softer touchdown should the wind die off suddenly, delivering the instrument gondola all too quickly back to terra firma.

As a service to the amateur community, the Society for Amateur Scientists has created an extensive library of links to Web sites for kite enthusiasts. Visit www.sas.org and click on the "Forum" button. You can write the society at 4735 Clairemont Square PMB 179, San Diego, CA 92117, or call 619-239-8807.



OTHER KITE TYPES that might be useful for lifting scientific payloads include the so-called parafoil design (above) and the "Rokkaku," or Japanese fighting kite (right).



Hex Marks the Spot

Ian Stewart shows how to make some winning connections

Bored with board games? If so, you should give the game of Hex a try. It's just as addictive as the best computer games, and it gives your brain a far more stimulating workout. Cameron Browne, a computer programmer in Brisbane, Australia, has recently published *Hex Strategy: Making the Right Connections* (A. K. Peters, 2000), the first book to take a comprehensive look at Hex and how to win it. The book is a must for every recreational mathematician.

Hex is a two-person game, played on a board made from hexagonal cells arranged in the shape of a rhombus [see illustration on opposite page]. The standard board is 11 by 11. Each player "owns" two opposite edges of the board, and the four corner cells are joint property. Each player also has a stock of counters; in the illustrations here, one player uses red counters and the other uses blue. The rules are astonishingly simple. Players toss a coin to determine who goes first, then take turns placing their counters on the unoccupied cells of the board. A player wins by constructing a chain of counters joining the two edges that he or she owns. The chain may have many branches and loops—all that matters is that the counters form a connected path from one edge to the opposite edge. It looks simple, but that appearance is deceptive. Hex is a game of deep subtlety.

The game was invented by Piet Hein, a Danish mathematician also known for his poetry. He called the game Polygon, and it first appeared in the December 26, 1942, edition of the Danish newspaper *Politiken*. It was independently reinvented by mathematician John Nash in 1948, when he was a graduate student at Princeton University. Nash later won the Nobel Prize in Economics for his work in game

theory. At Princeton the game was known as Nash, or sometimes John, because it was often played on hexagonal bathroom tiles. In 1957 Martin Gardner wrote about Hex in this column, and it became an overnight craze in virtually every mathematics department in the world.

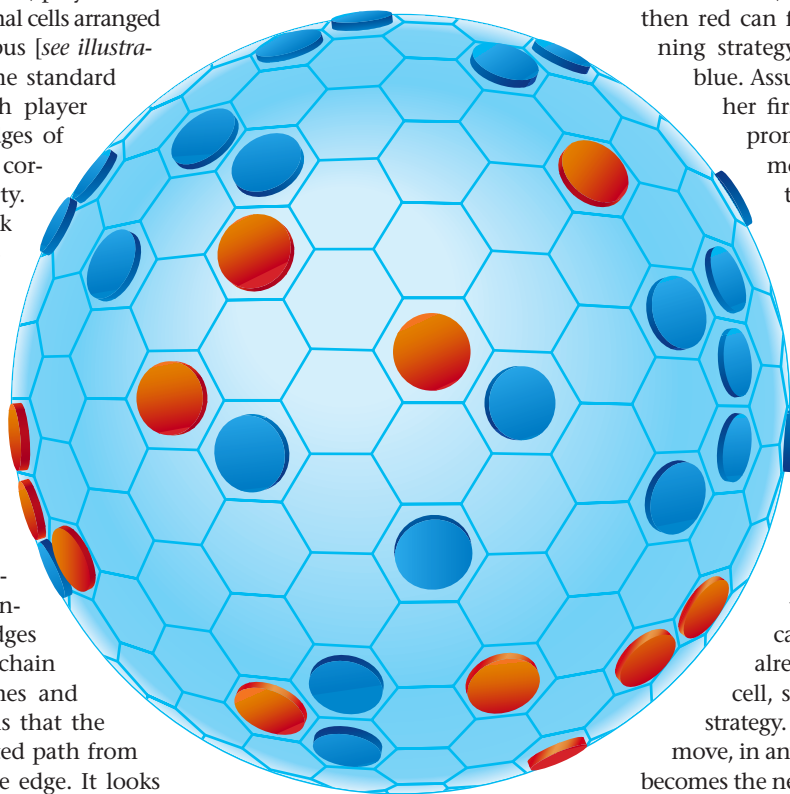
Some simple analysis can illuminate the game. The number of moves is finite—a maximum of 121 for the 11-by-11 board—and a connected chain from edge to edge for one player necessarily

blocks any connected chain for the other player. This makes it intuitive that eventually one player or the other must win: a player can be prevented from forming a winning chain only if the other player creates such a chain first. It can also be proved that with optimal play, the first player should always win.

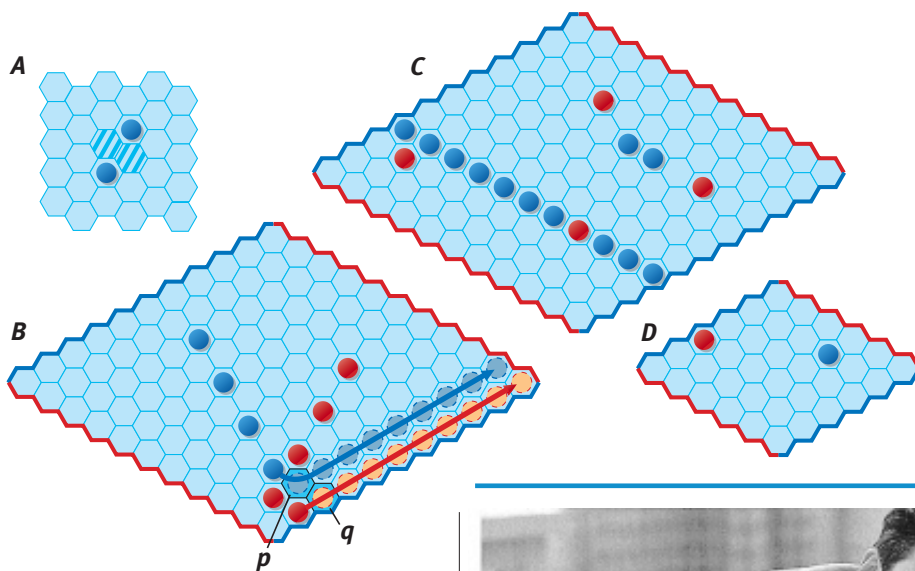
The proof uses a technique called strategy stealing. Suppose, for the sake of argument, that the red player goes first and that there is a strategy that guarantees a win for blue, the second player. If so, then red can figure out what that winning strategy is and use it to defeat blue. Assume that red, after placing her first counter on the board, promptly forgets her opening move. She then pretends that blue is opening the game and that she is the second player, not the first. Whatever move blue makes, red plays the correct response according to the alleged second-player strategy. Sometimes that strategy will require her to place a counter in the cell occupied by her "forgotten" opening move, but this poses no problem: because one of red's counters already occupies the desired cell, she is complying with the strategy. She therefore makes a new move, in any unoccupied cell, and this becomes the new "forgotten" move.

Continuing in this way, red can force a win. But now we find ourselves in a curious situation. By stealing the alleged second-player strategy in this manner, red has played first and won, no matter what moves blue makes. The only way out of this logical impasse is to conclude that no winning strategy exists for the second player. And because the game is finite and one player must eventually win, a winning strategy must exist for the first player.

At first sight, this proof renders the



BALL GAME of a different sort can be played on a sphere tiled with hexagons and pentagons. (The sphere's 12 pentagons lie along the rim of this figure, so they cannot be seen from this angle.) The first player to surround a cell (either unoccupied or occupied by the opposing player) wins this version of the game of Hex.

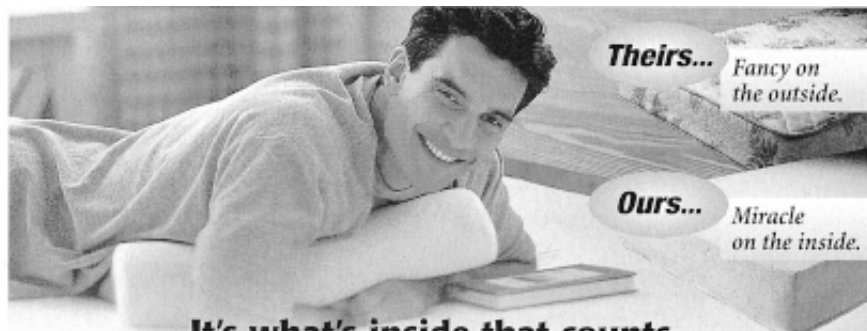


BASIC HEX STRATEGY is to build bridges from one edge of the board to the opposite edge. A player builds a bridge (A) by placing counters in two nonadjacent cells that are separated by two intermediate cells (*hatched*) that touch both occupied cells. More advanced strategies involve constructing ladders (B). In this example, the red player wins the ladder exchange. Last, two problems are posed as a challenge to readers (C and D). In each game, what cell can red play to guarantee a victory?

game pointless, because both players know who ought to win if they exercise perfect play. But the proof does not tell us what the first player's winning strategy is. In fact, the largest board for which a winning strategy is actually known is 7 by 7! So even on an 8-by-8 board, the first player knows that in principle she ought to win but has no idea how to go about doing it. And if that still doesn't seem fair to the second player, many people allow an optional rule: after the first player makes the opening move, the second player may elect to swap this counter for one of her own instead of playing on a new cell.

A full discussion of Hex would occupy about five years' worth of columns, so I'll focus on just two features. The first, which rapidly becomes clear to anyone who tries the game, is that cells do not have to be occupied to play a strategic role. Illustration A above shows a bridge in which two nonadjacent cells occupied by blue are separated by two intermediate cells that touch both blue cells. As long as the intermediate cells remain unoccupied by red, the two blue cells are in effect already joined, for as soon as red plays on one of the intermediate cells, blue can play on the other. Hex players often try to build chains of bridges across the board. A bridge is by no means invincible, however. A blue bridge can be defeated if red manages to occupy one of the intermediate cells while simultaneously threatening a winning move elsewhere. But this is usually a tricky task, so it is best to stop your opponent from building too many bridges.

A useful general principle is that a player's chain is only as strong as its weakest link. If your opponent can attack some part of your incipient chain with good



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hopes of success, then you should try to strengthen your own weakest link or attack your opponent's. To conceal your intentions, it is often advisable to sneak up on your opponent's weak points from some distance away.

More advanced strategies involve the construction of ladders, which arise when one player tries to form a connection to an edge. Illustration B on page 101 shows the start of a ladder, with blue to move. Blue has no option except to play at cell p ; otherwise, red can force a win. By the same token, red then has to play at cell q . If blue keeps trying to force a connection to the same edge (and for several moves she must do this or lose), then red is forced to keep blocking, and two parallel chains of red and blue counters extend along the edge. What blue has failed to notice, however, is that if this process continues, red will win. It is important to anticipate the occurrence of ladders and to block your opponent's ladders before he or she gets started. If blue had placed one of her counters near the edge earlier in the game, she would have won the ladder exchange.

In addition to exploring these issues, *Hex Strategy* discusses a host of variations on the basic Hex game. For example, the

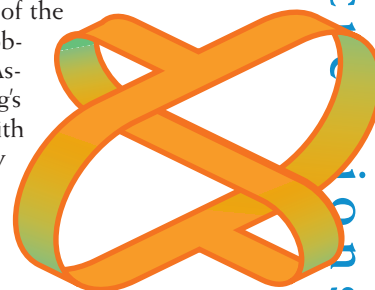
game of Y is played on a triangular board, and a player wins by forming a chain that touches all three edges. As with basic Hex, no winning strategies for Y are known except for very small boards. Hex can also be played on a map of the U.S.—just use the states as cells and the north-south and east-west boundaries as the edges to be connected. In this game the first player, who owns the north and south boundaries, can force a win by playing in California. Hex can even be played on a sphere tiled with hexagons and pentagons [see illustration on page

100]. The first player to surround a cell (unoccupied or occupied by her opponent) wins.

Finally, I've provided two Hex problems for readers to ponder at their leisure. The first, shown in Illustration C on page 101, is taken from Hein's original article on the game; the challenge is to find the one cell that red can play to guarantee a victory. If that one is too easy, try the puzzle devised by computer programmer Bert Enderton of Pittsburgh for a 6-by-6 board [see illustration D]. Again, find the cell that red can play to ensure a win. SA

READER_FEEDBACK

The Feedback section in this past May's column presented an elegant surface with one edge and one side (*below*), which was sent to me by Josiah Manning of Aurora, Mo. I asked readers whether this surface is topologically equivalent to a Möbius band. André Gramain of the University of Tours in France responded that the problem is discussed in his book *Topology of Surfaces* (BCS Associates, Moscow, Idaho, 1984). He says Manning's surface is topologically equivalent to a Klein bottle with a hole in it, whereas the Möbius band is topologically equivalent to a projective plane with a hole in it. And because the Klein bottle and the projective plane are not equivalent, the two surfaces must be topologically distinct. —I.S.



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A New Paradigm for Thomas Kuhn

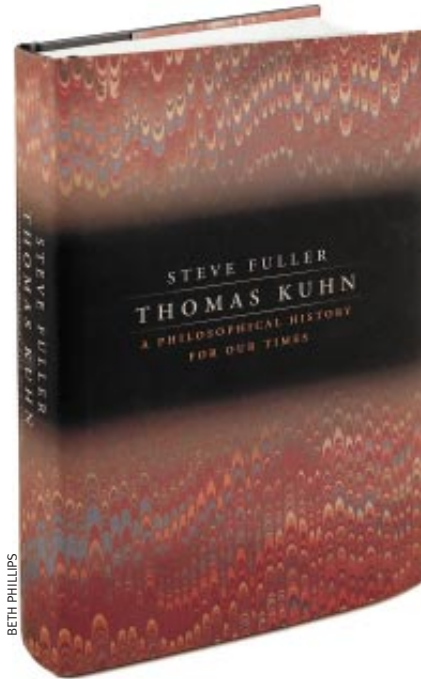
Steve Fuller argues that Kuhn's ideas were anything but revolutionary

Thomas Kuhn (1922–96) is known best, and almost exclusively, for a slim volume published in 1962, *The Structure of Scientific Revolutions*. The book is widely acclaimed to be the most influential academic work of the second half of the 20th century. It has sold nearly a million copies and has been translated into 20 languages. With undiminished regularity, it is cited by scholars in fields as diverse as political science and art history. Al Gore has mentioned *Structure* as his favorite book.

I read *Structure* in 1964, in its first paper edition, and like many of my scientific cohort I was much taken by Kuhn's analysis of science. To be sure, the sources of Kuhn's thought were in the air at the time: Piaget's work on how children acquire knowledge, Whorf's studies of language and worldviews, Gestalt psychology, Koyré's groundbreaking interpretations of the history of science, and so on. It was a heady time to be thinking about the history and philosophy of science, and Kuhn plugged into the prevailing culture with uncanny precision.

According to Kuhn, the authority of science resides in the community of scientists practicing what he called "normal science." Normal science is defined by a "paradigm," a kind of shared worldview, or, as Kuhn described it, "universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners." Within normal science, anomalies are generally ignored. Eventually, however, difficulties within a paradigm become unsustainable, and a revolution occurs. A new paradigm is established, incorporating social and cultural influences of the time, and work goes on.

What Kuhn had going for him (or against him) was a dazzlingly simple schematic (with that magic word "paradigm") embedded in an inchoate epistemic stew. This made him easy to latch onto by almost anyone, regardless of philosophical or political predilections. Indeed, Kuhn has been taken to heart by



BETH PHILLIPS

Thomas Kuhn: A Philosophical History for Our Times

by Steve Fuller

University of Chicago Press,
Chicago, 2000 (\$35)

scholars espousing almost directly opposite views about the nature of science. Combatants on both sides of the infamous "science wars" between scientists and sociologist critics of science regularly use Kuhn to buttress their respective positions or whack each other over the head.

Now along comes Steve Fuller to put Kuhn into a historic and philosophical context and to excoriate *Structure* for its presumed baleful influence on the authority and practice of science. Fuller is an American sociologist, currently professor at the University of Warwick, formerly of the University of Durham. His prolonged British residence is evidenced in the scrappy, iconoclastic, take-on-all-comers spirit of his work (one can find Fuller giving and taking his licks in the Internet lists). Nothing here of the sometimes wearisome pomposity of American academics who inhabit that obfuscated discipline called science studies.

Thomas Kuhn: A Philosophical History for Our Times is a heavily footnoted and almost impenetrably dense insider's account of 20th-century sociology of knowledge. Fuller marshals an astonishingly detailed grasp of recent intellectual history to argue that science as we know it has outlived its usefulness. The paradigms of normal science are not the ideal form of science, he says, but rather "an arrested social movement in which the natural spread of knowledge is captured by a community that gains relative advantage by forcing other communities to rely on its expertise to get what they want."

Fuller is especially effective at reconstructing the debates between Ernst Mach and Max Planck about the nature of science at the beginning of the 20th century, which he takes as emblematic of all such debates since. In Fuller's dichotomous scheme, Mach championed an instrumentalist philosophy of science; Planck was a realist. Mach lodged science in everyday psychological experience; Planck reduced everyday experience to the ultimate constituents of physics. Mach exalted technology; Planck promoted abstract problem solving. Mach was the liberal democrat, intent on empowering "citizen scientists"; Planck was the state corporatist, who thought ordinary folks had no claim on "real" science.

Kuhn is squarely on the side of Planck, Fuller says. The paradigms of normal science, Fuller goes on to assert, confer a phony legitimacy and autonomy on scientific practice. Alternative versions of the "truth" are delegitimized, and establishment science (with its consumerist-military alliances) becomes the only game in town. Young scientists are acculturated within the paradigm and spend the rest of their careers tweaking theories. Dissent is frowned upon. The real problems of society are ignored in the pursuit of the next decimal place.

Fuller, of course, comes down on the side of Mach, espousing a vaguely defined "citizen science." His democratizing instincts are admirable, but as he storms the Bastille of normal science he

will find himself in the teeming company of those who believe in creationism, alien abductions, parapsychology and other nonparadigmatic citizen sciences. He does not seem to cringe at the prospect of postestablishment intellectual anarchy.

Kuhn wrote: "The very existence of science depends upon vesting the power to choose between paradigms in the members of a special kind of community." Fuller has confidence in the intelligent good sense of ordinary folks and properly calls for "the right to be wrong." But do statements such as "the universe is light-years wide," "the earth is billions of years old," "all life is related by common descent," "organisms are composed of cells that contain double-helix DNA," and so on really have no greater claim on "reality" than the Genesis stories of creation-

By nipping at our heels, Fuller reminds us that science might in fact do a better job.

ists or the popular consolations of astrology? If the answer is no, as Fuller comes dangerously close to asserting, then most scientists would throw in the towel and get jobs flipping burgers.

Fuller underestimates the highly evolved "fitness" of the methodologies, sociologies and conceptual paradigms of normal science. The deprofessionalization of science and the establishment of a citizen marketplace of ideas are not likely to happen without the sociopolitical equivalent of an asteroid impact, and no such potential upheaval looms on our intellectual radar screens. Certainly, science studies lacks the weight to do it.

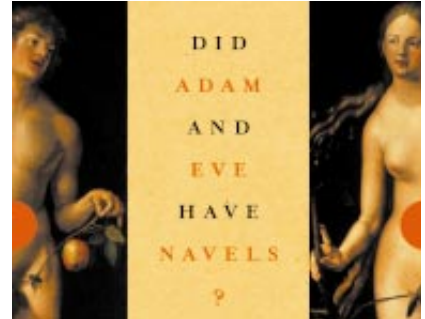
At the same time, it would behoove scientists to pay close attention to Steve Fuller's sprawling, brawling and gloriously provocative book. He is perhaps more friend than enemy, and by nipping at our heels he reminds us that science might in fact do a better job serving a socially and ecologically responsible agenda, empowering citizen science-kibitzers to live purposefully and with exalted spirit in the science-revealed world of galaxies and DNA. SA

CHET RAYMO teaches physics at Stonehill College in Massachusetts. He is a science columnist for the Boston Globe. His most recent book is *Natural Prayers (Ruminator Books, St. Paul, Minn., 1999)*.

THE EDITORS RECOMMEND

MARTIN GARDNER'S *Did Adam and Eve Have Navels?: Discourses on Reflexology, Numerology, Urine Therapy, and Other Dubious Subjects*. W. W. Norton, New York, 2000 (\$26.95).

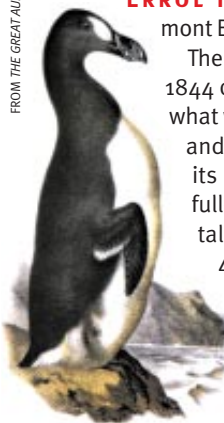
"Most of the chapters in this collection are attacks on far-out cases of pseudoscience," Gardner writes. All the chapters are from his column, "Notes of a Fringe Watcher," which appears regularly in *Skeptical Inquirer*, the organ of the Committee for the Scientific Investigation of Claims of the Paranormal. Gardner, who describes himself as a philosophical theist, is an immensely learned man who writes gracefully about many complex subjects, as readers of this magazine know from the popular "Mathematical Games" department that he conducted here for 25 years. In the book, under 10 section headings, he skewers such staples of pseudoscience as unidentified flying objects, gematria (the effort to find in a sacred text hidden mathematical structures said to prove the supernatural origin of the book) and Carlos Castaneda's New Age anthropology. In the last chapter, he considers science and the unknowable. Citing William James's statement more than a century ago that "our science is a drop, our ignorance a sea," Gardner asks, "How can we explain the brute fact that the universe, including such bizarre creatures as you and me, manages to exist?"



LAWRENCE M. KRAUSS'S *Quintessence: The Mystery of Missing Mass in the Universe*. Basic Books, New York, 2000 (\$26).

"The picture of cosmology we so carefully and optimistically developed over the 1980s, based on the fusion of ideas from particle physics and astrophysics, is now undeniably incomplete. Over the past five years it has become clear that 'dark matter' alone is not abundant enough to eventually halt the observed universal expansion." Thus Krauss, chairman of physics at Case Western Reserve University, introduces this revised edition of a book he published a decade ago under the title *The Fifth Essence*. The fifth essence, an allusion to a term of Aristotle's, was Krauss's name for dark matter. Now something else must be considered; he calls it "quintessence." It is "a nonzero vacuum energy" that "may dominate the energy of the universe, govern its ultimate destiny, and swamp all matter, even dark matter, in ultimate cosmic importance." Krauss is an accomplished guide through modern cosmology. The rewards of the search for dark matter and vacuum energy, he says, "could be spectacular: a window on the universe at the earliest instants of creation, an understanding of its destiny, and finally, an understanding of the formation of all the structure we observe."

FROM THE GREAT AUK



ERROL FULLER'S *The Great Auk*, Harry N. Abrams, A Peter N. Nevraumont Book, 1999, \$75.

The Great Auk was a flightless, penguin-shaped seabird last seen in 1844 on a remote Icelandic island, where hunters strangled to death what was most likely the only remaining pair. Fuller, a painter, writer and amateur natural historian, became intrigued with the bird and its history during his childhood, and his fascination grew into a full-blown obsession. He tells its haunting story in this monumental volume, augmenting the detail he has amassed with some 400 illustrations—artists' depictions (including several of his own), archival images, photographs of the isolated islands where the defenseless bird once thrived and artifacts from cigarette tins to Fabergé jewelry.

The Great Auk is one of the great icons of extinction, perhaps because the charm and whimsy of its appearance and the senselessness of its demise stir our passions. This book is both passionate and learned, a huge, glorious labor of love.

FRANK CLOSE'S *Lucifer's Legacy: The Meaning of Asymmetry*. Oxford University Press, New York, 2000 (\$27.50).

Strolling through the Tuileries Gardens in Paris on a spring day and taking note of the perfect symmetry of the design, physicist Close came upon an asymmetry. A statue of Lucifer had lost its head, which lay on the ground nearby, whereas the twin statue on the opposite side of the garden remained intact. The experience set Close to thinking about symmetry and asymmetry and led to this jewel of a book. He relates how our universe, symmetrical at the moment of the big bang, quickly developed an asymmetry. Lucky for us. "A perfect Creation, with its symmetry untainted, would have led to matter and antimatter in precise balance and a mutual annihilation when in the very next instant they recombined: a precisely symmetrical universe would have vanished as soon as it had appeared."

Whereupon Close, a professor of physics at the University of Birmingham in England, embarks on a deep and illuminating exploration of the symmetries and asymmetries that surround us. The journey leads him in the end to the concept of supersymmetry, "the belief that there may be one more aspect of symmetry at work among the particles and forces than we have mentioned so far, and that this could provide the key to completing the picture of symmetry and its disappearance."

LYALL WATSON'S *Jacobson's Organ: And the Remarkable Nature of Smell*. W. W. Norton, New York, 2000 (\$24.95).

The Organ of Jacobson, as it is formally named, consists of a pair of tiny pits in the nose, one on each side of the septum that divides the nostrils and, in humans, a centimeter or two above each nostril. It takes its name from its 19th-century discoverer, Ludwig Levin Jacobson, described by Watson as a "sharp-eyed Danish anatomist." "What it seems to do," Watson writes, "is to open up a channel quite separate from the main olfactory system. It feeds an older, more primal area of the brain, one that monitors airborne hormones and a host of other undercover patterns of information, making physiological changes that have profound effects on our awareness, on our emotional states and on our most basic behaviours."

Watson is a sharp-eyed naturalist, based in Ireland, whose training is in evolutionary biology and anthropology. His tale encompasses scents, smells and the power of odors for humans and a variety of animals. Delicate woodcuts from a 17th-century book on botany grace the text.

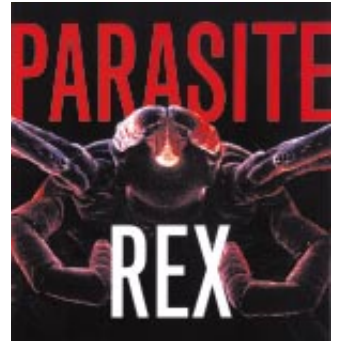
TERRY BURNHAM AND JAY PHELAN'S *Mean Genes: From Sex to Money to Food—Taming Our Primal Instincts*. Perseus Books, Cambridge, Mass., 2000 (\$24).

"Consider this book an owner's manual for your brain." Why does one need such a manual? Because we have inherited genes that worked well for our cave-dwelling ancestors but get us in trouble in an industrialized world. "A prime example is our love of eating. Ancestral humans were always hungry, having no reliable food source and no refrigerator or storage system. Their survival rule was simple: eat as much as possible. When we follow this

rule in our rich, modern world, many of us become overweight and unhealthy." We also battle these "mean genes" over sex, spending, drugs and many other things. Burnham, a professor of economics at Harvard University, and Phelan, a professor of biology at the University of California at Los Angeles, describe those battles and propose ways of moderating the compelling effect of the mean genes. "The key to a satisfying life," they say, "is finding a middle ground that combines free-flowing pleasure, iron willpower, and the crafty manipulation of ourselves and our situations."

CARL ZIMMER'S *Parasite Rex: Inside the Bizarre World of Nature's Most Dangerous Creatures*. Free Press, New York, 2000 (\$26).

"Every living thing has at least one parasite that lives inside it or on it." The parasites, even when bacteria and viruses are excluded from the category notwithstanding their parasitical nature, constitute "a vast menagerie." Thus raising the curtain on his dramatic tale, science journalist Zimmer presents a vivid portrayal of how parasites evolved, how resilient and adaptable they are, the effects they have on their hosts and the strategies the hosts have developed to combat them. He goes a step further: "Given how much parasites have shaped the human body, it's tempting to wonder whether they've shaped human nature." And he wonders also if humans have become parasites of Gaia—the biosphere. "We humans exist within Gaia, and we depend on it for our survival. These days we live by using it up." If we have joined the venerable guild of parasites, he says, we are clumsy ones. "If we want to succeed as the parasites, we need to learn from the masters."



M. LEE GOFF'S *A Fly for the Prosecution: How Insect Evidence Helps Solve Crimes*. Harvard University Press, Cambridge, Mass., 2000 (\$22.95).

"The suspect was convicted of second degree murder and the major witnesses were flies." With these words entomologist Goff introduces his somewhat exotic specialty: forensic entomology. In this murder case, as in many where the specialty has a role, fly maggots on the murdered woman's body showed by their stage of development approximately when she had died and so helped to convict the man who was with her when she was last seen alive. Forensic entomology, Goff writes, assists criminal justice in other ways—by providing clues about how a body may have been moved after death, by placing a suspect at the scene of a crime, and by showing that drugs or toxins have contributed to a death.

Goff, a professor of entomology at the University of Hawaii at Manoa, traces the development of his field from modest beginnings to its present wide acceptance as an adjunct of detective work and criminal trials. He now makes presentations at meetings of people working in various aspects of criminal investigation. "I never show a series of slides of just bodies in presentations to pathologists or show only insect slides at entomological meetings. Pathologists want to see insects and entomologists want to see dead bodies. Mixed groups require mixed slides, and lawyers are amused by almost anything."



FROM JACOBSON'S ORGAN

FROM A FLY FOR THE PROSECUTION

From Prototools to Language

Technology is by no means a recent invention. **Philip & Phylis Morrison** trace its origins back through our prehistoric ancestry



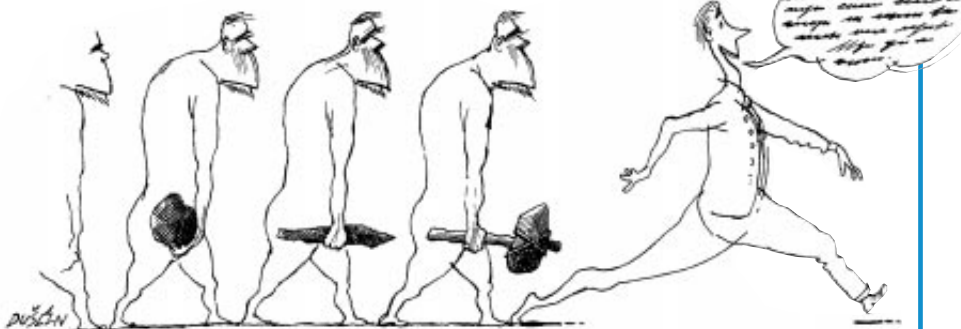
Some 20 miles from Olduvai Gorge in the Serengeti of Tanzania is a site called Laetoli. There, during a nearby eruption about 3.5 million years ago, three individuals walked erect, stepping gingerly across the falling volcanic ash, two of them perhaps hand in hand. A long string of their footprints remains, evidence of fully bipedal nature. Those small early cousins of ours (close kin to “Lucy”) were fit tree climbers, too, but already theirs was the regular posture we boast, hands freed in promise of dexterity. Although rudimentary stone tools do not appear for a million years more, that early cleft between hominids and other primates was the full liberation of hands.

Ethnographer Richard Lee once lured a chimpanzee into camp by setting out a supply of bananas overnight. Lee awakened to a comic sight: the chimp, greedily holding a banana or two in mouth, hands, underarms and between thighs, was waddling awkwardly off. Discovered, he lost all his prizes as he ran. What he really needed was a bag. Did some australopith make that early artifact, a wrapper perhaps folded out of one big leaf, to carry home pods, berries, even larvae, to her ailing kin? Such containers are key societal tools that may leave no record over geologic time.

Chimpanzees regularly use leaves and stems as casual tools and can pound stones, yet they have not, even after instruction, mastered flint flaking. Crude tool use is not enough to set our species sharply apart (although complex tools become in the end defining—take lasers, for example). The chipped stone flakes, choppers and hand axes made by the oldsters in our complicated lineage, assigned to putative earlier species, have always been something of a disappointment to the two of us. Ten thousand centuries pass while simple stone tools are being worked from the North Sea to Java, across sub-Arctic Eurasia and all of Africa. Useful enough, they show scant variety and modest change. (A recent European find of well-made wooden throwing spears about

halfway along this period is a real rarity.)

A South African site hints at one early ancestral triumph. A collapsed cavern called Swartkrans held a vast interior mix of bones, carefully sorted by C. K. Brain of the Transvaal Museum in South Africa. He counted many bones of australopiths in the earlier samples, along with those of antelopes, but saw few of the dominant felines that regularly pounced on their ape-folk prey near the cave entry.



Later, antelope remains abound, but by then both hominid bones and those of cats are lacking. The simplest explanation is that the cave was first ruled by the big cats, some dying within, until new predators—our forebears—took over. They freely hunted game but dragged in no bones of cats to gnaw. The date is poorly known—roughly a million years ago—so we are not sure how those early hunted folk became the hunters: Was it numbers, organization, weapons or only some unexpected faunal shift?

Or was it Promethean fire? Alone among animals we have mastered fire, if uneasily. The oldest plausible evidence for human use of fire is from ancient caves, where layered ashes imply long-used hearths. Fire making seems about half a million years old, although clear finds of fire are somewhat younger. Wildfire today is as often ignited by lightning bolts on forest and prairie as it is by people. Orbiting cameras catch seasonal fires lit by *Homo sapiens*, slash-and-burn fields and burning grasslands on all conti-

nents, save icy Antarctica. We might regard the early hominid use of fire as restricted to the capture, tending and breeding of wildfire but not to the actual making of fire anew. Now we engineers confine most flames within hearth, furnace and cylinder, as abundant as all open fire. But it was our impoverished forebears who first acquired shelter, self-defense, weapons,

simple tools and probably fire, a major share of our necessities. Their wisdom and courage cannot be ignored.

One more artifact marks full humanity: language. Here, too, there has been a new understanding. Many social animals, from dolphins to elephants, songbirds, even bees, have some claim to language, to encoded communication. It turns out that the sentences humans speak bear a structure remarkably common throughout all our 6,000 languages, even though particular language families differ widely in their sets of significant sounds and words. Only with our species does there rest the amazing property of human language so tellingly put by Wilhelm von Humboldt in his 1836 volume: “Infinite possibilities by finite means.”

Uttering new and old sentences lifelong, you yourself are not hard put to produce a brand-new sentence on demand. No other creature shows such intimate creativity. Our words are many, a good fraction of them active in memory, but our sentences are enormously more

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The Last Word

James Burke takes an encyclopedic look at wordsmiths, dirty old men, rock hounds, ETs and the visitor's London



DAVE PAGE

In 1775, at Isaac Newton's London home (by this time owned by an organist), Fanny Burney, the 23-year-old daughter of the house, penned a delicately satirical novel of middle-class manners: *Evelina, or The History of a Young Lady's Entrance into the World*, which to my mind now reads like wading through mud. But when it was published anonymously in 1778 (advertised in the local paper between a robbery summary and an ad for spot remover), the piece sold like hotcakes.

Fanny instantly became the thinking man's fancy (mind you, given the title, you have to suspect some of the book buyers' motives, nudge nudge). Well, the behavior of one of her avid groupies would today have had him in court for harassment. The fan in question, corpulent Dr. Samuel Johnson, was hooked by the novel, even more hooked to find out it had been written by the daughter of his organist pal, and is reported to have "greatly caressed" Fanny. It can't have been very much fun being groped by a fat hypochondriac with a tic who talked to himself and was notoriously short on both visual acuity and personal hygiene.

Johnson probably got away with it because he was the sharpest one-liner maven this side of Dorothy Parker and his acid tongue gave the self-important sleepless nights. To give him his due, Johnson was also a consummate scribbler and produced a 43,500-word dictionary that was unrivaled until the *Oxford English* (pace *Webster's*). Back in 1763 Johnson (and a few of his own literary lickspittles) had founded a London club called The Club, where the elite would meet and greet weekly for dinner and for what (by the third bottle) was Johnson being brilliant. If you were in, you were *in*. In 1775 one such was a prof who had given Johnson's dic-

tionary a boffo review in a Scots literary mag. Name of Smith.

But not just any Smith. Adam "Wealth of Nations" Smith. The guy who practically invented political economics, the market as a self-correcting mechanism, the division of labor, the "invisible hand," mass production and all the reasons you're scared to check your stock portfolio in the morning. (Strangely enough, you get the impression Smith wasn't really aware of the relevance of his efforts to help a young mechanic named James Watt get the job of re-

Hutton blew away the accepted idea of a 4004 B.C. seven-day Creation event.

pairman at Glasgow University.) Smith was one of the glitterati of the Scottish intellectual establishment, many of whom met regularly in Edinburgh to eat oysters and, in Smith's case, share pearls of economic wisdom. Perhaps no coincidence a fellow shucker of his was the son of the Edinburgh city treasurer: one James Hutton, who to my mind has never been properly recognized as a major player in the evolution of Evolution.

It was Hutton who blew away the accepted idea of a 4004 B.C. seven-day Creation event followed by the Flood, in favor of what became known as uniformitarianism. His *Theory of the Earth* (published in 1795 and so badly written that somebody else had to do an edit) described geologic processes, like erosion, that worked as slowly in the past as they do at present. Because that was slower than watching paint dry, for Hutton this meant an Earth older than he

could imagine and in any case one that had been around long enough for organisms to change to suit altered conditions. No surprise that Charles Darwin's mentor, Charles Lyell, was a Hutton freak.

Hutton himself had been turned on to his rock-tapping stuff (after a few years as a farmer with a natural interest in stones) by the work of a theologian named John Harris, who in 1704 had produced the best technical lexicon around. But, according to Ephraim Chambers, not best enough. So, in 1728, Chambers came out with his cross-indexed, two-volume *Cyclopaedia, or Universal Dictionary of Arts and Sciences*, and laid the groundwork for every encyclopedia since. By 1746 it was in five editions and inspiring a French publisher with an eye to a fast sou to look around for the nearest translation service. By 1747 or so that publisher's third choice was a fellow then probably best known for a pornographic novel published earlier that year. Finally, in 1751, Denis Diderot started cutting and pasting what would become the 28-volume *Encyclopédie*, a masterpiece that put the capital E on "enlightenment," because Diderot pulled together a group of contributors whose main aim in life seems to have been to sock it to authority of all stripes. At various times during the 14-year gestation period Diderot first went to le pokey for poking fun at the Jesuits, and then his presses were closed down when he did it again. Several volumes came out samizdat.

Diderot's co-editor for a while was the only illegitimate mathematician I know named after the church on whose steps he was abandoned: Jean Le Rond d'Alembert. All I want to say about him is that he showed that the maxim "For every action there is an



equal and opposite reaction” works as well for bodies free to move. And that his mother, Madame de Tencin, never acknowledged him. Too busy being the mistress of a prime minister, plus of the country’s regent, plus of other sundry bigwigs. And running one of those chit chat salons where you could thrill to the risky new skepticism from crazies like Bernard Le Bovier de Fontenelle, who from 1686 talked dangerous nonsense about inhabited planets and one day landing on the moon and religion being all mumbo-jumbo. De Fontenelle’s was the first real pop science, and the great Voltaire picked up on the technique in 1739 with a satirical piece on jacks-in-office as seen through the eyes of an ET from Sirius.

Late in Voltaire’s life, when he was retired in Ferney, Switzerland, and the line of visitors went around the block, one groveler was English culture-vulture Uvedale Price, who then went home to kickstart the Picturesque movement in 1794 with his country neighbor Richard Payne Knight. Both of them triggered a mania for wilderness gardens and medieval ruins (or pseudo-such), which hit the front page when Knight’s “keep things disorderly” message got to architect John Nash. Who, after a false start building country gaols, littered England with castellated (and asymmetric) imitation castles and ornamented cottages before coming to royal attention in the form of the prince regent, thanks to whom Nash got to tear down, remodel, colonnade and stucco large bits of London’s West End: among others, Regent’s Park, Buckingham Palace, Marble Arch and Regent Street. This last, to link the aforementioned park with the regent’s London residence at Carlton House. Of which the regent was so proud he’d invite well-known people to come and take the tour.

In 1815 one of these celeb invitees popped in during a visit to the Big City from her home out in the Hampshire sticks. That a bumpkin should have made it to the prince’s guest list was down to the fact that two years earlier country mouse Jane Austen had had her first smash hit with an opus entitled *First Impressions*, which you’ve never heard of because she changed the title after reading a novel whose last words were, “The whole of this unfortunate business ... has been the result of pride and prejudice.” Written by Austen’s fave rave: Fanny Burney.

And that’s *my* last word.

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Wonders, continued from page 107

numerous, often combined afresh in word strings that under orderly rules include words that make up to a tenth of any utterance, though only 1 percent of our lexicon. Consider the inferences that form around *for, to, but, as, if, that*—syntax at work. The incomplete language of two-year-olds, as of adults speaking in new-made languages, lacks syntax and has few real sentences. Read a few samples of actual protolanguage: *moi faim; me hungry; no can; horsie stuck*. Compare them with the rest of this page. Such phrases, workable for many purposes as new words are formed, are far from the full generative force von Humboldt recognized. (That combinatorial richness is shared by silent human gesture; witness American Sign Language and its like worldwide.)

A fascinating conjecture (offered in 1995 by Derek Bickerton, now emeritus professor of linguistics at the University of Hawaii at Manoa) is this: protolanguage developed among the later forebears of modern humans, demanding a growing memory for words yet using a minimum of rules. After a million-year growth in stature and in cranial capacity,

humans of fully modern anatomical kind first appeared about 120,000 years ago. With them—with us—detectable skeletal change ceased. It took another 50,000 or 60,000 years for our *H. sapiens* culture to flower. In the delay we can suppose a minor genetic upgrading of the brain to manage a skein of flexible rules (syntax)—so modest a neural enlargement as to go unseen in bony remnants but conspicuous in swift cultural change. Occupation of new continents, body ornamentation, cave paintings, burials, early ceramics, fire making, bead making, huts, fiber and cloth—all these had appeared by 20,000 years ago.

After that epochal change to full language, any task could be apportioned, any evidence weighed and the hypothetical fully evoked. Human society began the openness to rapid change. We differ from other earthly creatures not in the first visible step to working stone or using fire but more in the steady rise of entire societal technologies, now far beyond protolanguage. After long, inordinate growth in our global number, a plateau in human population draws near, perhaps to bring with it the comity of a more stable epoch.

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DAN WAGNER

Name Recognition

What's in a name? Would my Aunt Rose have been as sweet had she been my Aunt Petunia? wonders **Steve** (or Stevie, or even Steven) **Mirsky**

*Tiger, Tiger, golfing keen
From the teebox to the green
Would you be the litter's pick
By your real name, young Eldrick?
(with apologies to William Blake)*

A city full of people forced to attract one another's attention with an endless chorus of "Yo!" would be a ponderous place, or at least sound suspiciously like New York City. Therefore, handles come in handy. Theoretically, a name is merely a designation, a way to distinguish one individual from another. But various studies over the years have shown that some names also carry the weight of expectations. And those expectations, primarily on the parts of the parents who dubbed little Dub, can subtly influence the dubbee.

James Bruning has studied the appellation issue for some three decades, as a psychologist at Ohio University. (His institution's name often gets it confused with that other school that has all the big-name running backs, who, coincidentally, have their names on their backs when they run.) Bruning's years of re-

search lead him to offer this counsel for couples musing on names for the new arrival: the baby will be an adult for most of its life. "I always advise parents to at least put a Mr. or Mrs., or President, or King or Queen—some title that says 'adult'—in front of the name," he says. "Do that, and I think you very quickly could drop a lot of choices." If nothing else, we could avoid a future where the nursing homes are teeming with Briannas, Kaitlyns, Austins and Tylers.

Bruning's most recent foray into the name game, published in the latest issue of the *Journal of Social Psychology*, looked at how people's prejudices about names might lead to presumptions about someone's chances for career success. Twenty students who served as study subjects knew only two things about hypothetical job-seekers: their first names and the work they were interested in. The 16 names and 16 jobs, however, had been carefully chosen to enable the consideration of three criteria.

The first was simply whether the name

was male or female. Hank and Francis, for example, are men, and Emma and Hester are women.

The second variable was the perceived masculinity or femininity of the name, based on the results of a large survey. Hank was not only a guy name but was also judged to be a strapping, meat-eating-type guy name. On the other hand, Francis was rated among the most femi-

We could avoid a future where nursing homes teem with Briannas, Austins and Tylers.

nine of men's names. (Francis Albert in combination, however, was no doubt a very masculine man's moniker, at least while Sinatra was alive and moody. Nevertheless, honesty being the best policy, Francis knew he was better off being Frank.) Emma was one of the study's feminine female names, whereas Hester was thought to be a masculine female name. (Hey, Hawthorne stitched the scarlet letter on a Hester, not a Susie.)

The final consideration was the stereotypical masculine or feminine nature of the job. Most people assume, for example, that a plumber or truck driver is going to be a man and that a manicurist or flight attendant is a woman. They apparently haven't flown lately, but that's what they assume.

The data from the 20 Dicks and Janes showed, no surprise, that they put their money most confidently on women with feminine names trying for "female" jobs and on men with manly names trying for "male" jobs. "I wouldn't overestimate the impact of names," Bruning warns, "but at the same time, names are an important part of first impressions." And a first impression can be a lasting one. If you had to open one of two doors, to reveal an athlete for you to market worldwide, who would you hope came out: the Eldrick or the Tiger?

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"Perhaps, Hatten, you'd be happier at a guess tank."