Must Science and Religion Be Enemies? (*see page 88*)

SCIENTIFIC AMERICAN

Warmer Water, SUPER HURRICANES
page 44

July 2007 www.SciAm.com

The MEMORY CODE

Learning to read minds by understanding how brains store experiences

Hijacked Cells

How Tumors Exploit the Body's Defenses

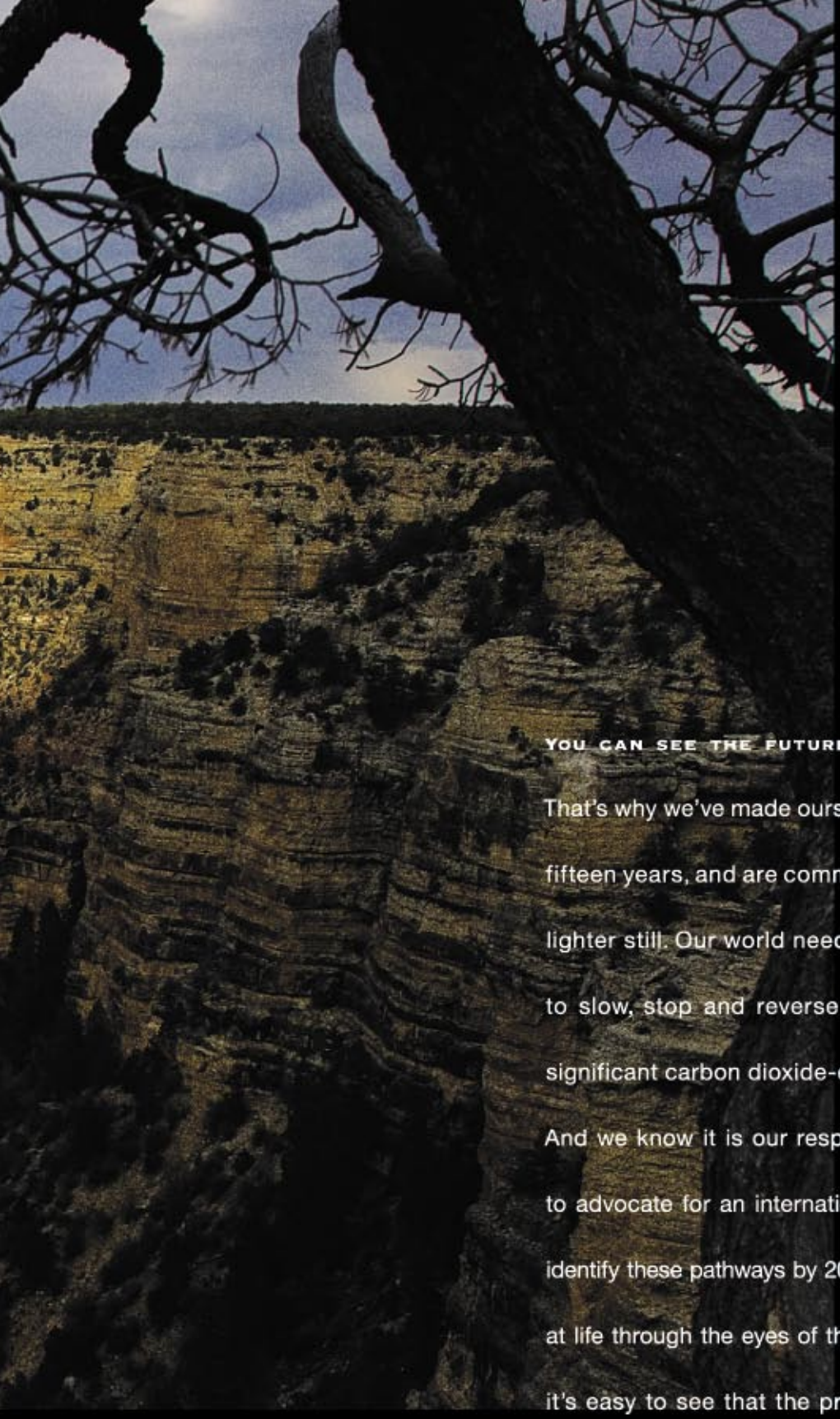
Wireless

Light Beats Radio for Broadband

No-Man's-Land

Suppose Humans Just Vanished ...

www.dow.com/climatechange



YOU CAN SEE THE FUTURE IN A FOOTPRINT.

That's why we've made ours lighter in the past fifteen years, and are committed to making it lighter still. Our world needs clear pathways to slow, stop and reverse emissions by all significant carbon dioxide-emitting countries. And we know it is our responsibility to advocate for an international framework to identify these pathways by 2010. When you look at life through the eyes of the Human Element, it's easy to see that the present is the most important part of the future.

Dow

OYSTER PERPETUAL SUBMARINER DATE

For more than 50 years, the Rolex Submariner has been the standard for professional diving watches. Designed to be waterproof to 300 meters, the Submariner features a Triplock winding crown and the unidirectional bezel that Rolex pioneered half a century ago. Today, it continues to be the quintessential sportsman's watch, above and below sea level. **ROLEX.COM**

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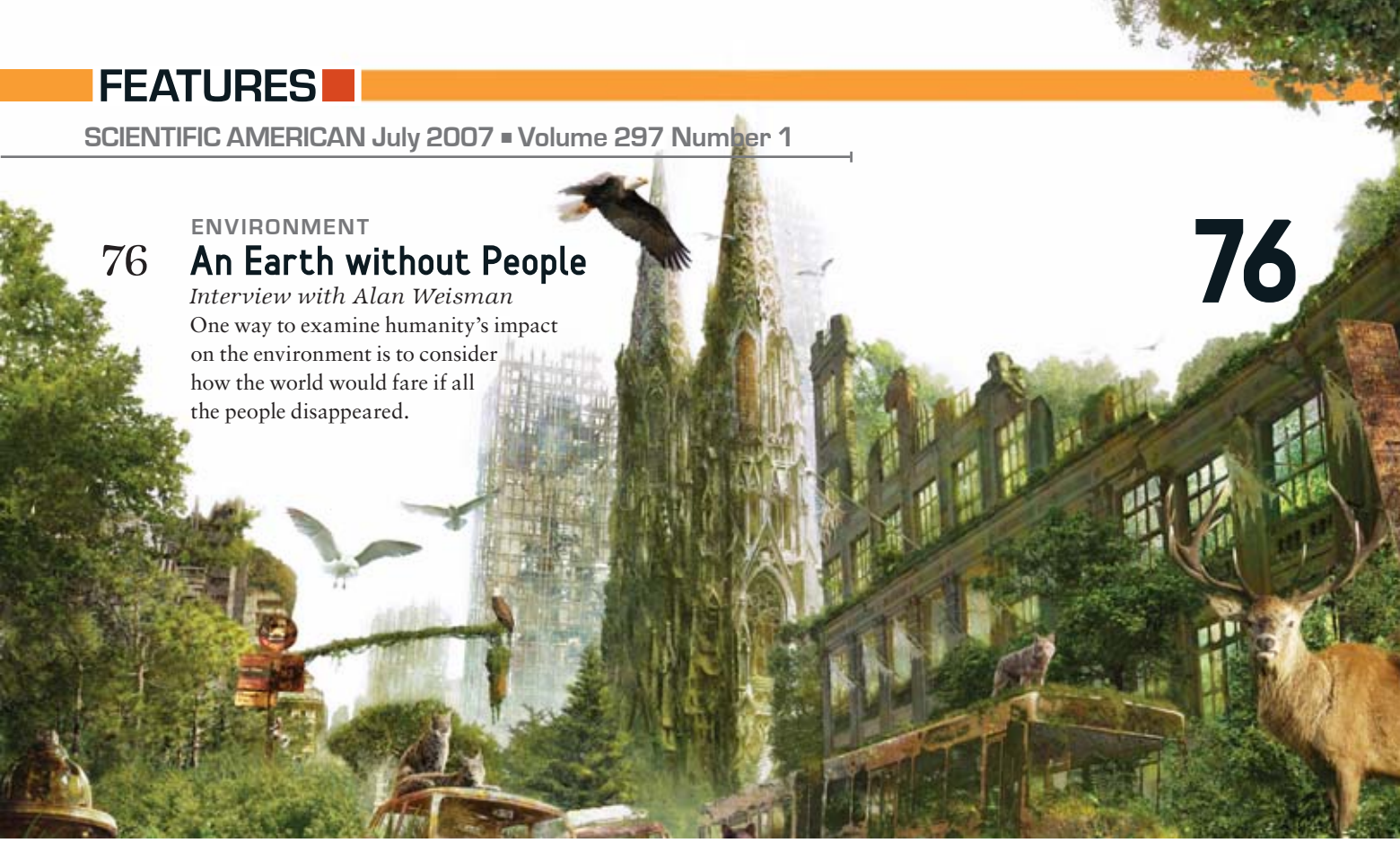
FEATURES

SCIENTIFIC AMERICAN July 2007 ▪ Volume 297 Number 1



ON THE COVER

Artist Jean-Francois Podevin (www.podevin.com) fancifully depicts the goal of uncovering a universal neural code: the rules the brain uses to identify and make sense of the body's experiences.

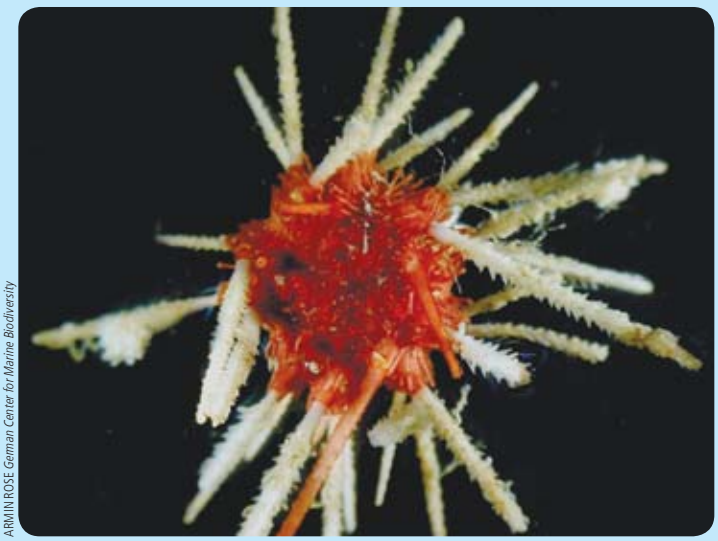
SCI AM

The Conversation Continues

Find an extended version of the views of Lawrence M. Krauss and Richard Dawkins at **www.SciAm.com/ontheweb**

SciAm.com

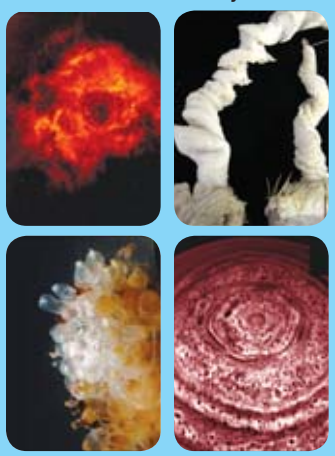
ANTARCTIC URCHIN (*below*) is one of the astonishing array of previously unknown creatures that populate the cold depths of the Antarctic. Three expeditions to the Weddell Sea between Antarctica and the wider South Atlantic brought more than 1,000 species, ranging from single-cell foraminifera to oddly shaped crabs. Catch other breaking news, analyses of key issues, photo essays and more at **www.SciAm.com/ontheweb**



ARMIN ROSE *German Center for Marine Biodiversity*

WHAT IS IT?

Find Out in the Gallery



IPHAS NORTHERN GALACTIC PLANE SURVEY/NICK WRIGHT *University College London (top left)*; PATRICIA BRENNAN *(top right)*; A. BRIESTEIN *(bottom left)*; NASA/JPL/UNIVERSITY OF ARIZONA *(bottom right)*

We're Number Two

For health care, Canada is as good as or better than the U.S. A recent study could fortify the argument that the U.S. should cease to be the only developed nation without universal health coverage.

Podcast: Battered Brains

Even when wearing headgear, amateur boxers suffer strokelike insults to the brain.

Blog: Scent of a Man

Sniffing around for a human pheromone.

News: Scaling Back Greenhouse Gas Emissions While Keeping the Lights On

Fact or Fiction?

Underwire Bras Cause Cancer

Is your bra killing you?

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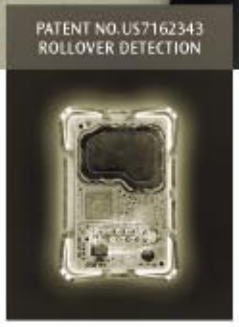

The new 2008 Mercury Mariner and Mariner Hybrid with the Safety Canopy™ system. Besides dual-stage front airbags,** Mariner also employs the Safety Canopy™ system, a network of sensors and side-curtain airbags that deploy in the event of a rollover. So that comfort you feel inside the Mariner goes way beyond the leather-trimmed seats.

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MERCURY | NEW DOORS OPENED

DEPARTMENTS

LISA KYLE

SCI AM

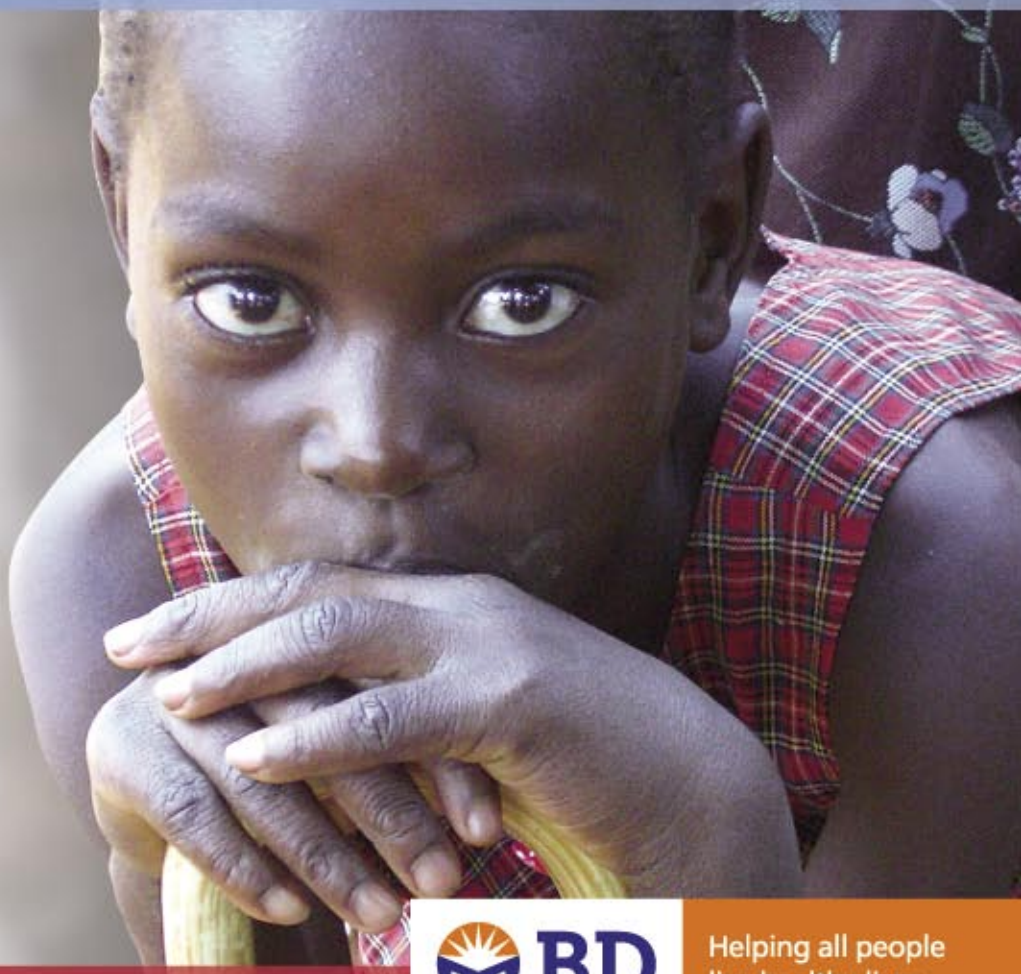
Featured Q & A
Latanya Sweeney and our reporter discuss "anonymizing" programs, "deidentifiers" and more at **www.SciAm.com/ontheweb**

Every day, 1,600 children die of HIV/AIDS … their lives cut short.

12 million children have been **orphaned by HIV/AIDS** in sub-Saharan Africa alone—who will raise them?

Last year, 1 million African schoolchildren **lost their teachers** to HIV/AIDS[1]—who is going to teach these children?

Up to 20% of the nurses in South Africa are HIV positive[2]—**who will care for the children?**



Save the Children.

GBC
GLOBAL BUSINESS COALITION ON HIV/AIDS, TUBERCULOSIS AND MALARIA

CLINTON HIV/AIDS INITIATIVE

iavi
International AIDS Vaccine Initiative

BD

Helping all people live healthy lives

Partners in the battle against HIV/AIDS

The impact of HIV/AIDS on children is nearly incomprehensible. A crisis of this magnitude requires an assault on many fronts.

BD, a medical technology company, is privileged to fight for future generations with partner organizations across the healthcare and policy spectrum.

Working to discover vaccines to prevent infection, the International AIDS Vaccine Initiative is using a $1 million BD gift, as well as the BD FACSCalibur™ flow cytometry system.

For those infected with HIV, the William J. Clinton Presidential Foundation is enabling providers to access affordable CD4 immunocytometry tests from BD.

With Save the Children, BD donates medical supplies and money to establish clinics in Eurasia, where infection rates are rising faster than anywhere else in the world.

Because the reuse of injection devices is a significant cause of disease transmission in developing countries, BD is working with the United Nations and nongovernmental organizations to help ensure that childhood immunizations and other injections are administered safely.

In addition, through its active association with the Global Business Coalition on HIV/AIDS, BD is helping to mobilize businesses in the fight against AIDS.

BD—selected as one of America's Most Admired Companies by *FORTUNE* magazine[3]—is proud to partner with these and other organizations to protect life by addressing fundamental healthcare issues in every corner of the world.

BD—Helping all people live healthy lives.

Please visit www.bd.com.

[1] UNAIDS statistics, 2000, 2003.

[2] *Nursing World.*

[3] "America's Most Admired Companies" annual survey, 2007; *FORTUNE* magazine, March 19, 2007.

Photo ©Gary Cohen

A Little Revolution

Bold and visionary science still has a home in our new design

July brings Independence Day, a time for celebrating freedom. With this July issue, SCIENTIFIC AMERICAN shakes off the constraints of its past design and embraces more of the opportunities of publishing in the digital age. The topflight content of SciAm is unchanged: our feature articles continue to be written by leading scientific authorities and journalists and illustrated by the finest artists. The layouts and figures, however, are more modern and approachable. Busy readers will also appreciate the introductions from the editors that highlight the major points of the feature articles. And for readers whose appetites are only whetted by the articles, notes throughout the issue point to related content online at www.SciAm.com that can further their explorations.

At your suggestion, we have taken our SciAm Perspectives editorial, bundled it with the voices of our regular columnists and added a Forum for guest essayists to create a consolidated Opinion section. We have also brought to print our popular online Fact or Fiction? column and installed it on the last page.

A widespread weakness of science journalism, in my own opinion, has historically been a lack of follow-up. News media routinely tout recent discoveries or announcements of promising inventions, then move on to the next breakthrough du jour, with nary a backward glance. Years go by, and the increasingly jaded public is left muttering, "Where's my flying car?" To at least a small degree, our new Updates page addresses that lapse: it looks back at the science in past headlines and reports on what did (or did not) come of it.

Turning back to the magazine in your hands, you will find a set of feature articles that are by turn informative, imaginative and provocative. Take our cover story by neurobiologist Joe Z. Tsien on "The Memory Code" (*page 52*). Tsien and his co-workers have begun to tease out of the brain a code for understanding how neurological activity corresponds to specific thoughts and memories. Some of the theoretical fruits of these studies—such as computers that can read human thoughts in detail—are far off in the future, if ever, but the fact that researchers today can even speak meaningfully about pursuing such goals is breathtaking.

A more pressing concern is climate change and how it contributes to the severity of cyclones, as Kevin E. Trenberth explains in "Warmer Oceans, Stronger Hurricanes" (*page 44*). Unlike rising sea levels that may become critical decades from now, intensifying storms already seem to be a problem. The 2007 hurricane season, unlike that of 2006, will most likely be a tough one—which, as Mark Fischetti reports in our News Scan section (*page 21*), is unwelcome news in New Orleans, where post-Katrina repairs to the levee system may not be enough to protect the city.

Author Alan Weisman, who discusses his new book in "An Earth without People" (*page 76*), is not specific about what calamity might eliminate the human race, but that is beside the point. Rather he argues that imagining a world without *Homo sapiens* illuminates how the footprint of our species on the environment can be at once transient and eternal. Finally, in the dialogue "Should Science Speak to Faith?" (*page 88*), scientists Lawrence M. Krauss and Richard Dawkins debate whether science and religion are or must be antagonistic. Their views will surely ignite discussions among readers—but then, it wouldn't be July without fireworks.

JOHN RENNIE *editor in chief*

FLYNN LARSEN

Among Our Contributors

RICHARD DAWKINS
Evolutionary biologist
University of Oxford
His nine books, ranging from *The Selfish Gene* (1976) to *The God Delusion* (2006), have made him one of the world's most celebrated essayists both on evolution and on scientific critiques of religion.

LAWRENCE M. KRAUSS
Physicist
Case Western Reserve University
A prolific writer and commentator on science, he is the author of seven popular books, including *The Physics of Star Trek,* and four articles for *Scientific American.*

STEPHEN J. O'BRIEN
Geneticist
National Cancer Institute
His DNA-based studies of cat evolution have brought home to him that almost all of the 37 feline species are in danger—a trend that he hopes science can reverse.

KEVIN E. TRENBERTH
Climatologist
National Center for Atmospheric Research
A lead author for all three Intergovernmental Panels on Climate Change, he has been outspoken on the need to protect coastal areas from flooding related to global warming.

ALAN WEISMAN
Science writer
A teacher of journalism at the University of Arizona, he is the author of five books, including *The World without Us,* due in July from St. Martin's Press.

It's silicon that thinks.

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Do You See What I See?

Color Perception ■ Digital Archival ■ Black Holes ■ Happiness

MARCH 2007

"One has the feeling that Gordon Bell will eventually begin to record his reviewing of his record of his experiences, setting him in an endless loop terminating only when his registers overflow."
—David Hopp DURHAM, N.C.

■ Colorful Origins

ACCORDING TO "Illusory Color and the Brain," by John S. Werner, Baingio Pinna and Lothar Spillmann, an object's color is made relatively stable by the brain despite environmental changes. I am partially color-blind and have observed that when looking at a particular object in natural light, the vividness of its color will be affected by my proximity to it. Furthermore, in my trade as an electrician, I have found that the use of a flashlight shined on color-coded wires at close range assists in their discernment.

TJ Downey
New Bloomington, Ohio

WERNER, PINNA AND SPILLMANN REPLY: *Changes in illumination can indeed influence color discrimination. A partially color-blind individual may find such discrimination more difficult to make, either because one type of his or her retina's cones (those cells that are responsible for absorbing light during the day) ceases to function or because photoreceptor pigments in the cones overlap in their absorption more than usual. Small differences in spectra might be easier to detect when they are under brighter lighting or when they take up a larger field of vision.*

It is important to distinguish between the discrimination and the appearance of colors (the latter being the main topic of our article). If one looks at a small white patch in a larger field of vision as its illumination from the sun varies throughout the day, the physical changes in its wavelength composition are striking. If all we could know about the patch's color were based on this observation, we might call it blue in the morning and yellow in the afternoon. The identification of objects by color would be considerably flawed if this were the case. Because of mechanisms in the eye and brain, most individuals can identify colors in the same way as one another when viewing a broad range of objects under a number of light variations, but this ability may fail when viewing an isolated part of a scene.

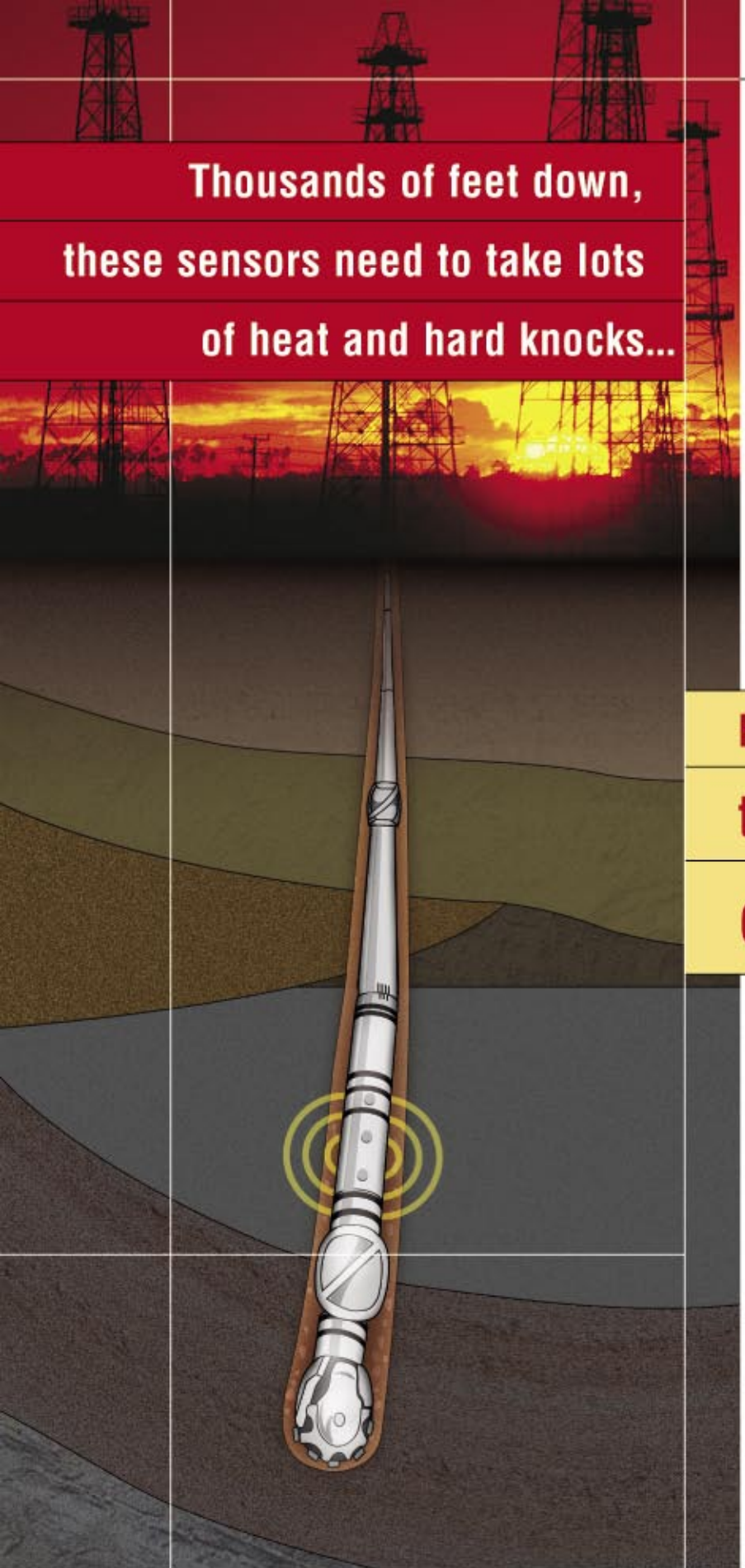
■ Egocentric Archival

IN "A DIGITAL LIFE," Gordon Bell and Jim Gemmell describe Bell's self-experimentation with the possibility of individuals digitally archiving their entire existence. The authors appear to be substituting the minute recordings of experience for a true life. One has the feeling that at some time Bell will begin to record his reviewing of his record of his experiences, setting him in an endless loop terminating only when his registers overflow.

The activity of recording an experience separates an individual from the experience itself. And digital recordings, being what they are, can be edited and reorganized. That stupid choice, the thoughtless remark, the road traveled—they can all be changed so that the record is no more than a "cult of personality."

This kind of archiving, it seems to me, is different from a life of contemplation or of meditative concentration, because these have enlightenment as a goal. Bell's approach isolates, which, I suppose, is what all compulsions do.

David Hopp
Durham, N.C.



Thousands of feet down, these sensors need to take lots of heat and hard knocks...

The science of well logging

Oil exploration uses "well logging" to measure and map the properties of each layer of rock and fluid as test holes are being drilled.

For one type of downhole testing, neutron or gamma radiation is emitted into the surrounding rock at each stratum. Then, the resulting radiation scatter is measured... Which reveals rock density and porosity—and also helps locate the prized hydrocarbon zones!

But detecting the scattered radiation requires very sensitive *photomultiplier tubes* (PMTs). Ones that can *remain* sensitive in the harsh downhole environment—withstanding severe shock and vibration, and temperatures of nearly 200°C!

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For decades Hamamatsu has been developing and optimizing PMTs—for many *hundreds* of applications...

Hamamatsu's unique ruggedized PMTs maintain sensitivity under extreme conditions.

For well logging we have made PMTs that are smaller and more robust. We have combined advanced materials with designs that perform under extreme conditions. Which may be why Hamamatsu supplies most of the PMTs used in the world's oil well logging systems!

For science and for mankind, Hamamatsu continues to open the new frontiers of Light.

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HAMAMATSU

Photon is Our Business

Extent Horizon

IN "BLACK HOLE BLOWBACK," Wallace Tucker, Harvey Tananbaum and Andrew Fabian refer to the diameters of black holes in regard to the size of our solar system. My understanding of black holes was that they have infinitesimally small volumes and densities that therefore approach infinity. How could a black hole have a diameter that could be related to the size of our solar system?

Matthew Briggs
Seattle

TUCKER, TANANBAUM AND FABIAN REPLY: *Our wording was imprecise. We should have specified that we were describing the diameters of the event horizons of the black holes in question.*

The event horizon defines the "point of no return" around a black hole: matter or radiation cannot escape a black hole's gravitational pull unless it is outside the radius of the event horizon. This radius, which increases with the mass of a black hole, appears in equations describing black holes' properties. The radius of the event horizon of a rapidly spinning black hole with a mass of a billion suns, such as we described, is about equal to the distance between Saturn and the sun.

Ancestral Avidity?

MICHAEL SHERMER'S reference in "(Can't Get No) Satisfaction" [Skeptic] to studies showing that individuals would prefer a lower income and even less for others, rather than a higher income and even more for others, does not surprise me. Most subjects would not believe that prices would stay the same if everyone else earned much more than they do. Humans have learned through personal experience, and perhaps that of many generations of ancestors, that resources are limited and often scarce. Lower income for others may be part of most people's prerequisite for happiness: being alive.

Brett Porter
Australia

SHERMER REPLIES: *The findings from these studies are counterintuitive when we think in rational terms, but using a model of evolutionary economics helps us to see that our wants related to what makes us happy or unhappy tend to be relative to what other people have and are not based on some absolute measure. In the Paleolithic past, humans evolved in tiny communities of economic simplicity and relative equality. Happiness could not be found through wealth accumulation, because there was so little to accumulate as well as social pressure to redistribute what could be accrued. Our senses and perceptions evolved for short-term assessments, direct comparisons and relative social rankings.*

JOHN S. WERNER, BAINGIO PINNA AND LOTHAR SPILLMANN

CORRECTED IMAGE from page 95 of "Illusory Color and the Brain."

ERRATA The illustration at the top of page 95 in "Illusory Color and the Brain," by John S. Werner, Baingio Pinna and Lothar Spillmann, contains an error. The black inside the colored rings was accidentally printed over cyan and magenta, making it physically darker than the black of the surrounding area. The correct illustration appears on the opposite page.

On page 82 of "Diesels Come Clean," by Steven Ashley, the box "Spark vs. Compression" incorrectly states that a diesel engine is more fuel-efficient than a gasoline engine because diesel fuel has a higher energy content. The diesel's superior efficiency derives mainly from its higher compression ratio and unthrottled air intake, among other factors.

"Back to the Future," by David Biello [News Scan], refers to Brodmann's area as a specific region of the brain. Brodmann's area in fact refers to several regions of the cerebral cortex.

Letters to the Editor

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Established 1845

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Strangeness Theory ▪ Alien Evidence ▪ Sensible Fish

Compiled by Daniel C. Schlenoff

JULY 1957

ELEMENTARY PARTICLES—"In the strangeness theory, then, we have a means of classifying strange particles. The theory is consistent with the fundamental idea of four groups of particles and three types of reactions. At present our level of understanding is about that of Mendeleyev, who discovered only that certain regularities in the properties of the elements existed. What we aim for is the kind of understanding achieved by Pauli, whose exclusion principle showed *why* these regularities were there, and by the inventors of quantum mechanics, who made possible exact and detailed predictions about atomic systems. We should like to know the laws of motion of the particles; to predict, among other things, how they will interact when they collide and how these interactions will deflect one particle when it collides with another.—Murray Gell-Mann and E. P. Rosenbaum"

[EDITORS' NOTE: Gell-Mann won the 1969 Nobel Prize in Physics for this work.]

RAINMAKING—"The Council of the American Meteorological Society recently summed up the present evidence for the effectiveness of cloud-seeding. Its verdict: Not proven. Conditions favorable for artificial rainmaking, the statement points out, are very much the same as those which usually lead to natural rain. Says the Council: 'Cloud-seeding acts only to trigger the release of precipitation from existing clouds.' There appears to be no convincing evidence that ground-based silver iodide generators can increase rainfall in flat country. They seem effective only in cold weather and in regions where a mountain range forces the air to rise. The seeding of inactive cloud formations may act to dissipate them rather than cause them to produce rain."

FIGHTING FIRES—protecting those who serve, 1857

JULY 1907

MARTIANS—"If vegetation exists on Mars, as Prof. Lowell would have us believe, we are at once introduced to the probability of life on that planet. The existence of a flora is ground for suspecting a fauna. On Mars we find ourselves confronted in the canals and oases by precisely the appearance which the planet should show if it is an inhabited world. Dearth of water is the key to the character of the canals. The only available water on Mars is that coming from the semi-annual melting at the one or the other cap of snow. If there are intelligent beings on Mars, they must find some means of conducting the scant supply of water from the poles to the centers of populations."

For the complete article on Mars from 1907, go to **www.SciAm.com/ontheweb**

AUTOCHROME LUMIÈRE—"A new process for photography in colors has been brought out at Paris by Messrs. Auguste and Louis Lumière, who are among the leading *savants* of France in this department of science. They are able to take a photograph in colors upon a single plate and in an ordinary camera, with exposures of one second or less. The specially prepared plate is formed by placing microscopic colored particles upon a glass plate (it is found that potato starch is the best adapted for the purpose). Three colors are used for the particles, and they form the color screens [filters] for the plate. The layer of colored grains is first covered with a waterproof varnish, then comes a layer of gelatino-bromide emulsion which is rendered perfectly panchromatic and is sensitive to all the colors."

[EDITORS' NOTE: The Autochrome process was the most popular one for producing color photographs until the advent of Kodachrome in 1935 and Agfacolor in 1936.]

JULY 1857

PROTECTING FIREFIGHTERS—"In apartments filled with smoke to an extent that would render it impossible to breathe at the height of a man's head above the floor, there is in nearly every instance a draft of cool, pure air near the floor. To take advantage of this circumstance a tight-fitting mask has been adapted, from which depend air tubes, through which a person breathes; the extremities of the tubes reach to within an inch or two of the floor."

PISCICULTURISTS—"We wish to impress indelibly upon the minds of those who wish to re-stock our streams with an abundance of good fish, that they must keep the streams clean and pure, if they expect to succeed. It is true that salmon and other fish have been banished from rivers and creeks in which they once abounded; but this was not owing to the great depredations of fishermen, as has generally been supposed. The erection of saw mills on creeks and rivers destroyed the spawn of both salmon and trout, and it has been found that the former fish have been banished from all rivers on which chemical works have been established. They love clear running streams of water—they are sensible fish." ■

SCIENTIFIC AMERICAN, VOL. XII, NO. 44, JULY 11, 1857

How do you keep your company filled with independent thinkers?

You stay independent.

Let's face it: being an idea person can be tough. It seems like everywhere you turn, barriers pop up. Bureaucracy, red tape, the "guys upstairs." It's a wonder any breakthrough ideas ever break through at all. At BMW ideas are everything. And as an independent company, we have the freedom to stand by the leading-edge concepts of our designers and engineers. For instance, green-lighting the idea to build an internal combustion engine powered by liquid hydrogen. This is no mere concept car, mind you. It's already complete. In fact, our first 100 hydrogen cars released in January, and the BMW H2R has broken speed records, traveling over 185 mph. Opportunities like this keep the best and brightest here at BMW. After all, they don't want to work at a place that simply talks about ideas. They want to work at a place that makes sure great ideas live on to become Ultimate Driving Machines.®

Methane Mystery ▪ Edible Vaccines ▪ Sun's Swift Core ▪ Painkillers

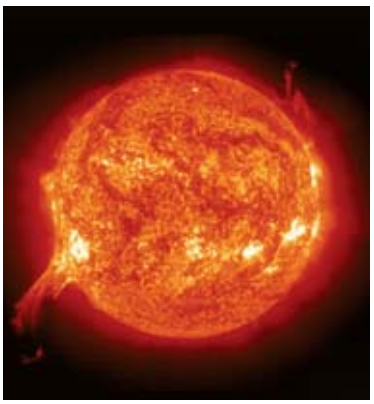
Edited by Philip Yam

Hepatitis-Beating Bananas

Potatoes, tomatoes and other edible plants might someday serve to immunize people, especially those in the developing world [see "Edible Vaccines," SciAm, September 2000]. In a review published in the June issue of *Biotechnology Progress*, Indian researchers conclude that bananas are the most promising edible vaccine against the hepatitis B virus, which lives in about 5 percent of the world's population. Potatoes have received more extensive study, but the researchers argue that bananas are the better choice because they can be eaten raw and taste good to most children. The task remains to boost the level of immune-triggering hepatitis protein in the fruit.

Spin in the Sun

After staring at the sun for the past 11 years, the Solar and Heliospheric Observatory (SOHO) still has not gone blind. Designed to last only two years, the instruments onboard continue to provide surprises [see "SOHO Reveals the Secrets of the Sun," SciAm, March 1997]. Among the latest revelations: the sun's core rotates faster than its surface. Researchers reporting online May 3 in *Science Express* analyzed tiny vibrations in the solar surface that may originate from down-rushing plumes, which create waves that can pass through the core and reach the surface on the other side. These waves raise the surface only millimeters, but that is enough for researchers to analyze them and to conclude that the core rotates three to five times faster than its overlying layers. The extra spin may be a remnant of the sun's formation.



MEDIOIMAGES/CORBIS (*bananas*); NASA (*sun*); JOHN KAPRIELIAN *Photo Researchers, Inc.* (*pills*)

No Methane from Plants?

German researchers upturned scientific dogma last year when they reported that plants release the potent greenhouse gas methane [see "Methane, Plants and Climate Change," SciAm, February 2007]. In the April 27 online issue of *New Phytologist*, a Dutch group contradicts the findings. Tom A. Dueck, a botanist at Wageningen University in the Netherlands, and his colleagues monitored methane emissions from six species of plants (basil, evening primrose, maize, sage, tomato and wheat) under controlled aerobic conditions. The researchers found no evidence that plants produce methane—not even those that the German group tested.

But methane emissions from plants vary tremendously and are dependent on many environmental parameters, asserts Frank Keppler of the Max Planck Institute for Chemistry in Mainz, Germany, who led the team that made the original discovery. "In our opinion, the Dueck et al. study did not cover these parameters sufficiently to allow them to conclude that plants do not produce methane," Keppler says.

The disparate findings should not necessarily come as a surprise, suggests plant biologist Kevin L. Griffin of Columbia University's Lamont-Doherty Earth Observatory. "Conclusions are not always 180 degrees out of phase like this, but they can be, especially when the thought is new," he says. A step toward solving this discrepancy is to figure out how plants produce methane—if, that is, they actually do.

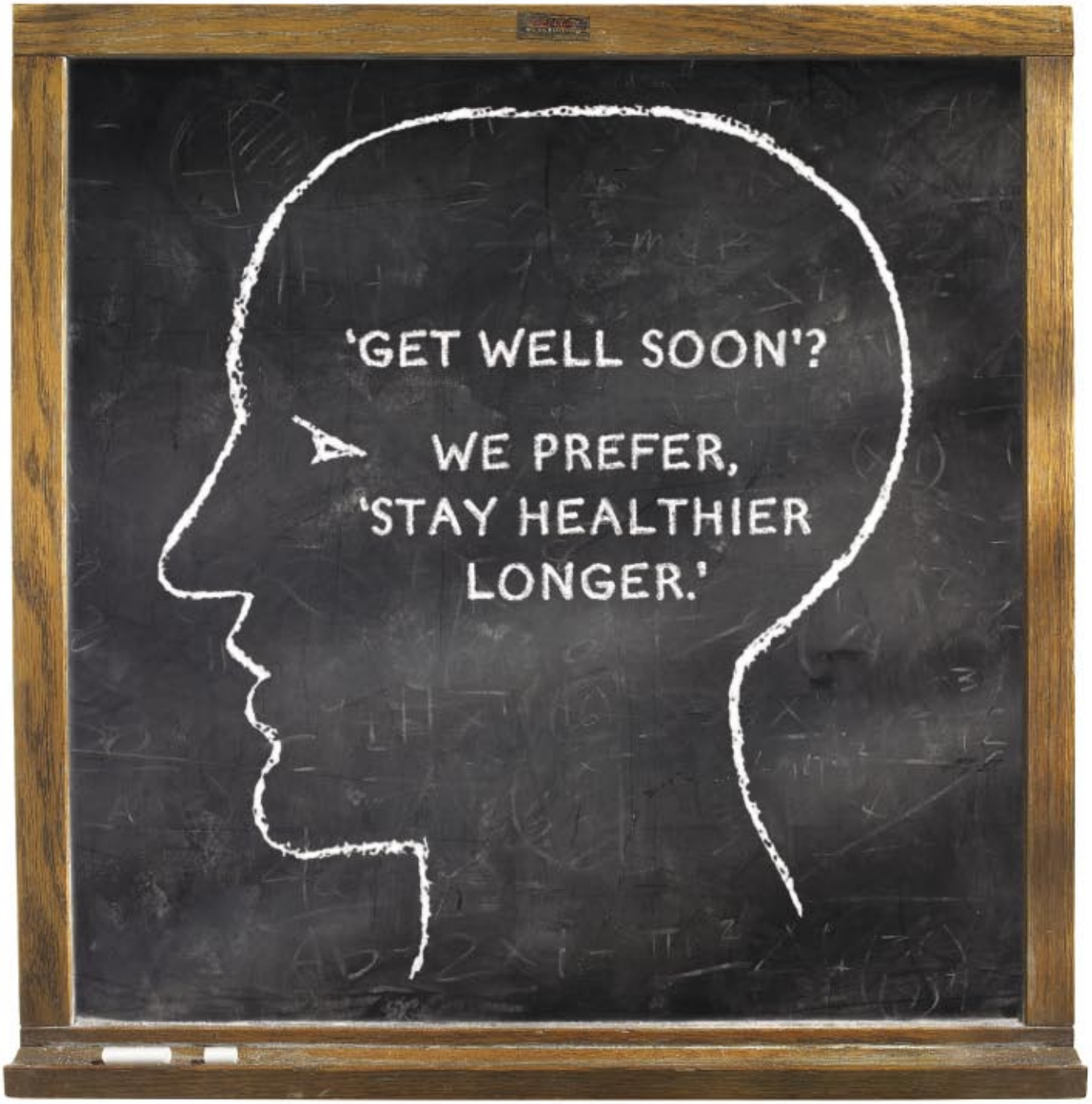
—Thania Benios

MAIZE PLANTS may or may not emit methane.

Not beyond Vioxx Yet

The world still needs more effective ways to combat pain. On April 27 the FDA rejected Arcoxia, a COX-2 inhibitor for osteoarthritis intended as Merck's follow-on to Vioxx. New drugs under development might avoid the cardiovascular problems linked to the COX-2 compounds [see "Better Ways to Target Pain," SciAm, January 2007].

PERRY MASTROVITO *Corbis* (*corn*); MEDIOIMAGES/CORBIS (*bananas*); NASA (*sun*); JOHN KAPRIELIAN *Photo Researchers, Inc.* (*pills*)



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CLIMATE

Warming to Law

After the U.S. Supreme Court ruling, how stiff will greenhouse gas regulations be? BY CHARLES Q. CHOI

In its first case confronting global warming, the U.S. Supreme Court ruled in April that greenhouse gases such as carbon dioxide are air pollutants that the Environmental Protection Agency can regulate. As a consequence, experts agree that greenhouse emissions from automobiles and possibly power plants will face regulations. The debate now will focus on how strict—or lax—those rules will be.

The EPA had long claimed to have no authority in regulating these gases because they were not air pollutants under the Clean Air Act. Moreover, the agency also stated that even if it did have the power to regulate such gases, it would not do so. Discontented with the federal response to global warming, environmental groups joined forces with three cities, one U.S. territory and a dozen states, led by Massachusetts, to challenge the EPA in court. Siding with the EPA were several industry groups and 10 states, a number of which rely heavily on coal, electricity or motor vehicle production.

In a 5–4 decision against the EPA, the Supreme Court majority decided that the scientific evidence (some of which came from the agency itself) suggested that Massachusetts and other states were experiencing harm from global warming and that the EPA had the authority to redress it. For instance, rising sea levels "meant hundreds of millions of dollars were at risk in terms of damage to our coastline," explains James Milkey, assistant attorney general for Massachusetts.

In the face of the Supreme Court decision, the EPA could still refuse to control tailpipe emissions of greenhouse gases, but such action will prove problematic given the decision and the EPA's mandate to regulate dangerous pollutants under the Clean Air Act. If the agency were to refuse, "there'd be a lawsuit against them that would win," predicts Michael Herz, an environmental, constitutional and administrative law professor at the Benjamin N. Cardozo School of Law in New York City. Indeed, in May, President George W. Bush ordered federal agencies to work toward regulations to reduce motor vehicle greenhouse gas emissions and gasoline consumption.

BRENDAN SMIALOWSKI Getty Images

GREENHOUSE GAS ATTACK: Attorney General Tom Reilly of Massachusetts, with Assistant Attorney General James Milkey looking on, spoke outside the U.S. Supreme Court last November regarding the state's lawsuit brought against the Environmental Protection Agency. The court decided that the agency must view greenhouse gases as pollutants.

Mass. v. EPA, as the case is known, should affect a number of other decisions around the nation that had been placed on hold. Notably, California and 11 other states had been seeking waivers from the EPA permitting them to pass laws requiring reduced car emissions of greenhouse gases from the 2009 model year onward. Cars release these gases as they burn fuel, so the proposed reduction in emissions "effectively means higher fuel mileage cars," Herz points out. (Federal laws prevent states from setting their own mileage standards.) California governor Arnold Schwarzenegger has threatened that his state would sue the EPA if the agency did not decide on the waiver by the end of October.

The major result of *Mass. v. EPA* "is that business will go and try to make a deal with Congress regarding federal regulations on greenhouse gas emissions," says Mary Nichols, director of the Institute of the Environment at the University

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of California, Los Angeles, and former EPA assistant administrator of air and radiation. "Congress is not just going to let the EPA take control of this issue."

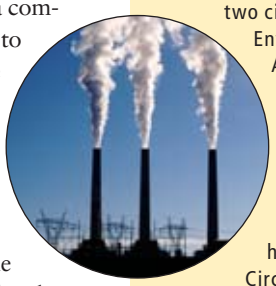
In essence, such federal laws could resemble "homegrown versions of the Kyoto Protocol," Herz says, referring to the international agreement to reduce greenhouse gas emissions. "At this point, it's going to be a battle about stringency and not whether or not standards will happen."

In the absence of federal legislation, some states have already seized the initiative and could set the tone for the rest of the nation. Ten northeastern and mid-Atlantic states are participating in the first mandatory program in the U.S. devoted to fighting global warming. Called the Regional Greenhouse Gas Initiative, the group seeks to cut current emissions by 10 percent by 2019 through a cap-and-trade system. Such a system limits the total amount of greenhouse gases emitted while allowing companies to pay for releasing more or to earn credit for spewing less.

Still, any federal regulations that Congess helps to create would probably preempt state laws regarding greenhouse gas emissions from tailpipes and elsewhere, Nichols points out. They would tell "California and the others they can't do anything they want to," she says. The Alliance of Automobile Manufacturers, which supported the EPA in the Supreme Court case, "certainly believes there needs to be a comprehensive federal policy in place to reduce carbon dioxide, and we intend to work constructively with members of Congress on that issue," says alliance spokesperson Charles Territo. The Supreme Court ruling may represent a milestone in the legal battle over climate change, but a long, hard road most likely remains ahead.

Charles Q. Choi is a frequent contributor based in New York City.

Going against the EPA



WILLIAM MANNING *Corbis*

Another case that had been held pending the U.S. Supreme Court's decision in *Mass. v. EPA* concerns the regulation of greenhouse gas emissions from new power plants and other stationary sources. A lawsuit brought on by three environmental groups, 10 states and two cities also claimed that the Environmental Protection Agency must regulate these emissions. Currently the case—*Coke Oven Environmental Task Force v. EPA*—is in the Washington, D.C., federal appellate court, "and it is very hard to see how the D.C. Circuit can do anything other than tell the EPA the exact same thing *Mass. v. EPA* did," states Michael Herz, a law professor at the Benjamin N. Cardozo School of Law in New York City.

CRIMINOLOGY

Reasonable Doubt

Data secrecy clouds judgments of lethal injection BY DAVID BIELLO

On May 13, 2005, Connecticut prison officials performed the first execution in the state since 1960. Following a protocol dictated in Oklahoma in 1977, they gave serial killer Michael Ross an overdose of an ultrashort-acting barbiturate, a chemical paralytic and a heart-stopping salt via an intravenous line. In 20 minutes, he was pronounced dead. But state officials were not finished with him: 20 minutes later the medical examiner drew a sample of blood from his femoral artery; hours later a second extraction was done during autopsy.

"We have to investigate it" as a homicide, explains H. Wayne Carver II, Connecticut's chief medical examiner. "Part of what you want out of an autopsy in these [homicide] cases is to determine not only what happened but also what didn't happen."

At issue was the humaneness of the execution procedure. Previous research had called into question whether enough of the ultrashort-acting barbiturate thiopental reached condemned inmates and anesthetized them. "It would be an unacceptably low dose if the inmate was a pig scheduled for euthanasia," argues Teresa Zimmers, a molecular biologist at the University of Miami Miller School of Medicine.

Thiopental, commonly used in general anesthesia, can reach the brain within 30 seconds, where it induces unconsciousness and, in high enough doses, can shut down basic functions such as circulation and breathing. Carver found that Ross's initial blood sample had a thiopental level of 29.6 milligrams per liter (virtually no risk of consciousness), whereas the second contained only 9.4 (a small but significant risk of consciousness). Thus, Carver showed that thiopental levels in the blood declined even after death as fat tissue absorbed the drug.

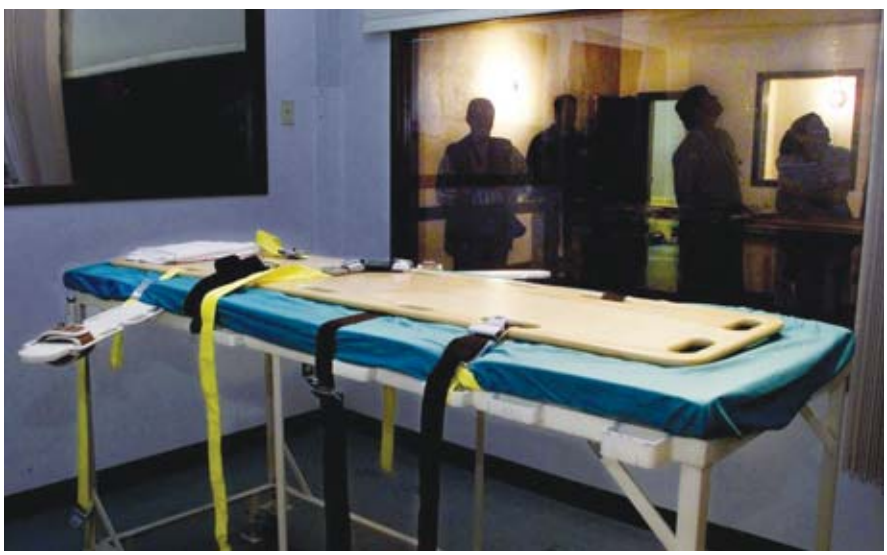
The change in levels challenges reports of inadequate anesthesia raised by Zimmers and her colleagues, who relied on autopsy information. With more immediate data, Carver provided some of the first scientific insight into the mechanics of death by lethal injection—a process in which protocols, dosages and outcomes remain shrouded in secrecy.

In a subsequent report, Zimmers and her group used publicly available data from 41 executions in North Carolina and California to show that injection of potassium chloride—a salt that speeds the heart until it stops—does not appear to speed the time of death appreciably, raising the specter that inmates are dying from as-

phyxiation as a result of the paralytic pancuronium bromide. "The inmates may die through suffocation, and they may be aware because the thiopental is insufficient," Zimmers says.

Several anesthesiologists interviewed for this story have rejected the awareness and suffocation arguments, particularly in light of the new evidence from Connecticut and several other states that have conducted postmortem investigations on thiopental levels. An adequate dose of potassium chloride reaching the heart will absolutely stop it, says Mark Dershwitz, a professor of anesthesiology at the University of Massachusetts Medical School as well as an expert witness in death penalty cases. The problem, though, is that "thiopental can stop the circulation at high doses. If the potassium chloride does not circulate from the arm to the heart, the heart will not be stopped."

Death penalty critics have also questioned the competence of those administering it. For example, Florida prison officials botched the lethal injection execution of Angel Diaz last December, most likely by failing to properly insert the IV. The American Medical Association has strict prohibitions against the involvement of physicians. Still, there is no reason that an IV port could not be established prior to the execution itself or by a professional who routinely finds veins, particularly given the challenge presented by inmates who have abused intravenous drugs or grown corpulent on death row. "Whoever puts the IV into the inmate, this should be part of their day job," Dershwitz says. "If the right drugs are given in the right dose in the right order through a working IV, there is no chance the inmate can suffer."



STEPHANIE S. CORDLE AP Photo

HUMANE ENOUGH? Lethal injection relies on a cocktail of drugs, the delivery of which can be botched. This execution chamber is at the Washington State Penitentiary in Walla Walla.

Unfortunately, evidence is currently lacking for all those preconditions. Only a tiny fraction of information on the specifics of the 907 executions carried out by lethal injection as of mid-May is publicly available, and much of that has come as a result of court orders. "While some scientists use microscopes or telescopes or particle accelerators, the study of lethal injection relies on attorneys and judges to bring forth the raw data," says Mark Heath, an anesthesiologist, expert witness and professor at Columbia University Medical Center. "There is an enormous amount of information from executions—autopsies, toxicology, ECG recordings, EEG recordings, execution logs and photographs—but most of it has been kept secret."

Science has brought to light failures in the criminal justice system via DNA evidence and could perform a similar role in evaluating what is intended as a humane method of execution. "This is not information that, for any reason that I can think of, needs to be withheld," says Jay Chapman, former chief medical examiner of Oklahoma and the originator of the lethal injection protocol. "If they didn't do something wrong, what are they hiding?"

NEW ORLEANS

Treading Water

The levees are patched up, but the flood risk remains high BY MARK FISCHETTI

The breaches in the levees around New Orleans have been repaired for a year now. But rebuilding the region itself will not gain momentum before the next decade. The levee system as a whole remains inadequate for large storms, and long-term protection for the city and the surrounding delta will not be in place until at least 2011.

To pin down the causes and implications of the levee failures after Hurricane Katrina, the U.S. Army Corps of Engineers has been working with other federal agencies and expert groups, which together form the Interagency Performance Evaluation Task Force (IPET). "We now have high confidence about the lessons learned," says Lewis E. Link, Jr., a civil and environmental engineer at the University of Maryland and director of IPET's final report, released in May.

IPET found that most of the breaches

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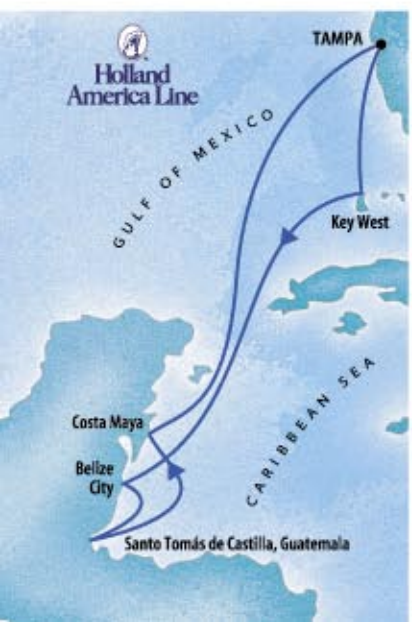

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***John Rennie** has been the Editor in Chief of Scientific American magazine since 1994. During his tenure, the magazine has won two National Magazine Awards for editorial excellence with the single-topic issues "What You Need to Know about Cancer" (Sept. 1996) and "A Matter of Time" (Sept. 2002). In 2000 Rennie was honored with the Sagan Award for Public Understanding of Science, bestowed by the Council of Scientific Society Presidents. In September 2003 the Potomac Institute for Policy Studies honored him with its Navigator Award for distinguished service in support of national science and technology policy.*

***Steve Mirsky** explains it all for you—evolution, antievolution, molecular biology, genetics, Darwin, Scopes, Kitzmiller. And after that, we'll all really need to shift gears and get Steve's take on what's funny about science, and how the Science Sausage gets made.*

FUTURE TECHNOLOGY & SOCIETY

Battlegrounds and Roads Forward for Emerging Technologies

Speaker: **John Rennie**

Nanotechnology, synthetic biology, artificial intelligence, new energy systems and a host of other radical technologies could transform the world as we know it over the next few decades. How they might do so and whether they will get the chance, however, depend strongly on how society copes with some of the dramatic conflicts those technologies will raise on issues such as personal privacy, security and preservation of the environment. John Rennie will explain these new technologies, strip the fiction from the facts about their capabilities and dangers, and discuss how best to prepare for them.

Global Warming and the Energy Transition

Speaker: **John Rennie**

Rising global temperatures and worries about the world's current dependence on fossil fuels will push civilization to make wider use of renewable energy, conservation, established technologies such as nuclear and new ones such as fuel cells. John Rennie will review future energy options and also consider how radical "geo-engineering" projects for reshaping the environment might be deployed if climate change prevention is not enough.

Free Will, Genetics, and Neuroscience

Speaker: **John Rennie**

Notions of free will influence not only our sense of ourselves as individuals but also social institutions like the law. As genetics and neuroscience trace the roots of our behaviors in more detail, however, it becomes harder to see human beings as completely free. How will further advances in science change our views of personal responsibility and legal guilt? After reviewing highlights in the current state of knowledge about human behavior and consciousness, John Rennie will prompt the class to discuss the significance of these findings to the real world.

Living Ethically in the Brave New World

Speaker: **John Rennie**

As technologies once known only through science fiction become part of our daily lives, all of us will increasingly be faced with troubling new ethical problems. Is it right for a grieving parent to try to clone a lost child? Should the wealthy be able to buy transplantable organs if poor people are willing to donate them? If an intelligent machine begs you not to turn it off, should you? Should genetics and neuroscience affect legal definitions of guilt and innocence? John Rennie will lead a Socratic discussion with the class that explores these complex topics.

COGNITIVE PSYCHOLOGY

What Are Thoughts Made Of?
Speaker: **Lera Boroditsky, Ph.D.**

Visualize an abstract discussion of the abstract. Whether dealing with scientific progress, business issues, or core human ideas like time, justice, and love, we need to conceptualize, reason, and communicate abstract thought. Without a framework of direct physical experience or sensory input to draw on in abstract thinking, how does our brain use perception and experience to give rise to the mind's thought? Have you wondered:

- What are the ingredients of meaning?
- How do we create meaning?
- How do our brains organize and store knowledge?

How Do We Imagine?
Speaker: **Lera Boroditsky, Ph.D.**

From Aristotle's day to ours, imagery and the ability to imagine have been key components in theories of mind. Dr. Boroditsky will bring us up to date on aspects of "imagination" such as attention, recall, formation of new images, and the neural structures involved. You'll learn:

- How well can we focus our attention? What is attention for?
- How do we imagine and re-create images in our minds? How good is our imagery?
- How do we remember, why do we forget, and why do we sometimes remember things that didn't happen?

How Do We See the World?
Speaker: **Lera Boroditsky, Ph.D.**

Take a look at the basics of visual perception. See the complex, thoroughly intertwined components of visual perception and the interaction of visual perception with other cognitive processes. This session will illuminate:

- How do our brains construct visual reality?
- Do we see what's really out there? Do we see things the way they really are?
- Why do we sometimes not see things that are there?
- Why do we sometimes see things that aren't there?

How Do the Languages We Speak Shape the Way We Think?
Speaker: **Lera Boroditsky, Ph.D.**

What is the relationship between language and thought? Dr. Boroditsky and colleagues have uncovered many fascinating cross-linguistic differences in thought and speech that shape the way we attend to, represent, and remember our experiences in the world. Get the latest on the big questions:

- Do people who speak different languages think differently?
- Does learning new languages change the way you think?
- Do polyglots think differently when speaking their different languages?
- Are some thoughts unthinkable without language?

ASTROPHYSICS & COSMOLOGY

Composition of the Universe
Speaker: **Tom Abel, Ph.D.**

Of what is the Universe made? How do we know this? Is it really true that 96% of the energy in the Universe is of unknown form? How can we be so sure? Can we still understand the origin of stars and galaxies if we only know the nature of 4% of the universe?

The Big Bang Theory and its Successes
Speaker: **Tom Abel, Ph.D.**

We've come a long way in our understanding of the Universe. Eighty years ago, Edwin Hubble showed that the Universe is expanding. Sixty years ago, we learned where all the hydrogen and helium in the Universe were made. About 40 years ago, we started observing the radiation left over from the beginning of the universe. Over the last 20 years, we've come to understand that without dark matter, there would be no galaxies nor any of us. What will we know in 2029 on the 100th anniversary of Hubble's discovery?

Computing the Universe
Speaker: **Tom Abel, Ph.D.**

We ask: How can we numerically solve the equations of fluid dynamics? Reactive flows? Radiation transport? Stellar winds and explosions? Consider the vastness of the scales: The sun is a trillion times smaller than the Galaxy! We have learned to model enormous numbers of bodies and their gravitational effects on each other. We'll discuss the physics that shape the Universe and how we now solve physical equations on modern supercomputers.

The First Things in the Universe and their Aftermath
Speaker: **Tom Abel, Ph.D.**

Ab initio simulations gives us unique details on the first things in the universe. The first things are very massive isolated stars, which have had an enormous impact on everything that has existed since then. These first stars evaporated their parent clouds, expelled the first heavy elements, and seeded the universe with the potential for life. The formation and evolution of galaxies are now being understood — one star at a time.

COMPUTATIONAL SCIENCE

Computational Science and Engineering
Speaker: **Bebo White**

Computational science has become an integral component of all scientific disciplines and promises to fundamentally change the way in which science will be done in the future. The impact of computational science can only be likened to how the execution of scientific research was changed by the elaboration of the Scientific Method. This lecture will describe the elements of computational science and engineering and research methods that take advantage of these elements. Case studies will be presented to illustrate applications of these methods.

The Once and Future Web
Speaker: **Bebo White**

Although the technology has only been around for slightly more than a decade, it is difficult to imagine computing without the World Wide Web. Beneath the simplicity that we see in our browsers, the underlying machinery of the Web has changed a great deal. How will the Web evolve in the next ten years and what will be the technological and social forces that drive its changes? Are "Web 2.0" and the "Semantic Web" just hype or genuine indicators of the direction in which the Web is moving? What will the "future Web" look like and how will it be used? We'll examine some of the clues of what we might expect in the "future Web" and how we can prepare for the changes to come.

High Performance and Grid Computing
Speaker: **Bebo White**

When the term "High Performance Computing (HPC)" is used these days it is more often than not referring to large "farms" or arrays of small, low-cost computers working together to accomplish a compute-intensive problem rather than to so-called supercomputers. "Farms" provide high throughput, are scaleable, use inexpensive components and open-source software, and are fault tolerant. Similar to "compute farms" are "computing grids" where networks (usually the Internet) provide the "glue" creating "a virtual computer architecture." "Computing grids" offer the promise of computing as a "utility" where anyone on the network has access to all the computing resources they want or need.

ARCHAEOLOGY

Pyramid Temples & Palaces: Architectural History of the Pre-Columbian Maya
Speaker: **Nicholas M. Hellmuth, Ph.D.**

Think of the Maya, and one of the first images that comes to mind is a pyramidal temple. Approaching the monumental architecture of the Maya can be done from the viewpoint of several disciplines. Dr. Hellmuth brings his learned work in architecture, archaeology, and anthropology, along with his expertise as a photographer and archivist, to this survey of Maya ritual and palace structures.

Ethno-botany: Plants Utilized by the Maya from Classic Times through Today
Speaker: **Nicholas M. Hellmuth, Ph.D.**

We know that plants served an extensive role in the Mayas' relationship with their deities. Back in the earthly Maya realm, what's for supper?

From the familiar cacao and vanilla to the odd-looking, night-blooming pitaya, Dr. Hellmuth will orient you to the interesting and exotic fruits and vegetables used by the Maya from pre-Columbian times through today.

Sacred Ballgames of Mesoamerica: Iconography & Ballcourt Architecture
Speaker: **Nicholas M. Hellmuth, Ph.D.**

The ritual ballgames of the Maya and neighboring civilizations are the stuff of legend and of a steadily increasing body of fact. Dr. Hellmuth, who has played the Maya ballgame himself (slightly modified rules!), will sort through the archaeology, architecture, evolving sociological and political theories of the game, and of course, the conduct and process of play.

Tomb of the Jade Jaguar: Excavating the tomb of the King of Tikal
Speaker: **Nicholas M. Hellmuth, Ph.D.**

It's Indiana Jones time. Dr. Hellmuth presents his experience and his "beginners' luck" in discovering one of the most richly stocked royal burials of the entire ancient Maya realm — the Tomb of the Jade Jaguar at Tikal.

Dr. Hellmuth will explain the scientific approach to such a find, as well as providing "color commentary" — a month of painstaking excavation to tunnel deep into the pyramid; documentation of progress; ten days of analysis of how best to tackle recording the over-filled tomb chamber and its royal mortuary offerings; and of course, life in the jungle.

Savor the rare opportunity to hear about the discovery of a great king's burial chamber directly from the discoverer!

Underwaterworld Iconography of the Classic Maya
Speaker: **Nicholas M. Hellmuth, Ph.D.**

The Maya underworld was an underwater world. Dr. Hellmuth will guide us through the mythology and iconography of the Maya underwaterworld. Using a multi-disciplinary approach and a scientist's keen eye for tropical flora and fauna, Dr. Hellmuth will decipher the design motifs of the supernatural plants, animals, and creatures that signal underwaterworld-related aspects of the Maya cosmos and belief systems.

You'll acquire an enhanced baseline understanding of the symbolism, the abstracted or abbreviated representations in Maya art, and the status of scientific efforts to document and preserve the corresponding living plants and animals that are associated with the Maya cosmos.

Sacred Plants of the 6th-9th Century Maya of Mexico, Belize, Guatemala, and Honduras
Speaker: **Nicholas M. Hellmuth, Ph.D.**

Plants were not only a central component of the Classic Mayas' physical environment, they richly populated and functioned in the Maya cosmos, and were highly significant in culture and ritual. To deepen your knowledge of the roles of sacred plants such as maize, cacao, flor de Mayo, hule (a rubber tree), the water lily, and a host of other sacred plants and flowers, Dr. Hellmuth will discuss the importance of the Mayas' sacred plants, their uses, and distribution in the Maya world.

You'll gain a sense of the interrelationship of Maya cosmology, botany, culture, agriculture, and history represented in the concept of sacred plants.

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LEVEES in New Orleans have been repaired, but the entire system is subsiding below its original design height, which only offered protection against a Category 3 hurricane.

in the earthen levees took place when water poured over the berms and scoured away the outside foundation. The group estimates, however, that two thirds of the flooding inside the city limits resulted from the major breaks in flood walls—tall, narrow concrete structures built in zones too crowded for the wide levees. The walls cannot simply be made higher, though, because forces from high water would then be redistributed throughout the walls in ways existing foundations could not support. "In most places, you'd almost be better off tearing them down and starting over," Link says. Col. Jeffrey Bedey, commander of the Corps' Hurricane Protection Office in New Orleans, which oversees recovery work and risk assessment, concurs: "If we were to add more height, we would introduce new stability concerns."

Subsidence has exacerbated the problem. The entire levee and wall system, parts of which are decades-old, has been slowly sinking. The repairs have brought the system back to its original design specification, but that metric was only for protection against a Category 3 hurricane. And because it has subsided, "in reality the system only provides Category 2 protection," says Hassan S. Mashriqui of Louisiana State University, who is a member of the American Society of Civil Engineers task force that investigated the levee failures. In addition, certain levees that have long been planned for the city's western edge still remain unbuilt.

Levees and walls alone will therefore not provide sufficient security, especially because more Category 4 and 5 storms may result from global warming [see "Warmer Oceans, Stronger Hurricanes," by Kevin E. Trenberth, on page 44]. A larger barrier system is needed—either a tremendous levee line roughly halfway between New Orleans and the Gulf of Mexico or an outer shield on the Gulf Coast itself, similar to that in the Netherlands.

NEW FLOODWALL stands along the Industrial Canal, where a huge breach inundated the Lower Ninth Ward.

Those alternatives were the leading options raised in February by the Coastal Protection and Restoration Authority of Louisiana—a coalition of many statewide agencies. The plan agrees with past determinations made by scientific experts [see "Protecting New Orleans," by Mark Fischetti; SCIENTIFIC AMERICAN, February 2006].

The authority has presented its plan to the Corps, which is devising its own report, due in December. Both blueprints include the installation of large gates where major natural and man-made channels had the undesired effect of "funneling" Katrina's storm surge into the city's inner waterways, causing the catastrophic collapsing of flood walls. Gates would also close off Gulf inlets to the vast Lake Pontchartrain resting on the city's northern border. The Corps has already installed three small gates at the ends of flood-control canals in the inner city, but much larger ones would be needed for the channels.

The Corps is talking with 11 design-and-build firms, but erecting the gates and implementing related measures will take time. "I would hope the structural piece could be in place by 2011 or 2012," Bedey says. The long levee out on the delta or the shield in the Gulf would take even longer. So would structures that divert freshwater and sediment from the Mississippi River down into the delta, needed to rejuvenate the delta's tattered wetlands so that they provide better natural storm barriers.

Although the region will not be much safer for the next several years, residents might have reason to be cautiously optimistic. Link has met with local, state and federal leaders and says they accept that "risk assessment has to inform the long-term redevelopment, instead of just rebuilding willy-nilly. That was not the case after the storm." Such concerted agreement among the three levels of government may be the best sign for New Orleans as it navigates its way into the future.

INTERAGENCY PERFORMANCE EVALUATION TASK FORCE (*top*); MARIO TAMA *Getty Images* (*bottom*)

ASTROPHYSICS

An Ear for Spacetime

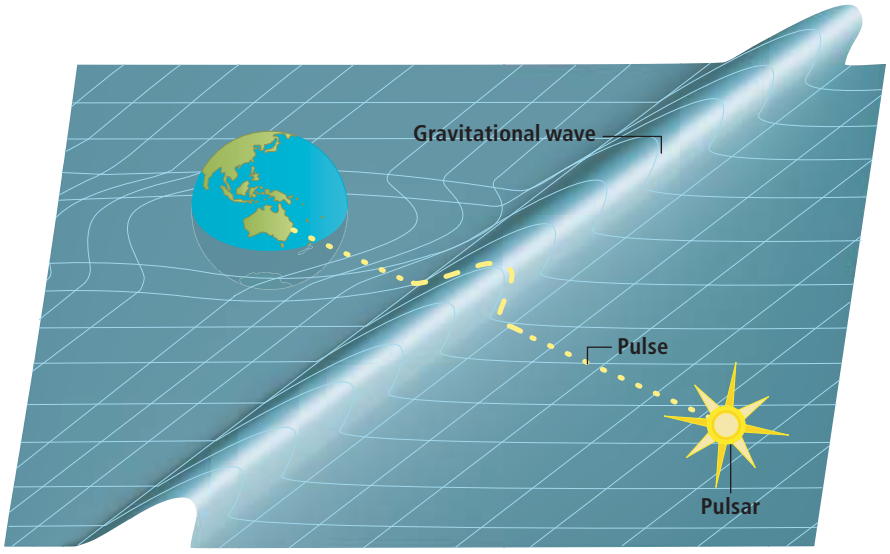
Pulsars provide an alternative way to detect gravitational waves BY GEORGE MUSSER

If a pair of black holes ever hit Earth, you would literally hear them coming: not by sound, which cannot cross the vacuum of space, but by waves of gravitational force, which, as the holes approached, would knead the bones of your inner ear by a perceptible amount, producing a whine like a camera flash charging up. Under normal circumstances, such waves are utterly inaudible, even though astronomers think they reverberate through our bodies all the time. Weakened by vast cosmic distances, the waves that reach us change the length of bones and other objects by less than the width of a proton.

To hear these waves, you need a supersensitive microphone such as the Laser Interferometer Gravitational-Wave Observatory (LIGO), whose twin facilities in Washington State and Louisiana are basically fancy laser range finders that look for wave-induced oscillations in the length of the instrument. But there are other ways to detect such oscillations, and a new study argues that one of those techniques might even test whether Einstein's general theory of relativity is the full story when it comes to gravitation.

The technique makes use of pulsars, stars that blink with the regularity of an atomic clock. If a wave passes between you and a pulsar, it will alternately stretch and compress the distance between pulses, so the blinking will appear to slow down and speed up. "We can measure the timing, and a gravitational wave will change the time of arrival of the pulse," says astrophysicist Kejia Lee of the Center for Gravitational Wave Astronomy at the University of Texas at Brownsville. Unlike past uses of pulsars to probe gravitational waves, this technique picks up the direct effects of the waves.

Waves emanating from the mergers of large black holes or processes in the early universe could change the pulse timing by one part in 10^{15}, which amounts to a deviation of one microsecond over 10 years. Vibrations occurring faster than once every few years would sink into the noise. LIGO has the opposite problem: slow vibrations are the ones it cannot see—because of seismic activity. So the two techniques are nicely complementary.



GRAVITATIONAL WAVE crossing the path of a pulsar signal will change the spacing between pulses and thus their timing. Telescopes could pick up a deviation of one microsecond.

To distinguish real timing fluctuations from spurious ones, astronomers compare dozens of pulsars. According to relativity theory, gravitational waves vibrate at right angles to the direction of propagation, stretching objects in one direction and squeezing them in the perpendicular direction. Consequently, they would cause one pulsar to appear to slow down and another 90 degrees away to speed up. Noise would exhibit no such pattern.

Lee and his Texas colleagues Fredrick Jenet and Richard Price have now extended the technique to theories of gravity besides Einstein's. These theories predict that objects could get alternately stretched and compressed in all directions at once (as if breathing) or in the direction of propagation (so-called longitudinal waves). Pulsars are the only feasible way to get at these unconventional vibrational patterns, which would represent distinct types of particles in a quantum theory of gravity. "Thank goodness somebody is willing to think about non-general-relativity gravitational waves," says another pulsar timing expert, Andrea Lommen of Franklin and Marshall College. "It's really important to consider it."

That said, the technique remains unproved. The team has not yet worked out how strong the vibrational patterns would be in plausible alternatives to relativity or how a mixture of patterns would be teased apart. The Parkes radio telescope in Australia has been monitoring 20 pulsars once every two weeks since 2004 and has yet to see any gravitational waves, Einsteinian or otherwise. That is no surprise: three years is still too short a period. LIGO has yet to detect any waves, either. Let us hope that it will not take a direct black hole collision with Earth to determine whether Einstein was right.

LUCY READING-IKKANDA

INFO TECH

Jam Session

A design to block RFID tags BY WENDY M. GROSSMAN

Privacy advocates have fretted for some time about radio-frequency identification (RFID) tags and their potential for enabling detailed tracking of an individual's activities. Some tags are obvious, such as those used for E-Z Pass toll collection on northeastern U.S. highways; others are more insidious, such as those tucked inside U.S. passports and on the London Underground's travel cards. Rapidly expanding in use, such tags may soon even report the amount of material in recycle cans.

Melanie Rieback and her colleagues at Free University in Amsterdam are working on RFID Guardian, which they hope will enhance privacy: a portable, battery-powered personal firewall. The notion is that anyone ought to be able to see what RFID tags are nearby and who owns them—and then have the ability to selectively jam the readers. In this way, you could allow security—and no one else—to read your passport RFID chip.

Although RFID tags vary in size from a postcard to a rice grain, they all rely on built-in antennas, along with logic and memory circuits. Passive tags get their power from the reader that interrogates them and can be read up to about one foot away. Active tags have onboard batteries and can be perused 100 yards away or more. All types have preset functions that prevent collisions—conflicts that arise when several tags respond to a query simultaneously.

Exploiting these anticollision protocols formed the basis of the first effort to create privacy enhancement for RFID, outlined in a 2005 paper by Ari Juels, chief scientist at RSA Laboratories in Bedford, Mass. His solution involved producing and deploying tags that would respond to all reader queries, making it impossible for a reader to determine what tags were present in the vicinity.

Rieback considered the idea brilliant but also saw shortcomings. One problem, she says, is that Juels's proposed tag had no power source and therefore could not respond to a reader if it were incorrectly oriented. Moreover, because each tag has only a tiny amount of memory, it could not store a consumer's preferences as to when to allow the tags to be read and by whom. Plus, if such policies were implemented on a tag that is widely distributed, finding and updating all those chips would be difficult.

Rieback reasoned that a battery-powered device would not share these limitations and could also scan and audit nearby tags and manage security protocols. For the past two years she and her team have been developing such a countertag, and the device is currently in its third version. They hope to make enough of them to supply other research groups and companies, which might improve and commercialize the idea. The team also intends to release the hardware and software with an open-source license so that anyone can freely modify or add to it.

"The ultimate vision is that we could make a one-chip version of it," Rieback says. With that, she notes, the functionality could become integrated into a PDA or cell phone so that the output could be displayed on a portable screen—and privacy carried in the palm of the hand.

Wendy M. Grossman is based in London.

PERSONAL FIREWALL: Electronic readers of RFID tags, such as those in passports, could be blocked to prevent eavesdropping.

JEFF HAYNES AFP/Getty Images

FORENSICS

Pieces of a Paranoid Past

A plan moves ahead to reconstruct East Germany's shredded secret police files BY MICHAEL DUMIAK

MAGDEBURG, GERMANY—In a boxy, windblown district in a workaday cathedral city on the Elbe River, a long warehouse sits near what was the regional post for the East German secret police, 90 minutes by train from Berlin. The warehouse is stacked three stories high with bin bags, some 50 to a shelf. Archive chief Jörg Stoye noses one with his shoe. "Potato sack," he grins.

But the contents are much heavier than potatoes. The sacks contain millions of shredded fragments snatched from lives during the Communist-run Deutsche Demokratische Republik (DDR, or German Democratic Republic). Some of the documents detail East German spying operations against West Germany, a natural

LOOK IN THE MOST UNLIKELY PLACES

THERE IS NO EASY OIL. MUCH OF IT IS SCATTERED IN HUNDREDS OF ISOLATED POCKETS. AND BUILDING LOTS OF OIL RIGS IS JUST NOT AN OPTION, ENVIRONMENTALLY OR ECONOMICALLY. THEN SHELL ENGINEER JAAP VAN BALLEGOOIJEN WATCHED HIS SON DRINK A MILKSHAKE. SUCKING THE BITS OF FROTH FROM THE CORNERS OF THE GLASS WITH HIS BENDY STRAW. HEY PRESTO, THE SNAKE WELL DRILL WAS BORN. A DRILL THAT CAN BEND ROUND CORNERS AND SNAKE FROM SIDE TO SIDE TO REACH THOSE SCATTERED POCKETS OF OIL, ALL FROM ONE RIG. REAL ENERGY SOLUTIONS FOR THE REAL WORLD. WWW.SHELL.COM/REALENERGY

specialty for the DDR, which fell on the Soviet side of the cold war. A few reveal dissidents informing on their comrades. Others are likely just mundane, obsessive notes on conversations and interactions that amounted to nothing of interest to the state but meant that a friend betrayed a friend. (The award-winning 2006 film *Das Leben der Anderen* [*The Lives of Others*] depicted life during those times.)

These torn papers have been gathering dust for 15 years. But this summer, scanners and grid computing will finally start piecing together the last missing charts of a country's dark side.

The idea of using custom software to reassemble the millions of paper scraps hand-shredded by the Stasi, the DDR's notorious secret police, has been kicked around since 1993. A competition to develop this software brought momentum and a blaze of publicity 10 years later, but funding problems in cash-strapped Berlin doused the enthusiasm. Finally, this past April, the government ponied up $8 million for a two-year pilot study, which will reconstruct 400 bags of scraps.

During the cold war, East Germany had some 90,000 on the Stasi payroll, and a network of 300,000 "unofficial informants" contributed to files on six million people, about one third of the country's population. Paranoia and fear radiated from the Stasi's East Berlin headquarters.

As the fall of the Berlin Wall neared in late 1989, the shredding began. People knew about the Stasi, but few guessed how far the police network had penetrated daily life. Agents recognized that they would have to answer for their activities. The most important and sensitive documents went first. The Stasi's shredders burned out quickly from overuse, says Berlin Stasi archive bureau chief Günter Bormann, and so agents and whoever they could recruit did it by hand. "They were tearing day and night," Bormann recounts. "These were the last efforts in the last days. They weren't doing it for fun."

Stitching those scraps together now falls to fast and complex algorithms developed at Berlin's Fraunhofer Institute for Production Systems and Design Technology. There Bertram Nickolay brought decades of experience in pattern-recognition software design to bear on the Stasi puzzle. Nickolay's group built what is essentially an adaptive search engine to match document scraps and paste them together.

Jan Schneider, a designer in Nickolay's group, explains that it is basically a logical, though complex, process of elimination. To demonstrate the system, Schneider pulls up a computer file with 200 scanned scraps. He selects a pale-green scrap, which has lines on it and blue-ink handwriting at a 75-degree angle. The algorithms discard all the other scraps that do not have similar characteristics. Then

the system examines the edges of the shred. "We have to wait. The machine has to try all combinations," Schneider says. When a match is found, a new scrap model is built and then compared with the remaining scraps. Seconds later a stitched-whole green document appears: the first page of a monthly report from Stasi agents in Potsdam in the spring of 1989.

The group will be using a dedicated grid of 100 networked servers to efficiently combine the processing power of the machines and to provide for the large amount of storage capacity—some 64 terabytes—needed to sort through the scraps. Other software for pattern recognition and document reconstruction exists, Schneider says, but none combines the kind of minutiae that will be used for this task.

As a kind of digital archaeology, the Fraunhofer project will re-create a time that is still raw but already packed away from public view. A decade ago Bormann got a trickle of requests to see Stasi documents. Only now is he starting to get thousands a month. Dealing with that past takes time—not everyone wants to find out if their husband, sister or lover informed on them. In puzzling out these snippets and storing them, the project will preserve that past until the time is more appropriate. "It's a basic human right. You should know your own history," Bormann remarks.

MICHAEL DUMIAK

THE LIVES OF OTHERS: Bags of shredded documents sit in a warehouse in Magdeburg, Germany. The documents were reports by East Germans who spied on one another for the notorious Stasi secret police.

The effort has drawn interest from South Africa's Bishop Desmond Tutu and officials from Chile, the former Yugoslavia and Iraq, Bormann says. Paper has power, he adds, and shredded documents, repressive regimes and mystery are, after all, hardly confined to Germany.

Michael Dumiak, based in Berlin, described efforts to bring sunlight to a shadowed European village in the April 2006 issue.

MICROCHIMERISM

All in the Family

Paternity shocker: marmoset twins pass on each other's genes BY CHRISTINE SOARES

Seeming to be a model of harmonious cooperation, the marmoset family unit includes offspring that stay at home past sexual maturity to help care for their younger siblings and fathers that share the duty of carrying newborns so mothers can take a break. As it turns out, all this sharing and caring may be facilitated by a fluid sense of identity among the tiny monkeys, which carry around not only one another's infants but bits of one another as well. The phenomenon could offer new insight into human immune reactions to foreign cells.

When University of Nebraska biologist Corinna Ross set out to determine whether hair samples could be a suitable source of genetic material for marmoset paternity testing, she found that many samples contained a patchwork of cells—some bearing an animal's own gene assortment and others with a DNA profile that was only about 50 percent similar, like that of a sibling. Indeed, the cells belonged to the animals' fraternal twins. Further testing revealed that this microchimerism—the harboring of another's cells or DNA—extended to all the 17 organs sampled, as well as to eggs and sperm. "We panicked a little at the beginning," Ross says of her original paternity project. "It suddenly became a much more complex issue."

Because even the animals' germ cells were chimeric, Ross found that in one case a female marmoset's egg cell carrying her male sibling's DNA had given rise to a baby marmoset whose genetic mother was actually its biological uncle. Of 36 fraternal twins examined, 26 carried chimeric cells in at least one tissue.

Marmosets are popular models for studying immunity because they have long been known for considerable microchimerism in their bone marrow, where blood and immune cells are manufactured. During a key stage in early fetal development, marmoset multiples share a blood supply and fused placentas, allowing liberal flow of fetal cells between siblings, according to Ross. Understanding how marmosets maintain immune tolerance for so many foreign cells throughout their lifetime would help researchers trying to learn how to prevent human rejection of transplanted organs or bone marrow [see "Graft and Host, Together Forever," by Marguerite Holloway; Insights, Scientific American, February 2007].

TWIN MARMOSET infants ride on their biological father's back. Cell sharing may make the siblings more closely related to one another—or to an aunt or uncle—than to Dad.

Studies in marmosets might also elucidate mechanisms of some autoimmune diseases in people. Growing evidence suggests that certain of those conditions, such as scleroderma, whose symptoms often mirror bone marrow rejection, may not be attacks on "self" so much as responses to chimeric foreign cells in the body, according to immunologist Anne Stevens of the University of Washington. An alternative possibility, she adds, is that the foreign cells are the ones attacking the host.

Stevens has found, for example, that maternal cells are present in the organs under assault in infants suffering from neonatal lupus syndrome as well as in the pancreas of male subjects with type 1 diabetes. "Our preliminary studies show that when we look in tissues of the male children, maternal cells can be as high as one in 1,000," Stevens says.

Scientists have amply documented two-way swapping of cells between human mothers and fetuses, but, as was once the case for marmosets, they have generally believed that chimerism was largely confined to bone marrow and something that faded with time. Bone marrow microchimerism in fraternal twins is also common and can represent as many as 20 percent of cells, Stevens says. Rare instances of sibling cells in organs have been identified, such as a young girl with a twin brother who carried male DNA in several of her tissues, but, Stevens adds, "no one has really looked for sibling microchimerism throughout the body." And because chimeric cells exist in people without any disease, the health implications of widespread human chimerism, if it does occur, remain unclear.

For marmosets, genetic ambiguity puts the species' close-knit family image in a new light. Once the marmoset genome sequence is completed this summer, scientists will have an easier time assessing which sibling genes might be active in chimeric marmosets, Ross says. But the incentive for cooperative group child care is already clear, she explains: "What we've discovered in this animal is that when an individual parents its offspring, it may actually be parenting its brother's offspring."

JEFFREY FITE *University of Nebraska*

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In Brief

FIBONACCI FANDANGO

The Fibonacci sequence—in which each successive number is the sum of the previous two (1, 1, 2, 3, 5, …)—appears all over the biological realm, describing, for example, how seeds spiral on strawberries and nautilus shells curve. Now researchers at the Chinese Academy of Sciences and their colleagues have created Fibonacci spirals in purely inorganic materials. The scientists tinkered with microstructures consisting of silver cores and silica shells. The stiff shells buckle as they harden on the compliant cores, and if the shells were encouraged into conical shapes during cooling, irregularities formed as Fibonacci spirals (*photographs*). The results, detailed online April 18 in *Applied Physics Letters,* support an old conjecture from biologists that these spirals arise as a means to minimize space or energy usage. —*Charles Q. Choi*

STEM CELL BLOOD REPAIR

After spending years devising the right chemical cocktail, researchers from Advanced Cell Technology in Worcester, Mass., have reported growing large numbers of human embryonic stem cells called hemangioblasts. In laboratory dishes the blast cells developed tissues that resembled blood-forming stem cells as well as blood vessels. The team injected them into body parts of rodents damaged by diabetes and other injuries that impair blood flow. The hemangioblasts turned up in the unhealthy blood vessels, and mice that received them were twice as likely to survive heart injury as control mice were. *Nature Methods* posted the report online May 7. —*JR Minkel*

BUT IT'S NOT KRYPTON, IS IT?

The most Earth-like extrasolar planet yet discovered, just five times as massive as Earth, circles a red dwarf star called Gliese 581 20.5 light-years away. Planetary temperatures might range from zero to 40 degrees Celsius. "The separation between the planet and its star is just right for having liquid water at its surface," says Stephane Udry of the Observatory of Geneva, whose team announced the finding in April. —*JR Minkel*

MATHEMATICS

Beer Head with Numbers

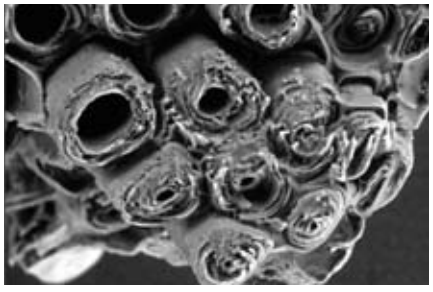
Fifty-five years ago the late über-genius John von Neumann proved that the area of any two-dimensional region subject to surface tension—such as a bubble—changes in proportion to the number of its sides. (Five or fewer, it shrinks; seven or more, it grows; six, it maintains its area.) Since then, physicists have struggled to apply von Neumann's result to the analogous case of microscopic crystal grains growing in three dimensions, according to materials scientist David J. Srolovitz of Yeshiva University.

Recently Srolovitz and Robert D. MacPherson of the Institute for Advanced Study in Princeton, N.J., derived such an equation for tension-induced volume change in three (or more) dimensions by adopting an abstract quantity called mean width. Analogous to surface area or volume, mean width is a nonintuitive measure of a region's size in units of length, no matter what shape it has. If physicists can apply the result to shifting clusters of crystal grains or bubbles, they may be able to engineer stronger materials—or minimize the foam on a glass of beer. "This formula," Srolovitz says, "basically tells you how every single bubble in the head of beer is going to change." Size up the April 26 *Nature* for more. —*JR Minkel*

PLANT SCIENCE

Seed Power

"Muscles" powered by changing humidity apparently help wild wheat seeds reach good places to sprout. Each pointy-tipped seed bears two long, bristly appendages called awns. Scientists at the Max Planck Institute of Colloids and Interfaces in Golm, Germany, found that cellulose fibrils make them expand with humidity, pushing the appendages together, and contract with dryness, pulling them apart. This flexing acts like the swimming stroke of a frog's legs, the researchers say, to propel the seeds along and into the ground. They suggest in the May 11 *Science* that wheat is optimized for the daily cycle of humidity seen during the dry period (which occurs after the seeds ripen) in the Fertile Crescent, where the crop originated. —*Charles Q. Choi*



GOING DOWN: An electron micrograph shows a cross section of an awn, used by wheat seeds to dig into soil.

NEUROSCIENCE

Twenty Percent Recall

It is a myth that people use only 10 percent of their brain, but it may be true that we use 20 percent to form memories. Working with mice and fluorescent probes, investigators monitored neurons in the lateral amygdalas, two almond-shaped regions on either side of the midbrain associated with learning and memory. In particular, they investigated the activity of the CREB protein, which plays a key role in memory formation in species ranging from sea slugs to humans, and they discovered that CREB activity occurs in one fifth of those midbrain neurons. Evidently neurons battle one another to make a particular memory. "It's like grading on a curve," says study co-author Sheena Josselyn of the Hospital for Sick Children in Toronto. "The same number [20 percent] of students are going to get As"—or in the case of neurons, help make the memory. The findings appear in the April 20 *Science*.

—*Nikhil Swaminathan*

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APPLIED PHYSICS LETTERS (left); COURTESY OF MAX PLANCK INSTITUTE OF COLLOIDS AND INTERFACES, GOLM, GERMANY (right)

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CHEMISTRY

No-Pressure Diamond Scratchers

As the hardest substance known, diamond is ideal for cutting rock and other tough stuff. But diamond is costly, and it degrades when machining steel and other ferrous metals because of reactions that create softer iron carbides. For cutting steel, the first choice is cubic boron nitride, which is almost as hard, resisting 40 to 50 gigapascals (GPa) of pressure compared with diamond's 70 to 100 GPa. But manufacturing the substance requires high temperatures (1,500 degrees Celsius) and extreme pressures (5 GPa), which make it expensive.

A low-pressure method may provide a less expensive route to ultrahard materials. "We wanted to design new hard materials, rather than finding them using trial-and-error methods," says physical chemist Sarah Tolbert of the University of California, Los Angeles. The hardness of diamond and boron nitride arises because of short, covalent bonds that keep the constituent atoms strongly stuck together and rigid in all directions. Certain "ultraincompressible" metals are rigid in two dimensions: they resist squeezing—the electrons inside them strongly repel one another—but they are relatively soft because their atoms are arranged in layers that can slide past one another. Tolbert and her colleagues found a way to harden these metals by introducing another element that covalently bonds to these layers, preventing them from slipping without disrupting incompressibility.

In 2005 the team members combined osmium metal with boron at 1,000 degrees C and ambient pressure to fabricate a material that is almost as incompressible as diamond and nearly as hard. In the April 20 *Science* they report that substituting osmium for less pricey rhenium resulted in rhenium diboride, which is hard enough (about 48 GPa) to scratch diamond and just about as incompressible. The method should lead to even less costly, ultrahard compounds. —*Steven Ashley*

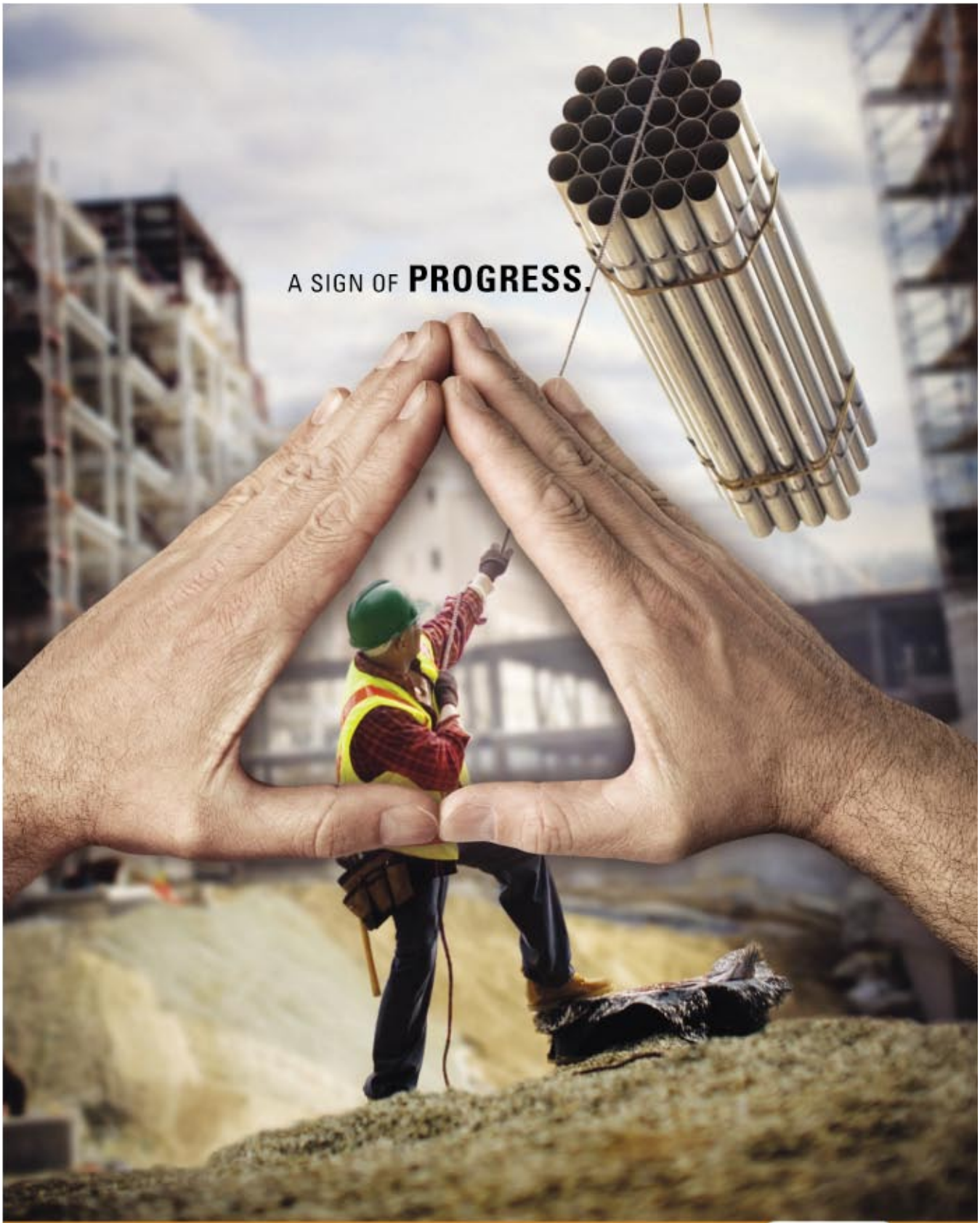
MAKING ULTRAHARD MATERIALS usually requires extreme pressures. Heat alone can convert rhenium diboride powder (*left*) into a pellet (*right*) hard enough to scratch diamond.

Data Points

Tour de Energy

Each day Tour de France cyclists expend incredible amounts of energy, especially during the mountain stages. We asked mechanical engineer David Gordon Wilson of the Massachusetts Institute of Technology and author of *Bicycling Science* to calculate energy output and other intriguing statistics associated with this year's grueling stage 14, which takes place on July 22. On the following day, during stage 15, the riders will do as much work again. —*Mark Fischetti*

OLIVIER LABALETTE *TempoSport/Corbis (top)*; RICHARD B. KANER AND JONATHAN B. LEVINE *U.C.L.A. (bottom)*; JEN CHRISTIANSEN *(data illustration)*



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SciAm Perspectives

Bad Execution

Lethal injection can cause undue suffering to the condemned. What's to be done?

BY THE EDITORS

In revolutionary France in the early 1790s, physician Joseph-Ignace Guillotin proposed that a surefire execution mechanism be used to carry out the death penalty for the state. Historians believe that Guillotin suggested the use of the instantaneous decapitation device that would later bear his name as a humane form of capital punishment. The guillotine was thought to bring quick mortality more reliably than the standard methods of prerevolutionary France—beheading by sword or ax, which sometimes involved repeated blows, or hanging by a noose, which could take several minutes or even longer.

In the U.S. in the late 1970s, Oklahoma state medical examiner Jay Chapman developed a fail-safe execution method that many states soon adopted as their main form of capital punishment. Lethal injection, in which three poisonous chemicals are administered to the condemned, largely replaced execution by hanging, firing squad, gas chamber and electric chair, each of which had at some point been judged to be inhumane or excessively violent.

MATT COLLINS

Yet this method is far from foolproof. According to reports, unskilled executioners have caused prolonged suffering in the condemned by mishandling the deadly drug jabs—instances in which they missed veins, used blocked IVs or miscalculated doses, leading to failed anesthesia and chemical burns. Meanwhile ethical prohibitions to the participation of trained medical personnel ("Do no harm...") have mostly kept the amateurs and their ad hoc methods on the job. In recent months, however, news of numerous botched lethal injections has led courts and state governments to place moratoriums on the practice in a third of the 38 U.S. states that have the death penalty.

In the meantime, some researchers have challenged the assumed airtight efficacy of the drug protocols used in most American lethal injections. The authors of two papers published in *Lancet* and *PLoS Medicine* in recent years have questioned whether the recommended protocols, even if carried out as prescribed, would produce death without unnecessary or gratuitous pain—the "cruel and unusual punishment" forbidden by the Eighth Amendment to the U.S. Constitution. Although some critics argue that the studies are flawed, the dearth of research on lethal injection merely highlights our limited knowledge of the procedure [see "Reasonable Doubt," by David Biello; News Scan, on page 20].

The generally accepted approach relies on introducing into the sentenced criminal's bloodstream a chemical cocktail consisting of a barbiturate to bring on sedation and suppress respiration, a neuromuscular paralytic to halt breathing and body convulsions, and a potassium electrolyte to stop the heart. The intent of the mixture is to provide toxic redundancy so that each drug alone would bring on death. Dosages remain the same whether the condemned weighs 150 pounds or twice that. Scientists have found that, as a result, there have been instances in which breathing has continued, the heart beat on, or nerves remained undeadened despite the injections.

In veterinary medicine, the federal government and professional associations keep data on animal euthanasia and have developed guidelines and procedures in accord with the research. Obviously, the same cannot be done for human execution techniques. It would help, however, if states released their data on lethal injections: only two have done so, leaving scientists able to analyze only 41 of the 904 lethal injections that have been conducted in the U.S. (at press time). More complete information would surely help society surmount the lingering uncertainties regarding the deadly protocol and its application.

For those of us who already believe capital punishment is wrong, this situation is just one more outrage. But even those who disagree would have to acknowledge that

the Constitution holds that the state must not execute people cruelly. Perhaps capital punishment can never be anything but inhumane, but until society is willing to accept that principle, it is obliged to execute as humanely as it can. Certainly some ways of killing are less cruel than others. So what can and must government do to be more humane? Clearly, the time has come for renewed public discussion and consideration of the death penalty, including all its distasteful details. ■

Sustainable Developments

The Promise of the Blue Revolution

Aquaculture can maintain living standards while averting the ruin of the oceans

BY JEFFREY D. SACHS

BRUCE GILBERT/EARTH INSTITUTE

Environmental sustainability is already very difficult to achieve with today's 6.6 billion people and average economic output of $8,000 per person. By 2050 the earth could be home to more than nine billion people with an average output of $20,000 or more. Many environmentalists take it for granted that richer countries will have to cut their consumption sharply to stave off ecological disaster.

There is another approach. Global public policies and market institutions can promote new technologies that raise living standards yet reduce human impact on the environment. A crucial group of such technologies is aquaculture, the farming of marine animals, which can support growing human consumption of fish and other aquatic species while relieving intense pressures on ocean ecosystems. The rapid development of aquaculture in recent years has been likened to a "Blue Revolution" that matches the Green Revolution of higher grain yields from the 1950s onward.

Between 1950 and today the total landed catch from open- and inland-sea fishing almost quintupled, from around 20 million to about 95 million metric tons. Both higher demand from rising world incomes and higher supply from more powerful fishing vessels contributed to the surge. So, too, did large and misguided subsidies to fishing fleets, reflecting the political power of geographically concentrated fishing communities and industries. The world put itself on a course to gut ocean ecosystems, with devastating consequences.

Into the breach has arrived the Blue Revolution, first in China, and now in many other parts of the world. Aquaculture yields have increased from around two million metric tons in 1950 to almost 50 million metric tons today. Thus, even though the global fish catch peaked in the late 1980s, aquaculture has enabled a continuing rise in human consumption of fish. China now accounts for around two thirds of total aquaculture production worldwide by weight and roughly half by market value.

Fish farming in China is of course an ancient activity, with several carp species grown among rice fields for thousands of years. The exciting news, however, is that recently Chinese scientists have both improved the efficiency of aquaculture and revolutionized the range of species

THE EDITORS' BLOG

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THE PRESENT AND FUTURE ROLE OF NUCLEAR WEAPONS

To some, nuclear weapons are the core of world peace.... To others, nuclear weapons are necessary but in need of a radical rethinking in light of a changed world. "If we want to develop a new warhead, it should be one that is going to reflect a dramatically new role for nuclear weapons," says Ivan Oelrich, vice president for strategic security programs at the Federation of American Scientists.

To yet others still, they have outlived their usefulness. "U.S. leadership will be required to take the world to the next stage—to a solid consensus for reversing reliance on nuclear weapons globally as a vital contribution to preventing their proliferation into potentially dangerous hands, and ultimately ending them as a threat to the world," wrote former government bigwigs George Shultz, William Perry, Henry Kissinger and Sam Nunn in an op-ed in the *Wall Street Journal.*

The role of nuclear weapons should be the subject of a wide-ranging debate, along with the future role (and privatization) of the national laboratories, the security of fissile material worldwide, nonproliferation, treaty obligations, and so on. Not to mention the fact that the scientists and engineers who created the last generation of nuclear weapons are aging, and they may need a new weapon to work with to transfer their knowledge to the next generation. (Science, in some cases, functions like an oral tradition.)

Yet that debate is not really happening, at least not in public....

Posted by David Biello, April 30, 2007

Read more of this post and others on SciAm Observations (www.blog.SciAm.com).

MATT COLLINS

that can be farmed. An insightful study by coastal ecologist Carlos Duarte and his colleagues in the April 7 *Science* documents the dramatic rate of domestication and commercialization of marine species. Of the more than 400 farmed marine species, as many as 106 have been domesticated in the past decade alone. In contrast, there has been almost no concurrent increase in the number of domesticated land species.

Aquaculture by itself will not solve the crises facing marine ecosystems. The farming of salmon and other fish-eating species, for instance, keeps pressure on the oceans because massive amounts of catch are needed to feed them. Equally important, aquaculture brings its own ecological challenges: it can spread diseases from farmed to wild fishes, pollute nearby waters with excess nutrients, lead to habitat destruction (such as the clearing of mangroves for shrimp farming), and threaten genetic diversity through the release of farmed species into the wild. Yet better aquaculture technologies are already evolving rapidly, and public funds and prizes could promote research to advance them.

At the same time, the pillaging of the oceans will continue unless regulations such as tradable fishing permits that limit the total catch to sustainable levels are also used to contain the exploitation of the ocean commons. Subsidies for excessive ocean fishing should also be slashed. Egregious practices such as bottom trawling on seamounts should be outlawed by international agreement. With sensible global policies, the Blue Revolution can indeed become a major force for improved human nutrition, economic well-being and environmental sustainability. ■

Jeffrey D. Sachs is director of the Earth Institute at Columbia University (www.earth.columbia.edu).

SCI AM An extended version of this essay is available at **www.SciAm.com/ontheweb**

Forum

The Limited Appeal of Nuclear Energy

To developing nations, the new arguments for nuclear power are far from compelling

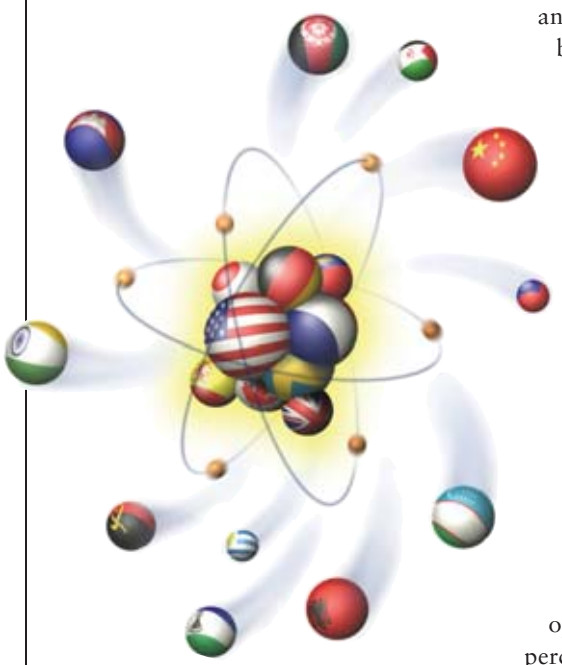
BY JOSE GOLDEMBERG

COURTESY OF JOSE GOLDEMBERG

After 20 years of stagnation, nuclear energy again finds favor in the eyes of many energy planners. In contrast with electricity generated from coal or natural gas, nuclear power contributes little to greenhouse gas emissions and could therefore help in the effort to reduce global warming. The establishment of a tax on carbon emissions, which has been widely proposed as an incentive to move away from fossil-fuel use, would make nuclear energy even more attractive. Such arguments may ultimately prove compelling to in-

dustrial nations—but to assume that the developing nations will follow suit is to ignore some important realities.

Currently 435 nuclear reactors operate around the world, with an electrical generating capacity of approximately 370 gigawatts (GW), providing about 17 percent of the world's electricity. Various analysts have optimistically foreseen a steep rise in those numbers. For instance, a 2003 interdisciplinary study by the Massachusetts Institute of Technology outlined a scenario of "low" nuclear growth that would still allow a tripling of nuclear generation by 2050. The contribution of the developing nations would soar to a third of the whole, from 10 to 307 GW. To reach that level, however, would demand about 8 percent annual growth sustained over 45 years.



MATT COLLINS

No economic modeling figured into that estimate; the analysts merely assumed that the developing nations would aim for the 10 to 20 percent share of electricity from nuclear power that the rest of the world would adopt. Yet financing the up-front investments needed for nuclear plants is a major challenge even in industrialized countries: so far nuclear power expands only where governments facilitate private investment, a practice that is at odds with strong market liberalization policies. That trend will hold even more markedly in developing countries.

Moreover, motivation to shift to nuclear energy may be lacking. Concerns about greenhouse gas emissions simply do not have a high priority now in developing nations. Neither the Kyoto Protocol nor any other international agreement constrains those emissions for them (they were exempted to assist their development). For poor countries, the pivotal problem is the allocation of scarce resources. Their financial authorities cannot easily justify subsidizing nuclear energy at the expense of more pressing needs in health, education and poverty reduction.

Nor is the need for energy a sufficient compulsion. Most of the anticipated growth in nuclear energy in the developing world is commonly ascribed to China and India. In recent years, they have become prime markets for nuclear technology imports because their indigenous programs have been at best qualified successes. Yet those countries, and indeed the rest of the developing world, have abundant nonnuclear energy alternatives, too. Cleaner coal-burning technologies would reduce emissions not only of greenhouse gases but also of soot and other by-products that cause local and regional pollution—and they could prove to be easier or less expensive to implement. Many developing nations have underexploited their hydroelectric power options: worldwide only around 32 percent of the economical hydroelectric potential has been tapped so far, and in sub-Saharan Africa that figure is far smaller. Other renewable energy sources, particularly biofuels for transportation, also have good prospects.

Further practical considerations can intrude, too. The smaller developing countries have electric grids with capacities of less than 10 GW. Large nuclear reactors will therefore not fit in them without violating the common best-practice guideline that no more than 10 percent of a

grid should draw from a single source.

The greatest objection to the spread of nuclear technology and power reactors to developing countries, however, is that it will increase the risks of nuclear weapons proliferation. The temptation for developing countries to go nuclear is particularly common when the political regime is not democratic, as happened previously in South Africa, Brazil and Argentina and as is currently happening in Iran, where national prestige can overrule rational economic decisions and sensible energy policies. Ultimately it seems likely that internal conflicts and international antiproliferation restrictions will contain the growth of even civilian nuclear programs.

Nuclear energy may well play a larger role in the future of the U.S. and other industrial nations. The rest of the world, however, will most probably look elsewhere for the clean energy it needs. ■

Jose Goldemberg, a physicist by training, is secretary for the environment of the state of São Paulo and previously served the government of Brazil as secretary of state for science and technology, secretary of the environment, and minister of education.

Skeptic

The Prospects for *Homo economicus*

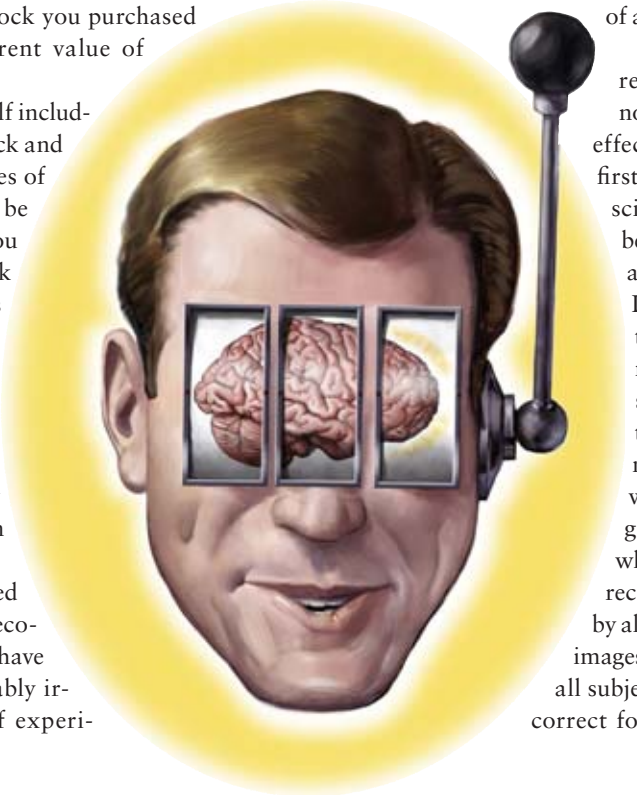
A new fMRI study debunks the myth that we are rational-utility money maximizers

BY MICHAEL SHERMER

Imagine that your child's private school tuition bill of $20,000 is due and the only source you have for paying it is the sale of some of your stock holdings. Fortunately, you got in on the great Google godsend and purchased 100 shares at $200 each, for a total investment of $20,000, and the stock is now at $400 a share. Should you realize your net gain by selling half of your Google stock and paying off your bill? Or should you sell off that Ford stock you purchased ages ago for $40,000 at its current value of $20,000?

If you are like most people (myself included), you would sell your Google stock and hang on to your Ford stock in hopes of recovering your losses. This would be the wrong strategy. Why would you sell shares in a company whose stock is on the rise, and hang on to shares in a company whose stock is on the decline? The reason, in a phrase, is "loss aversion," and the psychology behind it does not fit the model of *Homo economicus,* that figurative species of human characterized by unbounded rationality in decision making.

Homo economicus is extinct, felled by the new sciences of behavioral economics and neuroeconomics, which have demonstrated that we are remarkably irrational creatures. Thousands of experiments in behavioral economics since Daniel Kahneman and Amos Tversky founded the field with their seminal 1979 paper, "Prospect Theory: An Analysis of Decision under Risk," have demonstrated that most of us are highly loss averse. Specifically, most people will reject the prospect of a 50–50 probability of gaining or losing money, unless the amount to be gained is at least double the amount to be lost. That is, people feel worse about the pain of a loss than they feel better about the pleasure of a gain. Twice as badly, in fact.



Thanks to functional magnetic resonance imaging (fMRI), we now know where in the brain this effect happens. To see this science firsthand, I visited the lab of neuroscientist Russell A. Poldrack and behavioral economist Craig R. Fox at the University of California, Los Angeles, and climbed inside the cramped quarters of the magnetic tube. The MRI scanner snaps a picture of the brain every two seconds while the subject makes decisions about gambles, which are presented through goggles featuring tiny screens on which the choices are offered. Corrections for head motion are made by aligning the individual two-second images with one another; the data from all subjects are then warped together to correct for differences in brain size and

PHOTOGRAPH BY BRAD SWONETZ; ILLUSTRATION BY MATT COLLINS

Forces that cannot be stopped.
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shape. A statistical model is generated to show how the MRI signal should change over time in an area that has responded perfectly to the task, followed by statistical tests to compare the observed data with the perfect model, resulting in statistical maps that are then converted into colorful pictures of brains in action.

In "The Neural Basis of Loss Aversion in Decision-Making under Risk," in the January 26 *Science*, Poldrack, Fox and their colleagues Sabrina M. Tom and Christopher Trepel presented the results of their fMRI study, in which they offered subjects a prospect of accepting or rejecting a gamble that offered a 50–50 chance of gaining or losing money. As the potential for gains rose, they found increased activity in the mesolimbic and mesocortical dopamine systems (dopamine is a neurotransmitter substance associated with motivation and reward). As the potential for losses increased, they found decreasing activity in these same reward-sensitive areas. Interestingly, it appears that losses and gains are coded by the same brain structures—the ventromedial prefrontal cortex, associated with decision making and learning in the context of reward and punishment, and the ventral striatum, associated with learning, motivation and reward. Individual differences in loss aversion were predicted by how much more the brain was turned off by losses than it was turned on by gains.

This effect may be caused by differences in neurochemistry, which means that some of us may be hardwired to be high- or low-risk takers, translating into real-world financial prospects, both good and bad. ■

Michael Shermer is publisher of Skeptic *(www.skeptic.com). His latest book is* Why Darwin Matters.

THE EDITORS' BLOG

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HYDROGEN HUMMER AT THE SOUTH POLE?

File this under crazy things tech guys do with their computer-related billions: while Bill Gates spends his Microsoft fortune combating malaria and other diseases, the great and powerful Woz (Apple co-founder Steve Wozniak) plans to spend some of his hard-earned cash racing a hydrogen-fueled Hummer to the South Pole. He's potentially enlisted Buzz Aldrin as co-pilot and a host of other alternatively fueled vehicles—running on biofuels, electricity and ego—as competitors.

Of course, it's all for a good cause: to highlight the fatal flaws of the current internal-combustion engine. And Google is backing this ZERO SOUTH expedition (what aren't they backing these days?), which means this must be good, because their motto is "Don't be evil." Chris Paine (auteur of *Who Killed the Electric Car?*) is attached to direct the fun.

All well and good, but why Antarctica? I guess the answer lies in a "team of San Francisco Bay area professionals who use long-range driving expeditions to promote cross-border understanding and goodwill," to quote the Drive around the World Web site (www.drivearoundtheworld.org). I expect the penguins will be suitably impressed, if the trip ever happens (the original attempt, with James Cameron involved, failed to get on the road this year). But I'll hold my plaudits for another computer millionaire turned vehicle visionary: Elon Musk and the battery-powered Tesla Roadster he financed.

Posted by David Biello, May 2, 2007

Read more of this post and others on SciAm Observations (www.blog.SciAm.com).

Anti Gravity

Dog Bites Dog Story

Interpreting a collection of observations is a science in itself

BY STEVE MIRSKY

There are experimental sciences, and then there are historical and observational sciences. The experimental sciences, like chemistry and physics, are easy to spot. When stuff blows up or systems don't work right, you've got yourself an experiment.

Historical and observational sciences can be a little tougher to get a handle on. The researchers in these fields must adopt the Yogi Berra stance—"You can observe a lot just by watching"—and then interpret reality. Or, as the great scientist Ernst Mayr patiently explained in these pages [see "Darwin's Influence on Modern Thought," SciAm, July 2000], "Evolutionary biology, in contrast with physics and chemistry, is a historical science—the evolutionist attempts to explain events and processes that have already taken place.... One constructs a historical narrative, consisting of a tentative reconstruction of the particular scenario that led to the events one is trying to explain."

Consumer behavior may be considered to be, at times, a historical/observational science. For example, in his 1997 Quirks.com article called "Seven Rules for Observational Research: How to Watch People Do Stuff," Walt Dickie describes his field studies: "I once spent a week watching people nod off waiting for their cars to be repaired. I was Jane Goodall and they were the chimps." (Turns out

FLYNN LARSEN

the chimps mostly just wanted their cars to be serviced faster and were barely amused by the magazines and newspapers in the cage—er, customer lounge.)

Other historical sciences include crime scene investigation, geology and the interpretation of baseball box scores. All require the construction of narratives after the compilation of facts. More from Ernst: "The testing of historical narratives implies that the wide gap between science and the humanities that so troubled physicist C. P. Snow is actually nonexistent."

So we may discuss journalism as a semiscience, in which a reporter gathers facts and then constructs one or more possible narratives to explain those facts. Alternative narratives then fight it out, and the most parsimonious wins. Sometimes.

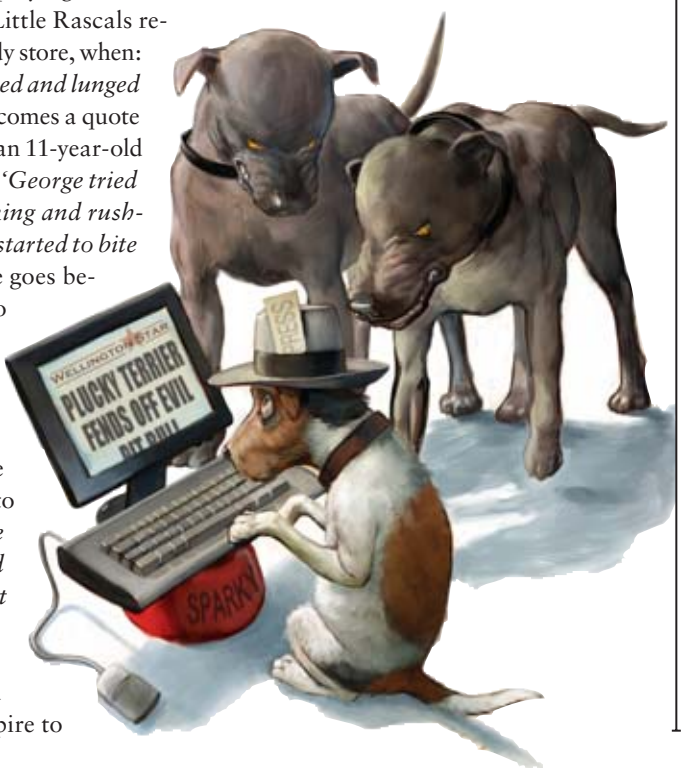
Consider this story, reported by the Associated Press in early May, carrying the headline "Tiny Terrier Saved Kids from Pit Bulls." The story, filed from Wellington, New Zealand, includes these details:

"*A plucky Jack Russell terrier named George saved five children from two marauding pit bulls.... George was playing with the group of children as they returned home from buying sweets.*" So far we have an anthropomorphized terrier—plucky, and *he* was playing with *them,* mind you—and the Little Rascals returning from the candy store, when: "*Two pit bulls appeared and lunged toward them.*" Next comes a quote from one of the kids, an 11-year-old animal behaviorist: "'*George tried to protect us by barking and rushing at them, but they started to bite him.*'" Note that she goes beyond description to narrative herself—George's primary interest was her safety. Now comes the resolution of the situation, according to the 11-year-old: "'*We ran off crying, and some people saw what was happening and rescued George.*'"

The headline and the article thus conspire to portray a brave little dog that tried to rescue human children. And that may indeed be what happened. Based solely on the facts reported in this piece, however, we may construct a somewhat different narrative. The pit bulls appeared and moved in on the group; the terrier rushed at them; the pit bulls focused their attention on the terrier; the kids ran away. In other words, the same reported facts could have led to a story that carried the headline "Five Frightened Kids Flee as Tiny Dog Is Attacked."

While lacking the heartwarming character of the published account, this version might have the virtue of being true. And while the journalist has a sciencelike task in interpreting objective reality, the news consumer has a related responsibility to evaluate the narrative. It's like your own forensics investigation! After which you can say, perhaps even accurately, "Mission Accomplished." ■

Steve Mirsky is the host of the Scientific American *weekly podcast, Science Talk. A collection of his Anti Gravity columns, cleverly called* Anti Gravity, *is now available in remainder bins at major bookstores.*



MATT COLLINS

FUTURE HURRICANES could be more severe thanks to global warming.

WARMER OCEANS, STRONGER HURRICANES

Evidence is mounting that global warming enhances a cyclone's damaging winds and flooding rains *By Kevin E. Trenberth*

The summer of 2004 seemed like a major wake-up call: an unprecedented four hurricanes hit Florida, and 10 typhoons made landfall in Japan—four more than the previous record in that region. Daunted, scientists offered conflicting explanations for the increase in these tropical cyclones and were especially divided about the role of global warming in the upsurge. Then Mother Nature unleashed a record-breaking 2005 season in the North Atlantic, capped by the devastating hurricanes Katrina and Rita. But in 2006, as insurance rates in the southeastern U.S. soared, the number of North Atlantic storms dropped well below predictions. If global warming was playing a role, why was the season so quiet?

Careful analyses of weather patterns are yielding a consensus explanation for both the dramatic rises in 2004 and 2005, as well as the strangely tame 2006 season. Unfortunately, that explanation forebodes meteorological trouble over the long term.

A hurricane begins as a tropical atmospheric disturbance that may develop into an organized system of thunderstorms. If the system begins to rotate and winds exceed 39 miles an hour, meteorologists give it a name. When the maximum wind speed exceeds 74 mph, the system is called a tropical cyclone. The synonym "hurricane" is used for such storms in the Atlantic and northeastern Pacific, "typhoon" in the northwestern Pacific, and simply "cyclone" in the Indian Ocean. In this article, I will use the terms interchangeably.

To determine whether global warming is affecting the number, size or intensity (wind speed) of hurricanes, scientists first need to understand the recipe for cooking up such storms. Over the years they have devised ever more detailed models of how hurricanes form. Hurricanes require warm water, and most take shape in the tropics where the sun beats down from almost vertically overhead. The ocean absorbs most of the incoming energy and then expels the excess heat mainly through evaporation; when the rising moisture condenses into rain, it releases latent energy, heating the atmosphere. In winter, winds carry this heat to higher latitudes

KEY CONCEPTS

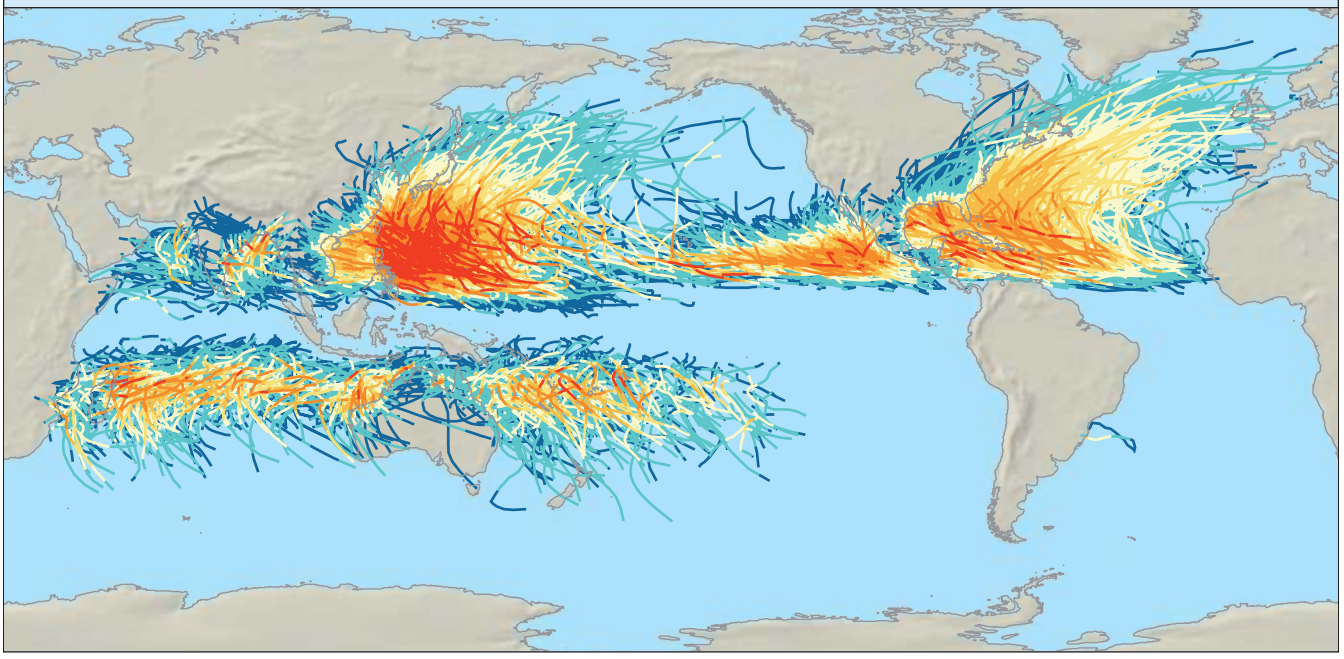
- Global warming caused by human activity is raising the temperature of the world's oceans as well as increasing their evaporation. These two factors are exacerbating the strength of hurricanes.
- Even a small increase in the ocean's warmth can turn more tropical disturbances into hurricanes or pump up an existing storm's power and add to its rainfall.
- Nevertheless, the number of hurricanes in any given year is strongly influenced by the seasonal ocean patterns known as El Niño and La Niña—which calmed Atlantic cyclone activity in 2006. *—The Editors*

ALFRED T. KAMAJIAN

WHERE CYCLONES ROAM

Tracks and wind speed of all tropical storms recorded through September 2006 show the regions at highest risk.

STORM SEVERITY: Tropical depression | Tropical storm | Category 1 | Category 2 | Category 3 | Category 4 | Category 5



RATING STORMS BY WIND SPEED

HURRICANE CATEGORIES
(Saffir-Simpson scale)

- 5 156+ mph
- 4 131 to 155 mph
- 3 111 to 130 mph
- 2 96 to 110 mph
- 1 74 to 95 mph

TROPICAL STORM
39 to 73 mph

TROPICAL DEPRESSION
38 mph or less

A TROPICAL CYCLONE IS CALLED A ...

Hurricane in the Atlantic and northeastern and southern Pacific

Typhoon in the northwestern Pacific

Cyclone in the Indian Ocean and Australian region

where it can radiate to space. But in summer, the energy primarily rises through convection to higher altitudes within the tropics, creating various phenomena, from cumulus clouds to thunderstorms. Under the right circumstances, a collection of thunderstorms can organize into a vortex—a hurricane—that pumps large amounts of heat out of the ocean.

A preexisting atmospheric disturbance is needed to initiate vortex formation; in the North Atlantic, such disturbances typically slip off the west coast of central Africa, where they are often set up by temperature contrast between inland desert and forested coastal mountain regions. Other favorable conditions are also needed, including a sea-surface temperature (SST) greater than about 26 degrees Celsius (80 degrees Fahrenheit), plentiful water vapor, low pressure at the ocean surface, and weak wind shear between low and high altitudes (strong wind shear tends to tear a nascent vortex apart).

Given that sea-surface temperature is a key driver of hurricane formation, scientists wondering about the recent patterns wanted to know how SSTs may have changed over the past decades and whether the number, size and intensity of hurricanes have changed with them. If so, was global warming, now known to be caused by human activities, a major contributor? And what was unique about conditions in 2004 and 2005 that made them record years? Scientists have long understood that mounting greenhouse gases (such as carbon dioxide from burning fossil fuels) warm the planet and can raise SSTs, as well as the production of water vapor, thereby elevating the potential for the convective activity that forms hurricanes. The question after 2005 was, Had SSTs in fact risen already and to what extent was global warming responsible?

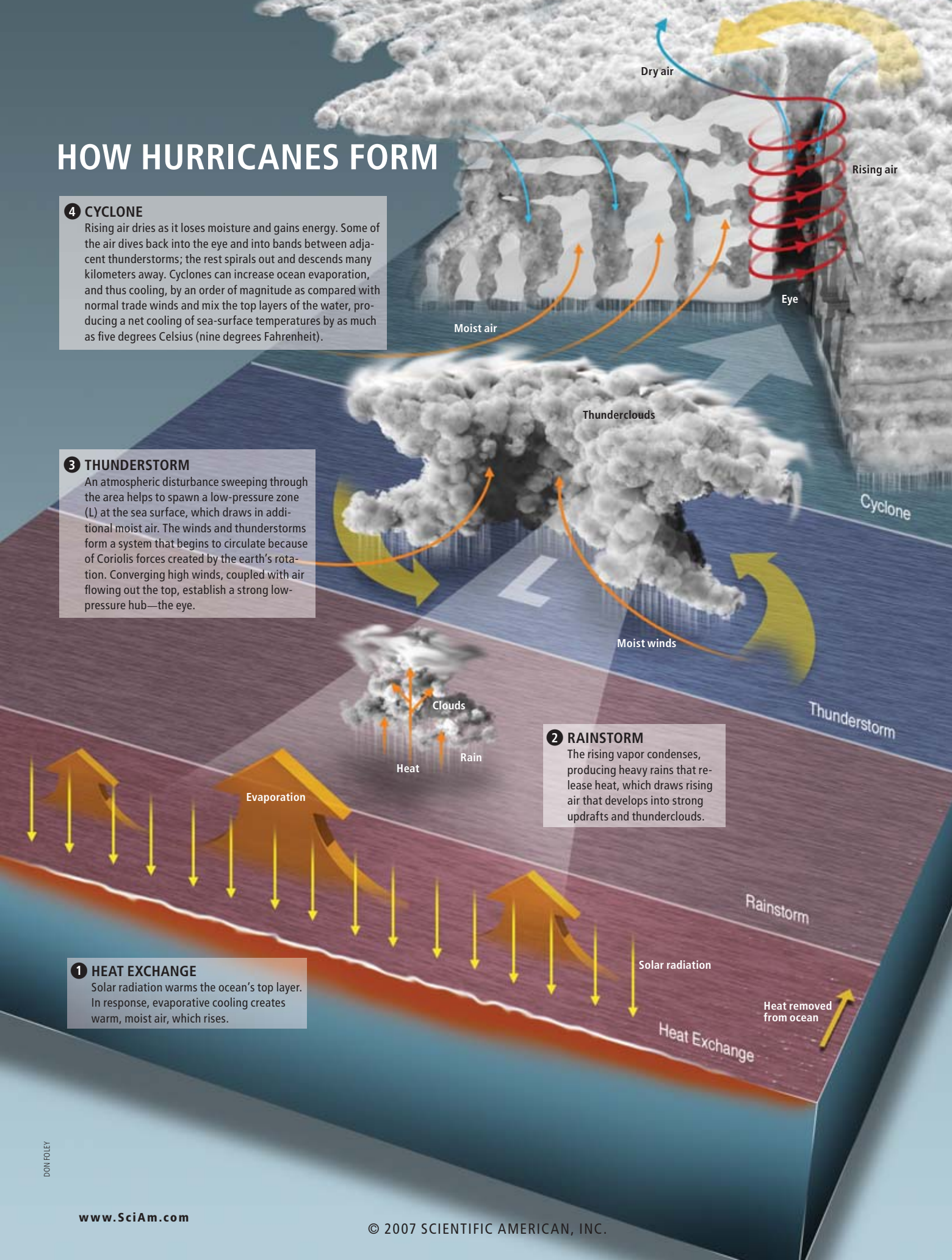
Hotter Spawning Ground

Climatologists are not certain about the number of hurricanes that occurred worldwide before 1970, when satellite observations became routine. But they consider the record in the tropical North Atlantic quite reliable from 1944 on, when aircraft surveillance of tropical storms began. A look at that history indicated that the number of named storms and hurricanes in the North Atlantic had risen since 1994—and that, notably, the rise coincided with an increase in SSTs in a latitudinal region from about 10 to 20 degrees north. This band of tropical water just north of the equator, stretching from Africa to Central America, is the critical zone of hurricane formation.

Some scientists claim that the rise in North Atlantic SSTs since 1994 simply reflects the so-

MAPPING SPECIALISTS; SOURCES: ROBERT A. ROHDE; NATIONAL HURRICANE CENTER; JOINT TYPHOON WARNING CENTER

HOW HURRICANES FORM



4 CYCLONE
Rising air dries as it loses moisture and gains energy. Some of the air dives back into the eye and into bands between adjacent thunderstorms; the rest spirals out and descends many kilometers away. Cyclones can increase ocean evaporation, and thus cooling, by an order of magnitude as compared with normal trade winds and mix the top layers of the water, producing a net cooling of sea-surface temperatures by as much as five degrees Celsius (nine degrees Fahrenheit).

3 THUNDERSTORM
An atmospheric disturbance sweeping through the area helps to spawn a low-pressure zone (L) at the sea surface, which draws in additional moist air. The winds and thunderstorms form a system that begins to circulate because of Coriolis forces created by the earth's rotation. Converging high winds, coupled with air flowing out the top, establish a strong low-pressure hub—the eye.

2 RAINSTORM
The rising vapor condenses, producing heavy rains that release heat, which draws rising air that develops into strong updrafts and thunderclouds.

1 HEAT EXCHANGE
Solar radiation warms the ocean's top layer. In response, evaporative cooling creates warm, moist air, which rises.

DON FOLEY

[THE AUTHOR]

Kevin E. Trenberth is head of the Climate Analysis Section at the National Center for Atmospheric Research in Boulder, Colo., where his work focuses on energy and water cycles in the climate system. Originally from New Zealand, he is a coordinating lead author on the Intergovernmental Panel on Climate Change's latest 2007 assessment report. He also has held leading roles in the World Climate Research Program, a partnership of international bodies that operates from Geneva under the United Nations.

called Atlantic multidecadal oscillation (AMO). This phenomenon is a natural cycle in which North Atlantic sea temperatures remain relatively low for several decades, rise to a warmer phase for decades after that, then drift downward again (the maximum temperature difference is on the order of 0.5 degree C). Experts think the pattern results from a change in ocean currents—such as those caused by the Gulf Stream that runs across the Atlantic—and deeper return flows. From the 1970s to early 1990s, North Atlantic SSTs were low. Since then, the AMO has returned to warmer conditions, and more hurricanes have formed than arose during the cooler phase. Yet computer models indicate that the AMO cycle cannot solely explain the heightened trend since 1995 or what happened in 2005 and 2006.

Although humanity is performing a giant, uncontrolled experiment by significantly adding greenhouse gases to the atmosphere, climate scientists have no way to run experiments that alter the real earth. Instead climate models are needed to tease out the various factors influencing SSTs and hurricanes. These models attempt to replicate all the important physical, chemical and biological processes that affect climate. After many years of work, scientists at the National Center for Atmospheric Research (NCAR) in Boulder, Colo., and elsewhere have devised global climate models that replicate reasonably well the actual air and sea-surface temperatures recorded worldwide over the past century. The simulations take into account changes in the atmosphere's chemical composition, the sun's energy output, and conditions such as large volcanic eruptions that can block solar radiation enough to cool the planet for a year or two.

Using the models, we can isolate changes imposed by humans, such as dumping smoke and

It does not take much of a change in ocean temperature to significantly affect a storm's power.

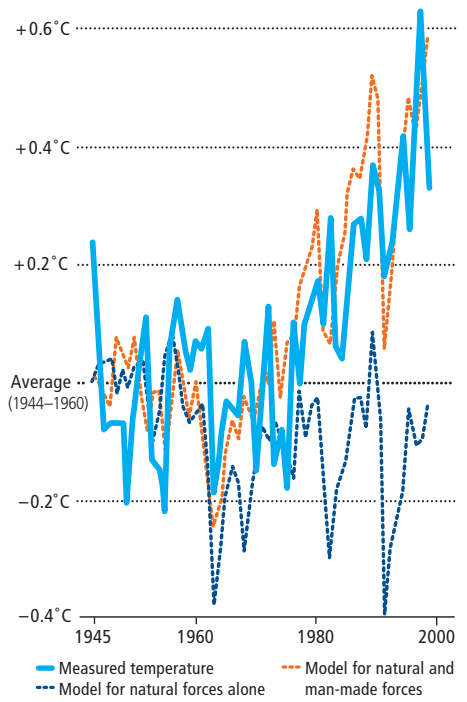
[CAUSE AND EFFECT]

Global Warming Exacerbates Storms

As human activities raise the earth's temperature ❶, sea-surface temperatures increase ❷, leading to more hurricanes in the North Atlantic ❸.

❶ HIGHER TEMPERATURES EXPLAINED

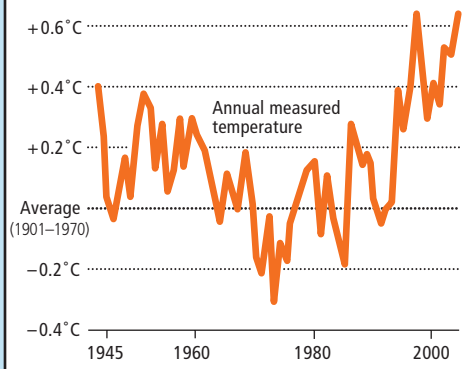
Variation from historic global average



Climate models that include the effects of man-made greenhouse gases and natural factors (sunlight, volcanic eruptions) match measured changes in temperature since 1970 better than models based only on natural forces.

❷ SEA-SURFACE TEMPERATURES UP

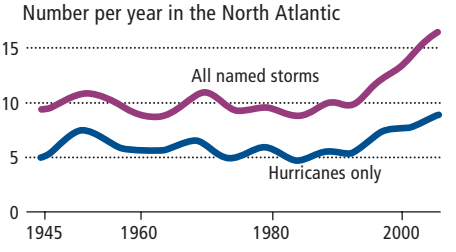
Relative values in the North Atlantic



Sea-surface temperatures vary slightly year to year, but since 1994 they have been far higher than the average.

❸ STORMS ON THE RISE

Number per year in the North Atlantic



Since the mid-1990s the number of named tropical storms and hurricanes in the North Atlantic has been high. (Aircraft observance of storms began in 1944.)

CARLYE CALVIN *UCAR (Trenberth)*; JEN CHRISTIANSEN; SOURCES: KEVIN E. TRENBERTH AND GERALD MEEHL *NCAR (graphs)*

pollution into the atmosphere, and assess their impact. Doing so clearly shows that warming of the Atlantic, beyond anything attributable to the AMO, has occurred and is related to atmospheric heating caused by human actions. A recent study published by climate scientist Ben Santer of Lawrence Livermore National Laboratory and his colleagues goes further, concluding that warming in both the tropical Atlantic and Pacific is attributable to increases in greenhouse gases generated by humans. Leading estimates indicate that global SSTs have risen about 0.6 degree C (one degree F) from global warming, mainly since about 1970. Although this number may sound small, it does not take much of a change to significantly affect a storm's power; as Hurricane Katrina traveled across the Gulf of Mexico, a rise or fall in SST of a mere one degree was enough to change the storm's intensity by an entire category (such as from Category 2 to 3).

Because tropical cyclone activity depends greatly on SSTs, we can conclude that global warming has led to more intense storms. I published a detailed rationale for this link in the June 2005 *Science*, and Kerry Emanuel of the Massachusetts Institute of Technology independently published direct observational evidence in *Nature* only two months later. He showed that significant increases in cyclone intensity and duration around the world since 1970 have been strongly related to rising SSTs. Challenges from other experts have led to modest revisions in the specific correlations but do not alter the overall conclusion. In September 2005 Peter Webster of the Georgia Institute of Technology and his colleagues published an article in *Science* that explicitly showed a substantial rise in the number of Category 4 and 5 hurricanes since 1970 and in the percent of total hurricanes that fit that description. They concluded that the rise was to be expected, given the observed increase in SSTs.

Why the Lull?

The record number of hurricanes in 2004 and 2005 was also in line with these conclusions. But if that is the case, why was the 2006 hurricane season so quiet? During the summer of 2005, SSTs in the tropical North Atlantic (the 10 to 20 degree north band) were at record highs. They were 0.92 degree C above the 1901 to 1970 norm, which is more than even the AMO fluctuation plus global warming can account for. What was at fault, then? The main added factor was a force that operated during the preceding winter and spring: El Niño. This phenomenon is a warming of the tropical Pacific Ocean that arises when a coupling occurs between oceanic and atmospheric flows.

In the Northern Hemisphere winter of 2004 to 2005, a weak to moderate El Niño was under way. It led to sunny skies and weak winds in the tropical Atlantic, which meant less evaporative cooling, allowing the ocean to warm by an estimated additional 0.2 degree C. But the El Niño petered out by summer, minimizing wind shear in the Atlantic, which created another favorable condition for hurricane formation. The end result for 2005 was that El Niño—on top of the AMO and global warming factors—allowed a record number of hurricanes to spawn as well as grow large.

In contrast, a La Niña—marked by cooling of the tropical Pacific—took hold during the 2005 to 2006 winter, leading to much stronger than normal North Atlantic trade winds that pulled heat out of the ocean. That left SSTs slightly below or near normal levels for the 2006 hurricane season. Moreover, during the 2006 summer an El Niño began to form, contributing to greater wind shear in the Atlantic. The lower SSTs and unfavorable wind shear fundamentally changed the tropical Atlantic conditions from those of a record-breaking 2005 hurricane season to a quiet 2006 season. Although a new background of higher SSTs now exists overall, annual variabilities are superposed on that and can dominate in any given year.

RICK WILKING Reuters/Corbis

GRETNA, LA., just outside New Orleans, is hit by Hurricane Katrina.

WORST CYCLONES

Costliest:
Katrina, Gulf Coast, in 2005; more than $100 billion in damage

Deadliest:
Bhola, Ganges Delta, in 1970; killed more than 300,000

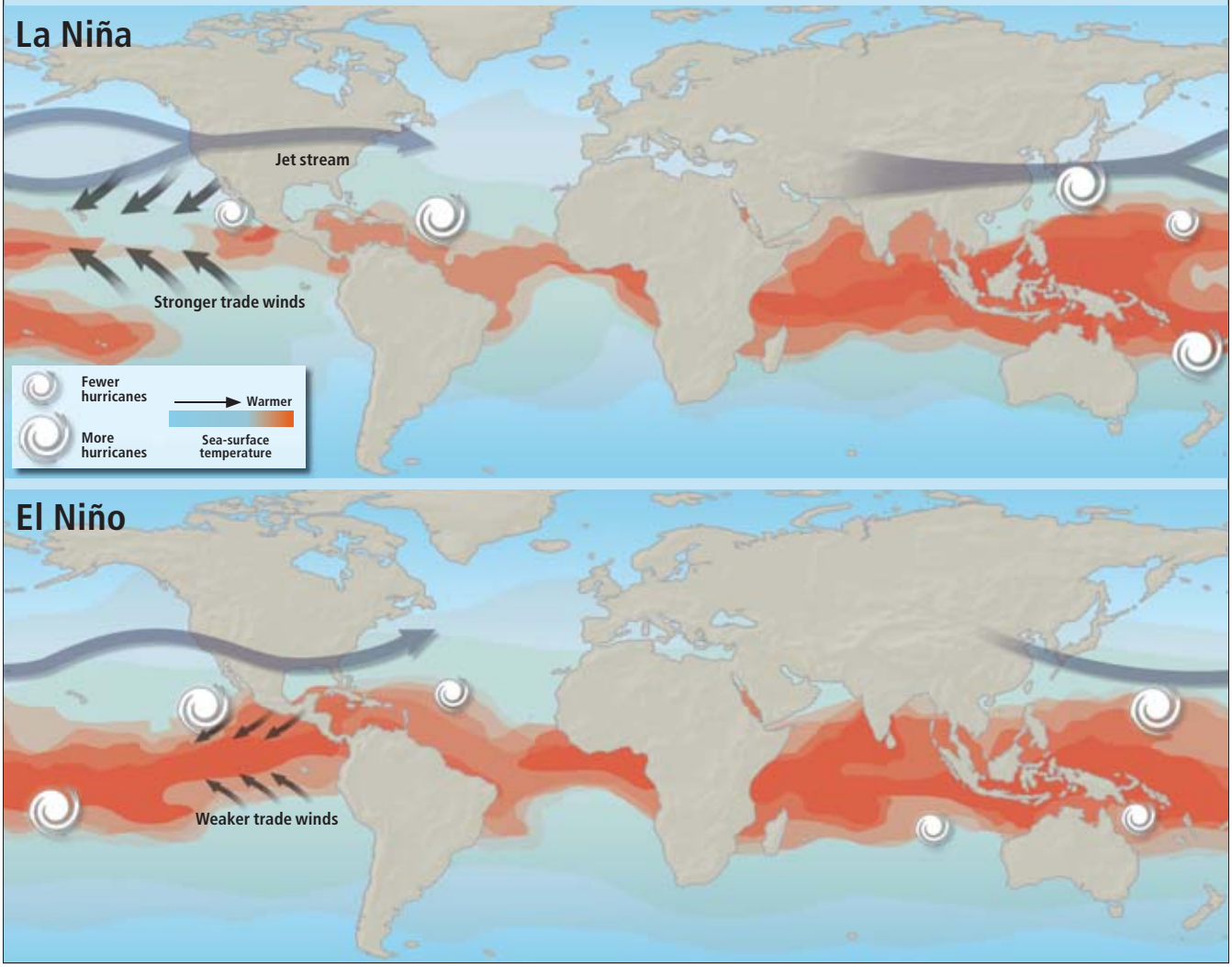
Most Intense on Landfall:
Camille, Gulf Coast, in 1969; maximum sustained wind speed of 190 mph

Longest-Lasting:
John, Pacific Ocean, in 1994; duration of 31 days

Widest:
Tip, Pacific Ocean, in 1979: 2,200 km (1,350 miles) across

THE 2006 LULL EXPLAINED

Despite warmer oceans, transient couplings between atmosphere and ocean can influence how many hurricanes form in a given year. If a La Niña (cooling of the Pacific) occurs during a Northern Hemisphere winter and spring, stronger than normal eastern Pacific trade winds pull heat from the ocean, lessening the potential energy for storms there. But the phenomenon splits the Pacific jet stream and holds the Atlantic portion to the north, allowing hurricanes that form off of Africa to advance west toward the Caribbean. That tendency is part of what led to a record year there in 2005. If an El Niño (warming of the Pacific) grows during spring and summer, the jet stream dips south over North America, creating greater wind shear that will tear apart nascent storms that try to organize in the Atlantic. These conditions led to fewer hurricanes there in 2006.



MAPPING SPECIALISTS

More Flooding, Too

These conclusions, of course, are only as trustworthy as the observations and models that produce them. In simulating and forecasting hurricanes, at NCAR we use the so-called Weather Research and Forecasting model, which segments real-world climate data into a grid with nodes four kilometers apart—high resolution by most standards. Global simulations run by the National Weather Service have 35-kilometer resolution, and their regional models have 12- to eight-kilometer resolution. Calculating at four-kilometer resolution requires massive computer power and long run times; weather forecasters must limit themselves to an eight-kilometer grid to make their predictions timely. Our models calculate convection effects directly.

We also have faith in our models because they have replicated features of actual storms very well when real data are fed into them, notably the storm tracks of hurricanes occurring in 2004 and 2005. When we entered SST data from the days Katrina spent over the Gulf of Mexico into our computer, the resulting mod-

eled hurricane closely matched the track of the real one.

Assured by such results, we have also tried to discern how elevated SSTs affect the amount of rain hurricanes drop. In the case of Katrina, a one degree C increase in SST raised the ambient water vapor in the atmosphere by about 7 percent. The maximum winds rose, too, transporting more moisture into the storm and furthering evaporation. Together the effects of a one degree C increase in SST raised rainfall by about 19 percent within 400 kilometers of the model storm's eye.

It is fair to say, then, that global warming increases a cyclone's rainfall. The 0.6 degree C rise in SSTs that has occurred since 1970 from global warming means that climate change has increased water vapor in the atmosphere by 4 percent over the past 37 years. Consistent with those findings, microwave instruments on satellites have observed an actual rise of 2 percent since 1988 alone. Recall that in a cyclone, the added water vapor condenses and gives up latent heat, which increases the rising air and thus the inflowing winds by a comparable amount. A 4 percent rise in water vapor can lead to an 8 percent rise in precipitation rates.

Given these calculations, we can say that of the 30 centimeters (12 inches) of rain Katrina dumped onto New Orleans, about 2.5 centimeters (one inch), or 8 percent, can be attributed to global warming. No one can declare that a given cyclone was "caused" by global warming, but heating the planet clearly influences cyclone power and precipitation.

Trouble to Come

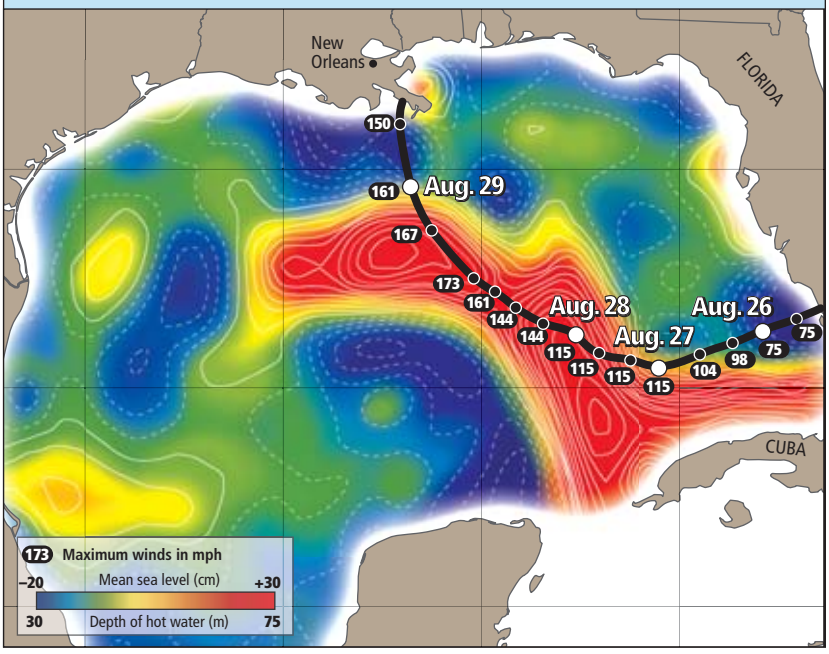
Both observations and theory therefore suggest that hurricanes are becoming more intense as the earth warms. It is difficult to say if the absolute number of cyclones is likely to increase, however, because tropical storms are much more effective than average thunderstorms at removing heat from the ocean. One big storm may also be more effective than two smaller ones, so it is possible or even likely that fewer cyclones might form, with those that do arise being larger and more intense. Once a strong storm is over, it leaves a cooler ocean behind, lowering the likelihood that more storms will flare up, at least immediately.

Questions remain about past observational data about storms, too; some scientists say that the historical data are too inconsistent to allow firm conclusions. Others say the data for the North Atlantic are solid (at least since 1944) but are less certain for the Pacific. One helpful step would be to reprocess all the satellite data that are stored in archives using modern techniques, to eke out more consistent information on past storm intensity, size, duration and other metrics of activity. Faster computers will further improve modeling, as will new knowledge from expanded field experiments. These advances will better establish how well our models perform and thus how credible they are in projecting the future.

Nevertheless, the continually improving scientific record indicates that global warming is raising sea-surface temperatures. That rise, in turn, will probably bolster the intensity of hurricanes, including those that target the Americas. In its landmark report in May, the Intergovernmental Panel on Climate Change concluded that "there is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea-surface temperatures." As we continue to improve our models and observations, we all would be wise to plan for more extreme hurricane threats. ■

HOT WATER FIRES UP STORMS

A cyclone mixes the ocean's top layer of water, down to 100 meters deep. After crossing Florida on August 26, 2005, Hurricane Katrina was barely a Category 1. But it latched onto a deep reservoir of warm water known as a loop current (*red*), which featured raised sea level and provided huge stores of energy as it mixed, pumping Katrina up to Category 5 in fewer than three days.



MAPPING SPECIALISTS; SOURCE: UNIVERSITY OF COLORADO AT BOULDER

MORE TO EXPLORE

Divine Wind: The History and Science of Hurricanes. Kerry Emanuel. Oxford University Press, 2005.

Increasing Destructiveness of Tropical Cyclones over the Past 30 Years. Kerry Emanuel in *Nature,* Vol. 436, pages 686–688; August 4, 2005.

Changes in Tropical Cyclone Number, Duration and Intensity in a Warming Environment. P. J. Webster, G. J. Holland, J. A. Curry and H.-R. Chang in *Science,* Vol. 309, pages 1844–1846; September 16, 2005.

Atlantic Hurricanes and Natural Variability in 2005. Kevin E. Trenberth and Dennis J. Shea in *Geophysical Research Letters,* Vol. 33, No. 12; June 2006.

The Memory

Researchers are closing in on the rules that the brain uses to lay down memories. Discovery of this memory code could lead to the design of smarter computers and robots and even to new ways to peer into the human mind

KEY CONCEPTS

- The brain relies on large populations of neurons acting in concert to represent and form a memory of an organism's experiences.
- In the mouse hippocampus (an area critical to memory formation), subsets of such populations—dubbed "neural cliques"—have been shown to respond to different aspects of an event. Some represent abstract, general information about a situation; others indicate more selective features.
- The same hierarchical organization used to lay down memories could be applied by the brain to convert collections of electrical impulses into perception, knowledge and behavior. If so, the memory work brings investigators closer to uncovering the universal neural code: the rules the brain uses to identify and make sense of the body's experiences.
- The author and his colleagues have converted recordings of clique activity into binary code. Such digitization of brain signals could create a foundation for assembling a codebook of the mind—a tool for cataloguing thoughts and experiences and comparing them across individuals and, perhaps, species. *—The Editors*

By Joe Z. Tsien

Anyone who has ever been in an earthquake has vivid memories of it: the ground shakes, trembles, buckles and heaves; the air fills with sounds of rumbling, cracking and shattering glass; cabinets fly open; books, dishes and knickknacks tumble from shelves. We remember such episodes—with striking clarity and for years afterward—because that is what our brains evolved to do: extract information from salient events and use that knowledge to guide our responses to similar situations in the future. This ability to learn from past experience allows all animals to adapt to a world that is complex and ever changing.

For decades, neuroscientists have attempted to unravel how the brain makes memories. Now, by combining a set of novel experiments with powerful mathematical analyses and an ability to record simultaneously the activity of more than 200 neurons in awake mice, my colleagues and I have discovered what we believe is the basic mechanism the brain uses to draw vital information from experiences and turn that information into memories. Our results add to a growing body of work indicating that a linear flow of signals from one neuron to another is not enough to explain how the brain represents perceptions and memories [see "Seeking the Neural Code," by Miguel A. L. Nicolelis and Sidarta Ribeiro; Scientific American, December 2006]. Rather the coordinated activity of large populations of neurons is needed.

Furthermore, our studies indicate that neuronal populations involved in encoding memories also extract the kind of generalized concepts that allow us to transform our daily experiences into knowledge and ideas. Our findings bring biologists closer to deciphering the universal neural code: the rules the brain follows to convert collections of electrical impulses into perception, memory, knowledge and, ultimately, behavior. Such understanding could allow investi-

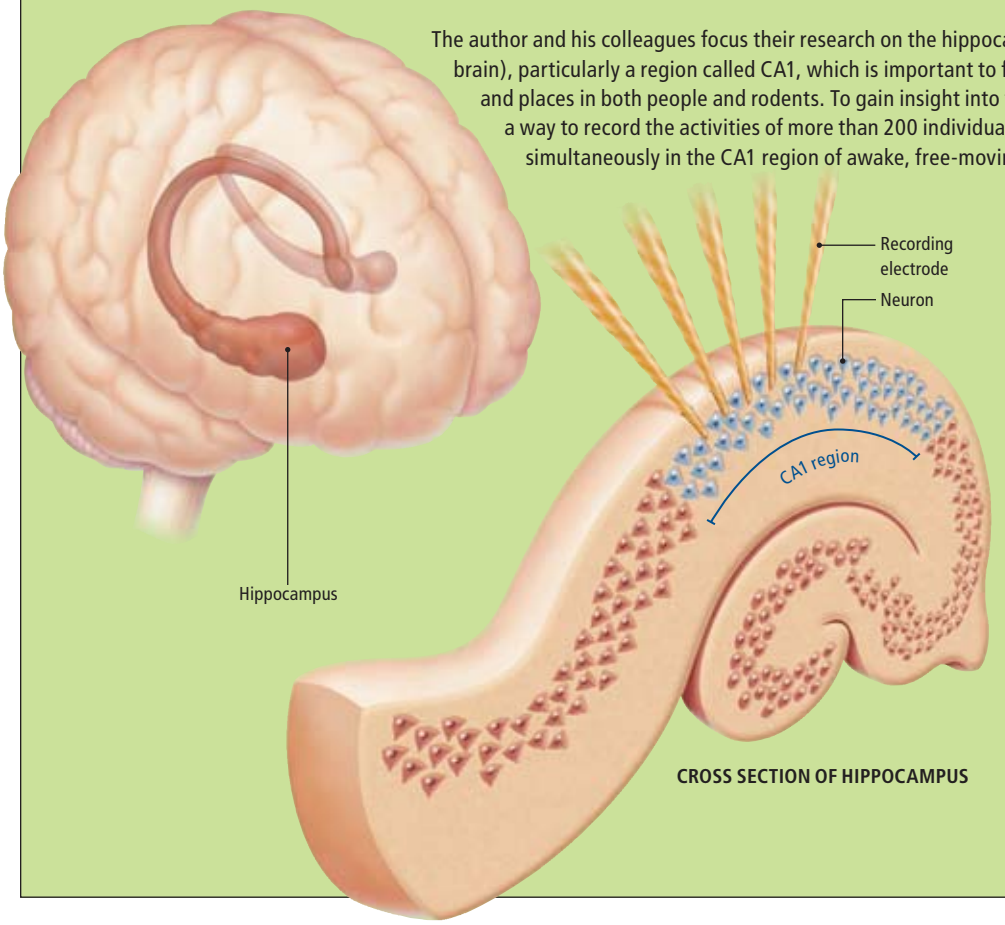
TOM DRAPER DESIGN; IMAGE SHOP/CORBIS (*photograph*)

Code

[BASICS]

A SEAT OF MEMORY

The author and his colleagues focus their research on the hippocampus (shown in human brain), particularly a region called CA1, which is important to forming memories of events and places in both people and rodents. To gain insight into the process, they developed a way to record the activities of more than 200 individual nerve cells, or neurons, simultaneously in the CA1 region of awake, free-moving mice.



▼ CA1 neurons branch dramatically, a feature well captured in this micrograph depicting mouse nerve cells coaxed to produce a yellow fluorescent protein.

We designed experiments that take advantage of what the brain seems to do best: laying down memories of dramatic events.

gators to develop more seamless brain-machine interfaces, design a whole new generation of smart computers and robots, and perhaps even assemble a codebook of the mind that would make it possible to decipher—by monitoring neural activity—what someone remembers and thinks.

Doogie Raises Questions

My group's research into the brain code grew out of work focused on the molecular basis of learning and memory. In the fall of 1999 we generated a strain of mice engineered to have improved memory [see "Building a Brainier Mouse," by Joe Z. Tsien; SCIENTIFIC AMERICAN, April 2000]. This "smart" mouse—nicknamed Doogie after the brainy young doctor in the early-1990s TV dramedy *Doogie Howser, M.D.*—learns faster and remembers things longer than wild-type mice. The work generated great interest and debate and even made the cover of *Time* magazine. But our findings left me asking, What exactly is a memory?

Scientists knew that converting perceptual experiences into long-lasting memories requires a brain region called the hippocampus. And we even knew what molecules are critical to the process, such as the NMDA receptor, which we altered to produce Doogie. But no one knew how, exactly, the activation of nerve cells in the brain represents memory. A few years ago I began to wonder if we could find a way to describe mathematically or physiologically what memory is. Could we identify the relevant neural network dynamic and visualize the activity pattern that occurs when a memory is formed? And could we discern the organizing principles that enable neuronal populations to extract and record the most vital details of an experience?

To learn something about the neural code involved in memory, we first needed to design better brain-monitoring equipment. We wanted to continue working with mice, in part so that we could eventually conduct experiments in animals with genetically altered abilities to learn and remember, such as the smart mouse Doogie and mutant mice with impaired memory. Researchers had monitored the activities of hun-

ALICE Y. CHEN (*illustrations*); M. FUHRMANN AND JOCHEM HERMS *Center for Neuropathology and Prion Research, Ludwig Maximilians University Munich (micrograph)*

dreds of neurons in awake monkeys, but investigators working with mice had managed at best to record from only 20 or 30 cells at once—mostly because the mouse brain is not much bigger than a peanut. So Longnian Lin, then a postdoctoral fellow in my lab, and I developed a recording device that allowed us to monitor the activities of much larger numbers of individual neurons in the awake, freely behaving mouse.

We then designed experiments that take advantage of what the brain seems to do best: laying down memories of dramatic events that can have profound influences on one's life. Witnessing the 9/11 terrorist attacks, surviving an earthquake or even plummeting 13 stories in Disney's Tower of Terror are things that are hard to forget. So we developed tests that would mimic this type of emotionally charged, episodic event. Such experiences should produce memories that are long-lasting and strong. And encoding such robust memories, we reasoned, might involve a large number of cells in the hippocampus, thus making it more likely that we would be able to find cells activated by the experience and gather enough data to unravel any patterns and organizing principles involved in the process.

The episodic events we chose include a lab version of an earthquake (induced by shaking a small container holding a mouse), a sudden blast of air to the animal's back (meant to mimic an owl attack from the sky) and a brief vertical free fall inside a small "elevator" (which, when we first started doing these experiments, was provided by a cookie jar we had in the lab). Each animal was subjected to seven episodes of each event separated by periods of rest over several hours. During the events—and the intervening rest periods—we recorded activity from as many as 260 cells in the CA1 region of the hippocampus, an area that is key to memory formation in both animals and humans [*see box on next two pages*].

Startling Patterns

After collecting the data, we first attempted to tease out any patterns that might encode memories of these startling events. Remus Osan—another postdoctoral fellow—and I analyzed the recordings using powerful pattern-recognition methods, especially multiple discriminant analysis, or MDA. This mathematical method collapses what would otherwise be a problem with a large number of dimensions (for instance, the activities of 260 neurons before and after an event, which would make 520 dimensions) into a graphical space with only three dimensions. Sadly for classically trained biologists, the axes no longer correspond to any tangible measure of neuronal activity, but they do map out a mathematical subspace capable of discriminating distinct patterns generated by different events.

When we projected the collected responses of all recorded neurons from an individual animal into this three-dimensional space, four distinct "bubbles" of network activity popped out: one associated with the resting brain state, one with the earthquake, one with the air puff and one with the elevator drop. Thus, each of our startling episodes resulted in a distinct pattern of activity in the CA1 neural ensembles. The patterns, we believe, represent integrated information about perceptual, emotional and factual aspects of the events.

To see how these patterns evolved dynamically as the animals endured their various experiences, we then applied a "sliding window" technique to hours of recorded data for each animal—moving through the recordings moment by moment and repeating the MDA analysis for each half-second window. As a result, we were able to visualize how the response patterns changed as the animal laid down memories of each event while it happened. In an animal that went through an earthquake, for example, we could watch the ensemble activity begin in the rest bubble, shoot out into the earthquake bubble and then return to the resting state, forming a trajectory with a characteristic triangular shape.

This temporal analysis revealed something even more interesting: the activity patterns associated with those startling experiences recurred spontaneously at intervals ranging from seconds to minutes after the actual event. These "replays" showed similar trajectories, including the characteristic geometric shape, but had smaller amplitudes than their original responses. The recurrence of these activation patterns provides evidence that the information traveling through the hippocampal system was inscribed into the brain's memory circuits—and we imagine the replay corresponds to a recollection of the experience after the fact. This ability to qualitatively and quantitatively measure spontaneous reactivations of memory-encoding patterns opens a door to being able to monitor how newly formed memory traces are consolidated into long-lasting memories and to exam-

In an animal that went through an earthquake, we could watch the neural ensemble activity begin in the rest bubble, shoot out into the earthquake bubble and then return to the resting state.

[THE AUTHOR]

Joe Z. Tsien, professor of pharmacology and biomedical engineering and director of the Center for Systems Neurobiology at Boston University, has made major contributions to the understanding of learning and memory and is a pioneer in the development of techniques for knocking out genes or proteins at a specific time in a specific tissue. He made headlines in 1999, when, at Princeton University, he generated a smart mouse strain called Doogie, which learned faster and remembered things longer than standard laboratory mice. Tsien, who moved to Boston University in 2004, recently founded the Shanghai Institute of Brain Functional Genomics at East China Normal University, his alma mater.

COURTESY OF JOE Z. TSIEN

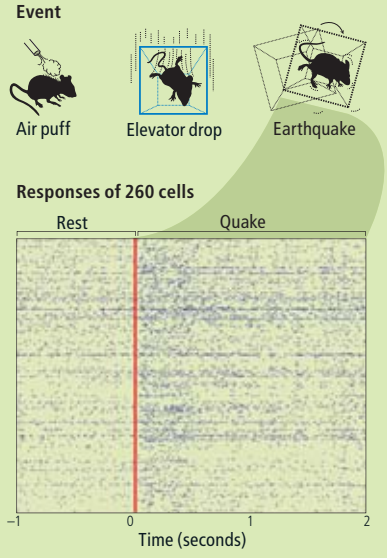
[FINDINGS]

FIRST STEPS TO UNCOVERING THE MEMORY CODE

To gain insight into the code that the brain uses to lay down memories, the author and his co-workers analyzed brain signals in a series of innovative ways.

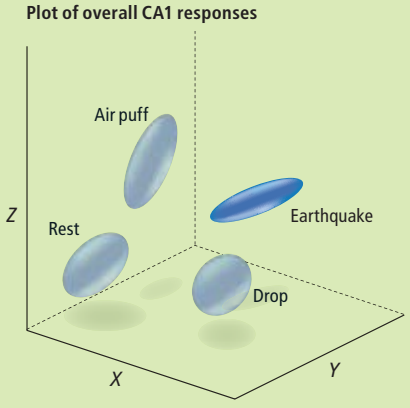
1 RECORDED EXPERIENCES

The team exposed mice to three startling experiences—a puff of air on the back, a fall in a container (the "elevator" drop), and shaking in a cage (the "earthquake")—while a recorder plotted firing from a large set of CA1 neurons. Each row in the plot below (from the quake) captures firing of a single cell over time.



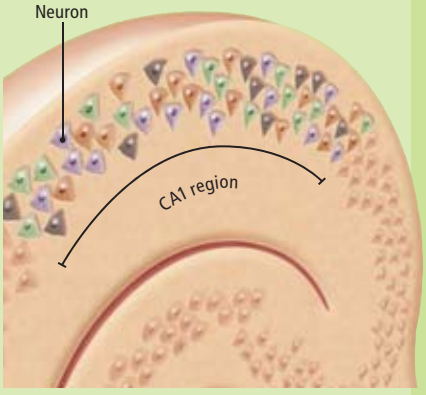
2 APPLIED PATTERN-RECOGNITION ALGORITHMS

Software translated the data from an individual mouse into a 3-D plot that represented the activity of the full ensemble of recorded neurons when the animal was at rest and undergoing startling events. Such plots enabled researchers to "read" what was happening to an animal simply by watching the recorded signal move within that 3-D space. (See a movie clip at www.SciAm.com/ontheweb)



3 DISCOVERED CODING CLIQUES

Further analyses revealed that neuron ensembles active during an event contain subsets—termed neural cliques. The cells in a clique all show very similar firing patterns and are not part of the other cliques.



Our findings suggest a number of things about the organizing principles that govern the encoding of memory.

ine how such processes are affected in smart mice and learning-impaired ones.

The Power of Cliques

With the patterns indicative of specific memories in hand, we sought to understand how the neurons among those we were "tapping" actually work together to encode these different events. By coupling another mathematical tool called hierarchical clustering analysis with the sequential MDA methods, Osan and I discovered that these overall network-level patterns are generated by distinct subsets of neural populations that we have dubbed "neural cliques." A clique is a group of neurons that respond similarly to a select event and thus operate collectively as a robust coding unit.

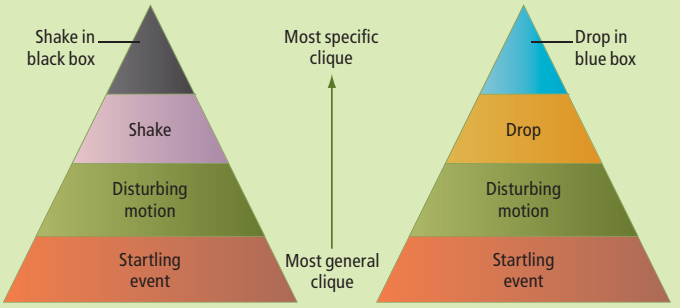
Furthermore, we found that each specific event is always represented by a set of neural cliques that encode different features ranging from the general to the specific. Notably, an earthquake episode activates a general startle clique (one that responds to all three startling stimuli), as well as a second clique that responds only to the events involving motion disturbance (both the earthquake and the elevator drop), a third clique that is activated exclusively by shaking and a fourth clique that indicates where the event took place (we put the animal in one of two different containers before each quake). Thus, information about these episodic events is represented by neural clique assemblies that are invariantly organized hierarchically (from general to specific). We think of the hierarchical arrangement as forming a feature-encoding pyramid whose base encodes a general characteristic (such as "startling event") and whose apex represents more specific information (such as "shaking" or "shaking in the black box") [*see panel 4 in box on opposite page*].

The CA1 region of the hippocampus receives inputs from many brain regions and sensory systems, and this feature most likely influences what type of information a given clique encodes. For example, the clique that responds to all three startling events could be integrating infor-

ALICE Y. CHEN (*1, 3*); LUCY READING-IKKANDA (*2, 4, 5*)

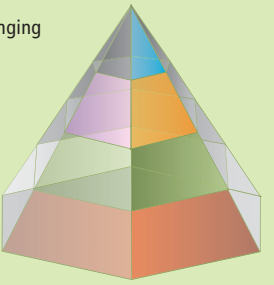
4 FOUND ORGANIZATION OF MEMORIES

Other analyses showed that each clique encodes a different aspect of an experience, ranging from the general to the specific. The author conceives of this hierarchical organization as a pyramid with the most general clique at bottom, as is shown below for two events. (The sizes of the pyramid "layers" do not signify the number of neurons in the cliques.)



Earthquake pyramid

Elevator drop pyramid



Startling event polyhedron

Any given pyramid can be a component of a polyhedron representing all events of a given category, such as "all startling events."

5 TRANSLATED BRAIN ACTIVITY INTO BINARY CODE

The investigators then represented clique activity as a string of binary code that revealed details of the event an animal experienced. In the string fragments shown here, a 1 means a particular clique was active and a 0 signifies inactivity. Binary translations of neural activity could prove useful in many realms, such as helping investigators to peer into minds of those who cannot speak or to advance development of robots controlled by thoughts alone.

Clique	General startle	Motion	Air puff	Drop	Shake
Earthquake binary code	1	1	0	0	1
Elevator drop binary code	1	1	0	1	0

mation from the amygdala (which processes emotions such as fear or the experience of novelty), thereby encoding that "these events are scary and shocking"; the cliques that are activated by both the earthquake and the elevator drop, on the other hand, could be processing input from the vestibular system (which provides information about motion disturbance), thus encoding that "these events make me lose my balance." Likewise, the cliques that respond only to a particular event occurring at a particular place could be integrating additional input from place cells (neurons that fire when a creature passes through a particular familiar spot in its environment), thereby encoding that "this earthquake took place in the black container."

The Road to Knowledge

Our findings suggest a number of things about the organizing principles that govern the encoding of memory. First, we believe that neural cliques serve as the functional coding units that give rise to memories and that they are robust enough to represent information even if some individual neurons in the ensemble vary somewhat in their activity. Although the idea that memories and perception might be represented by neural populations is not new, we think we have the first experimental data that reveal how such information is actually organized within the neural population. The brain relies on memory-coding cliques to record and extract different features of the same event, and it essentially arranges the information relating to a given event into a pyramid whose levels are arranged hierarchically, from the most general, abstract features to the most specific aspects. We believe, as well, that each such pyramid can be thought of as a component of a polyhedron that represents all events falling into a shared category, such as "all startling events."

This combinatorial, hierarchical approach to memory formation provides a way for the brain to generate an almost unlimited number of unique network-level patterns for representing the infinite number of experiences that an or-

WHAT'S NEXT?

In future work, the author hopes to explore these questions, among others, in mice:

- **Do subpopulations of neurons within a given clique encode different aspects of an event? For instance, do cliques that record memories of fear include a subset that responds to the intensity of the fear, while another subset just notes the frightening nature of the event?**
- **How do memory traces—recurrences of the firing patterns that occurred when a memory was first laid down—differ soon after an event and much later on? How do false memories arise over time?**
- **How might the binary codes extracted from electrical signaling in the brain be used to download memories and thoughts directly into computers and to control robotic machines or assist real-time monitoring of learning processes?**

PRINCETON UNIVERSITY (*mouse*)

TO YOU, A DISH TO ME, A NEST

Recently published work supports the idea that some neural cliques in the hippocampus indeed encode abstract concepts. Some cells in mice turn out to react to items having varied shapes and textures only if the things have accessible depressions and can thus function as a nest. Cover the depressions, and the cells no longer respond.

▼ **MOUSE RELAXES in a dish it views as a nest.**

ganism might encounter during life—similar to the way that the four "letters" or nucleotides that make up DNA molecules can be combined in a virtually unlimited number of patterns to produce the seemingly infinite variety of organisms on earth. And because the memory code is categorical and hierarchical, representing new experiences might simply involve substituting the specific cliques that form the tops of the memory pyramids to indicate, for example, that the dog barking behind the hedge this time is a poodle instead of a German shepherd or that the earthquake took place in California rather than in Indonesia.

The fact that each memory-encoding pyramid invariably includes cliques that process rather abstract information also reinforces the idea that the brain is not simply a device that records every detail of a particular event. Instead neural cliques in the memory system allow the brain to encode the key features of specific episodes and, at the same time, to extract from those experiences general information that can be applied to a future situation that may share some essential features but vary in physical detail. This ability to generate abstract concepts and knowledge from daily episodes is the essence of our intelligence and enables us to solve new problems in the ever changing world.

Consider, for instance, the concept of "bed." People can go into any hotel room in the world and immediately recognize the bed, even if they have never seen that particular bed before. It is the structure of our memory-encoding ensembles that enables us to retain not only an image of a specific bed but also a general knowledge of what a bed is. Indeed, my colleagues and I have seen evidence of this in mice. During the course of our experiments, we accidentally discovered a small number of hippocampal neurons that appear to respond to the abstract concept of "nest." These cells react vigorously to all types of nests, regardless of whether they are round or square or triangular or made of cotton or plastic or wood. Place a piece of glass over the nest so the animal can see it but can no longer climb in, and the nest cells cease to react. We conclude that these cells are responding not to the specific physical features of the nest—its appearance or shape or material—but to its functionality: a nest is someplace to curl up in to sleep.

The categorical and hierarchical organization of neural cliques most likely represents a general mechanism not only for encoding memory but also for processing and representing other types of information in brain areas outside the hippocampus, from sensory perceptions to conscious thoughts. Some evidence suggests this supposition is true. In the visual system, for example, researchers have discovered neurons that respond to "faces," including human faces, monkey faces or even leaves that have the shape of a face. Others have found cells that respond only to a subclass of faces. Back in the hippocampus, researchers studying patients with epilepsy have discovered a subset of cells that increase their firing rates in response to images of famous people. Itzhak Fried of the University of California, Los Angeles, further made the fascinating observation that one particular cell in a patient's hippocampus seems to respond only to the actress Halle Berry. (Perhaps it is part of a Halle Berry clique!) Together such observations support the notion that the general-to-specific hierarchical organization of information-processing units represents a general organizing principle throughout the brain.

Remember 11001?

Our work with mice also yielded a way for us to compare patterns from one brain to another—and even to pass information from a brain to a computer. Using a mathematical treatment called matrix inversion, we were able to translate the activities of neural clique assemblies into a string of binary code, where 1 represents an active state and 0 represents an inactive state for each coding unit within a given assembly we examined. For example, the memory of an earth-

LONGNIAN LIN

ON HUMAN MIND READING

Our increasing ability to read the minds of mice raises an intriguing possibility: if enough neurons in a human brain could be recorded simultaneously, such recordings could well be able to reveal human thoughts.

Of course, to be practical, this technology would have to be noninvasive. Existing tools, such as EEG monitors and functional magnetic resonance imaging devices, are noninvasive but are not sensitive enough. They record averaged signals from or oxygen consumption by millions of nerve cells. Using such tools would be like listening in on a crowded football stadium from the outside; noise would simply overwhelm any individual conversations.

If a sensitive method existed, it could potentially be used to determine whether someone who seems to be in a vegetative state is actually able to think or whether someone with Alzheimer's disease who can no longer talk is able to understand conversation. Such "mind reading" might also be helpful for diagnosing mental disorders or assessing how well some medications are working. Much better lie detectors would also be possible.

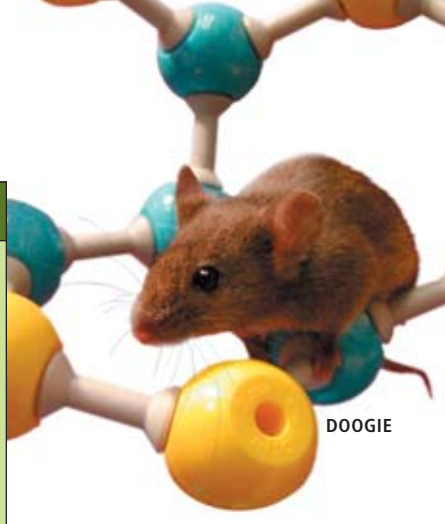
With such benefits, though, would come major moral, philosophical and societal questions that would have to be addressed. Each of us might like to read other people's minds, but who among us would want our own mind read by others? *—J.Z.T.*

MOLECULES OF MEMORY

In 1949 Canadian psychologist Donald O. Hebb postulated that a memory is produced when two nerve cells interact in a way that somehow strengthens future signaling through the synapse—the contact point between two neurons. But it was not until the 1980s that scientists saw Hebb's rule in action in brain slices. By stimulating neuron pairs in the hippocampus with electrodes, Holger Wigström of Göteborg University in Sweden and his colleagues found that activating a presynaptic neuron (a signaling cell) at the same time as a postsynaptic neuron (the signal's recipient) led to enhanced synaptic efficacy: the postsynaptic neuron came to respond more vigorously to the same amount of input from its presynaptic partner. The researchers suggested that the NMDA receptor—a protein complex found in the membranes of postsynaptic neurons—acted as the coincidence detector responsible for this synaptic strengthening.

To test this hypothesis, my laboratory decided to genetically manipulate one version of the NMDA receptor, which comes in different forms. We confirmed that adult mice lacking NMDA receptors in the hippocampus showed profound memory deficits. But we also showed the opposite is true: when we boosted the production of a specific NMDA receptor subunit (known as NR2B) in the hippocampus and cortex, the resulting mouse strain—which we named Doogie—learned faster and retained memories longer than unaltered mice did.

We believe that NMDA receptor activation—and reactivation—may serve to inscribe the ensemble activity patterns of the neural cliques that encode memories, thereby linking memory traces from the molecular level to the network level. *—J.Z.T.*



DOOGIE

quake might be recorded as "11001," where the first 1 represents activation of the general startle clique, the second 1 represents activation of the clique that responds to a motion disturbance, the first 0 indicates lack of activity in the air puff clique, the second 0 indicates lack of activity in the elevator drop clique and the final 1 shows activation of the earthquake clique. We have applied a similar binary code to the neural ensemble activity from four different mice and were able to predict, with up to 99 percent accuracy, which event they had experienced and where it had happened. In other words, by scanning the binary code we could read and compare the animals' minds mathematically.

Such a binary code of the brain could also provide a potentially unifying framework for studying cognition, even across animal species, and could greatly facilitate the design of more seamless, real-time brain-to-machine communication. For example, we have arranged a system that converts the neural activity of a mouse experiencing an earthquake into a binary code that instructs an escape hatch to open, allowing the animal to exit the shaking container. We believe our approach provides an alternative, more intuitive decoding method for powering the kinds of devices that have already allowed patients with neural implants to control a cursor on a computer screen or a monkey to move a robotic arm using signals recorded from its motor cortex. Moreover, real-time processing of memory codes in the brain might, one day, lead to downloading of memories directly to a computer for permanent digital storage [see "A Digital Life," by Gordon Bell and Jim Gemmell; Scientific American, March].

In addition, we and other computer engineers are beginning to apply what we have learned about the organization of the brain's memory system to the design of an entirely new generation of intelligent computers and network-centric systems, because the current machines fail miserably in the type of cognitive decision making that humans find easy, such as recognizing a high school classmate even though he has grown a beard and aged 20 years. Someday intelligent computers and machines equipped with sophisticated sensors and with a logical architecture similar to the categorical, hierarchical organization of memory-coding units in the hippocampus might even do more than imitate, perhaps exceeding our human ability to handle complex cognitive tasks.

For me, our discoveries raise many interesting—and unnerving—philosophical possibilities. If all our memories, emotions, knowledge and imagination can be translated into 1s and 0s, who knows what that would mean for who we are and how we will operate in the future. Could it be that 5,000 years from now, we will be able to download our minds onto computers, travel to distant worlds and live forever in the network? ■

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HUIMIN WANG

MORE TO EXPLORE

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Understanding chronic inflammation, which contributes to heart disease, Alzheimer's and a variety of other ailments, may be a key to unlocking the mysteries of cancer

A Malignant FLA

KEY CONCEPTS

- Until recently, cancer researchers had focused primarily on genetic changes as the underlying cause of the disease.
- In this decade investigators have come to realize that the developing tumor can commandeer the immune system's inflammatory component—normally part of the wound-healing process—to foster carcinogenesis.
- A new generation of anti-inflammatory drugs may join traditional chemotherapies, which could keep solid tumors or premalignancies localized to one place. —*The Editors*

More than 500 million years ago a set of specialized enzymes and proteins evolved to defend our primitive ancestors against assaults from the outside world. If a microbe breached the shell of some Cambrian-era fauna, the members of this early vintage immune system would stage a savage but coordinated attack on these interlopers—punching holes in cell walls, spitting out chemical toxins or simply swallowing and digesting the enemy whole. Once the invaders were dispatched, the immune battalion would start to heal damaged cells, or if the attacked cells were too badly damaged it would put them to rest.

This inflammatory immune response worked so well that many aspects of it have been preserved during the protracted aeons of evolution. We know this to be true because studies have found that we share many of the same immune genes as the lowly fruit fly—and vertebrates and invertebrates diverged from a common ancestor in excess of half a billion years ago.

For years, immunology researchers have paid relatively little attention to this thuggish innate immune system, basically thinking of it as a crew of biochemical bouncers that pummel anything able to penetrate the tiniest opening in a living being's skin or shell. They lavished their attention, instead, on the more advanced adaptive immune system, which can marshal antibodies and other weaponry that identify and then target an intruder with a specificity lacking in the untamed innate system.

In the past 15 years, innate immunity has come into its own. Inflammation, its hallmark characteristic, has gained recognition as an underlying contributor to virtually every chronic disease—a list that, besides obvious culprits such as rheumatoid arthritis and Crohn's disease, includes diabetes and depression, along with major killers such as heart disease and stroke [*see sidebar on page 65*]. The possibility of a link with a third major killer—cancer—has received intensive scrutiny in this decade. "The connection between inflammation and cancer has moved to center stage in the research arena," notes Robert A. Weinberg of the Massachusetts Institute of Technology's Whitehead Institute for Biomedical Research, who has highlighted the changing emphasis in a revision of his leading textbook, *The Biology of Cancer* (Garland Science, 2006).

This transformation recognizes that the immune inflammatory state serves as a key mediator of the middle stages of tumor development. Cancer begins with a series of genetic changes that prompt a group of cells to overreplicate and then invade surrounding tissue, the point at which true malignancy begins. Eventually some tumor cells may break off and establish new

ME

BY GARY STIX

growths (metastases) at distant sites. That much has been understood for a long time. But cancer biologists and immunologists have begun to realize that the progression from diseased tissue to full-blown invasive cancer often requires cells that normally participate in healing cuts and scrapes to be diverted to the environs of the premalignant tissue, where they are hijacked to become co-conspirators that aid and abet carcinogenesis. As some researchers have described the malignant state: genetic damage is the match that lights the fire, and inflammation is the fuel that feeds it.

In this rewriting of the textbooks, a tumor is not just a clump of aberrant cells; it also includes a support system, a tumor microenvironment, which encompasses a multitude of varying immune cell types and crisscrossing chemical signals, along with a network of blood vessels. The tumor assumes the status of an outlaw organ that exists not to pump blood or rid the body of toxins but to serve only its own ends.

This new view implies that rooting out every

TUMOR DEVELOPMENT progresses in some cancers through the effects of what cancer biologists have labeled a "smoldering" inflammation, in which the tumor recruits immune cells that linger in its surroundings and within the malignant mass.

JEFF JOHNSON *Hybrid Medical Animation*

THE PLAYERS

The immune system consists of innate cells, which form a first line of defense against pathogens, and members of the adaptive system, which targets invaders with greater specificity.

INNATE

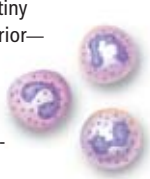
MACROPHAGE

This immune defender engulfs and consumes pathogen invaders.

MAST CELL

This cell releases histamine and other chemicals that promote inflammation.

GRANULOCYTE



Three cell types with tiny granules in their interior—the neutrophil, eosinophil and basophil—participate in the inflammatory response.

DENDRITIC CELL

It presents antigens—fragments of protein or other molecules from pathogens or cancer cells—to adaptive immune cells, inducing the cells to attack bearers of the displayed antigens.

NATURAL KILLER CELL

This cell destroys the body's own cells that have become infected with pathogens; it also goes after cancer cells.

ADAPTIVE

B CELL

Antigens stimulate this cell to divide and produce antibodies that neutralize invaders or tag them for killing.

T CELL

A killer T cell destroys an infected cell in which it detects the presence of antigens. Other T cells—such as helper and regulatory types—coordinate the immune response.

last cancer cell in the body might not be necessary. Anti-inflammatory cancer therapy instead would prevent premalignant cells from turning fully cancerous or would impede an existing tumor from spreading to distant sites in the body. Cancer sufferers might then be able to survive, in the same way that new drugs have let HIV patients live longer. "I don't think a cure is necessarily the goal. It doesn't need to be," comments Lisa M. Coussens, a cancer biologist at the University of California, San Francisco. "If you can manage the disease and live your natural life span, that's a huge win."

Multiple Lines of Defense

Comprehension of the link between inflammation and cancer requires knowing how the body reacts to invaders—and how normal healing is then subverted into promoting cancer when the inflammatory state lasts too long. After you step on a nail, the bacteria that invade the sole of your foot receive a welcome from an array of proteins and white blood cells that resemble rejects from central casting for the movie *Creepshow 2*. Just one example: Some 20 complement proteins, so called because they complement other bodily defense mechanisms, chemically spritz pathogens until the invaders explode into a big protoplasmic mess. While the complement system slimes the area, an assemblage known in immunology textbooks as professional phagocytes—literally "expert eating cells"—goes to work.

Lacking table manners, these Pac-Man-like macrophages and neutrophils proceed to engulf and consume the uninvited guests. Other members of the attack brigade include natural killer cells, mast cells and eosinophils. Healing represents more than launching an offensive against invaders. Blood platelets involved with clotting migrate to the break in the skin from an inner layer infused with blood vessels. Enzymes direct the repair of the extracellular matrix, the protein-based mortar in which the cells are immobilized. A scab forms, the skin grows back and the whole process of inflammation ends. Sometimes, though, inflammation does not stop. Any tissue (not just skin) that is chronically inflamed because of the persistent presence of pathogens, toxins or genetic damage helps to spur illness, from heart disease to cancer.

Beyond this first layer of defense, vertebrates are equipped with additional weaponry. The adaptive system learns an invader's specific molecular signature and then uses it as a target for killing. Among the protagonists are B cells, which produce antibody molecules able to neutralize pathogens or mark them for destruction, and T cells, which prompt infected cells to kill themselves or secrete chemicals that direct the activities of other immune players.

In recent years a body of evidence has accumulated to show that chronic inflammation can play an important role in the progression of some types of tumors from a premalignant state to full-blown disease. A link between cancer and inflammation has long been suspected. In 1863 the prominent German pathologist Rudolf Virchow noted the presence of so-called lymphoreticular infiltrate (white blood cells) in malignant tissue. As early as 1978 Alberto Mantovani of Humanitas Clinical Institute and the University of Milan had observed that innate immune cells tend to congregate around some tumors. Cancer biologist Harold F. Dvorak of Harvard Medical School remarked in 1986 that tumors are "wounds that do not heal." The status quo, though, lay elsewhere. Even a decade ago many biologists still hewed to the idea that the immune system serves not only to eliminate pathogens but to ferret out cells that are the abnormal precursors of cancer. But a closer look at the microenvironment surrounding tumors found the unexpected.

Hunting Pigeons

In the late 1990s Frances Balkwill of the Institute of Cancer at Queen Mary, University of London, had been doing research on a cytokine (a hormonelike immune signaling molecule) known as tumor necrosis factor (TNF), which was named for its ability to kill cancer cells when administered directly into a tumor at high levels. But when TNF lingers as a chronic, low-level presence in the tumor, it acts very differently. Balkwill's lab turned off the TNF gene in mice so that the rodents could not produce the protein: to their surprise, the mice did not contract tumors. "That really put us as the cat among pigeons," she recalls. "All the people who were working on TNF as an anticancer agent were horrified. This cytokine they thought was a treatment for cancer was actually working as an endogenous tumor promoter."

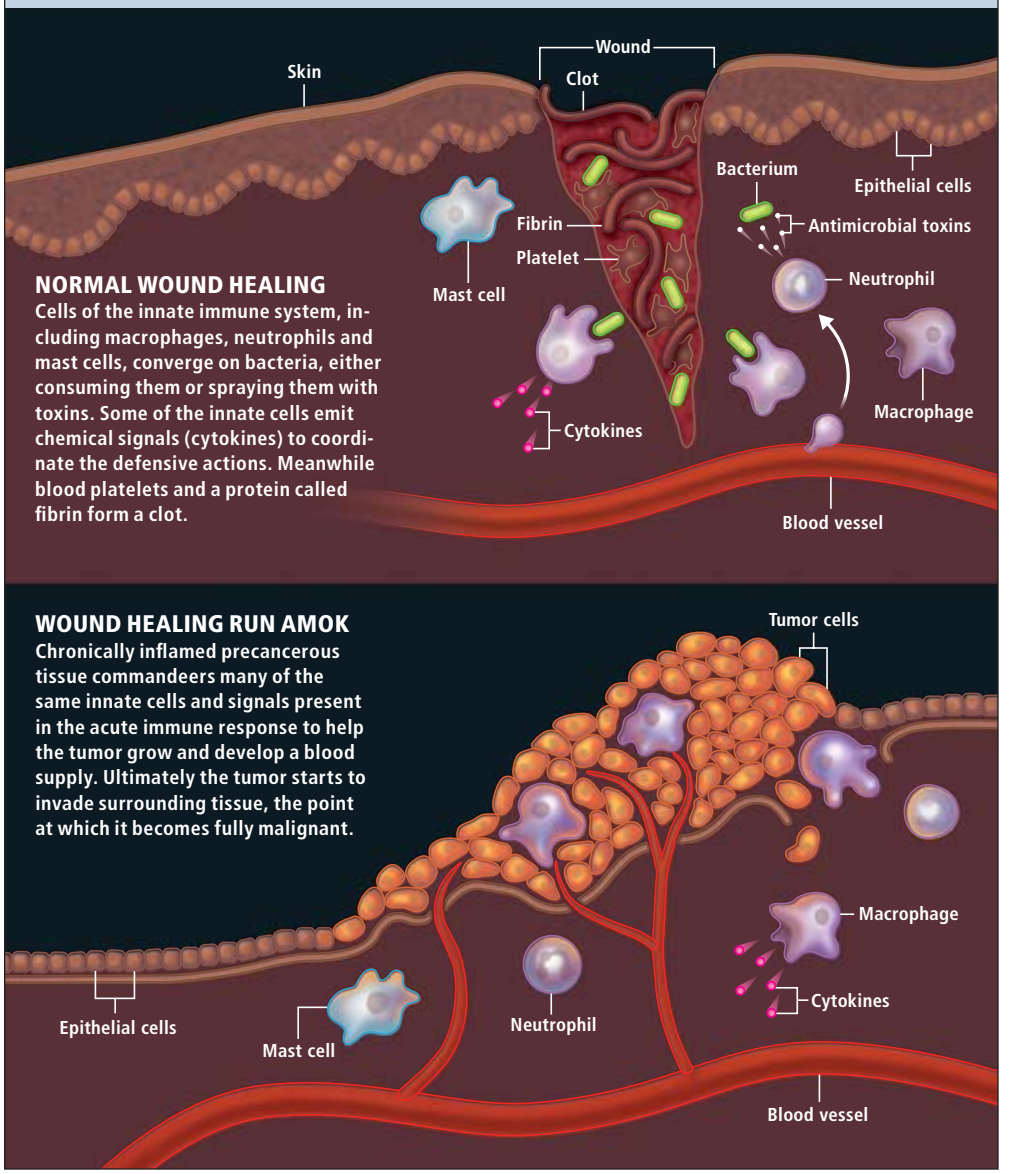
The ready availability of knockout mice, in which the effects of selectively switching off genes could be tested, helped to highlight the cancer-inflammation link. Coussens and her U.C.S.F. colleagues Douglas Hanahan and Zena Werb reported in 1999 that mice engineered with activated cancer genes but without mast

cells (another type of innate immune cell) developed premalignant tissue that did not progress to full malignancy. In 2001 Jeffrey W. Pollard and his co-workers at the Albert Einstein College of Medicine described mice that were genetically engineered to be susceptible to breast cancer tumors but that produced precancerous tissue that did not turn fully malignant unless it enlisted the assistance of macrophages.

The altered picture does not completely overturn the old one. In fact, it reveals that the immune system functions as a double-edged sword. The network of molecules and cells, second in complexity only to the brain, remains a paradox: sometimes it promotes cancer; other times it hinders disease. Some types of innate immune cells, such as natural killer cells, can actually protect against tumor growth. Others may nurture a malignancy only when the microenvironment is "polarized" into an inflammatory state; when not, they may blot it out. Inflammation, moreover, produces tumors in many organs, but not all—and its link to blood-borne cancers is not well characterized.

CANCER HIJACKS WOUND HEALING

Innate immunity responds to an insult, such as a puncture wound, with a cellular and chemical arsenal. Cancer biologists have recently begun to understand how chronically inflamed premalignant tissue uses many of the same biochemical players to promote cancer development.



NORMAL WOUND HEALING
Cells of the innate immune system, including macrophages, neutrophils and mast cells, converge on bacteria, either consuming them or spraying them with toxins. Some of the innate cells emit chemical signals (cytokines) to coordinate the defensive actions. Meanwhile blood platelets and a protein called fibrin form a clot.

WOUND HEALING RUN AMOK
Chronically inflamed precancerous tissue commandeers many of the same innate cells and signals present in the acute immune response to help the tumor grow and develop a blood supply. Ultimately the tumor starts to invade surrounding tissue, the point at which it becomes fully malignant.

JEN CHRISTIANSEN

CANCER BASICS

A developing malignancy proceeds in stages—a process that may take years, even decades, to fully evolve.

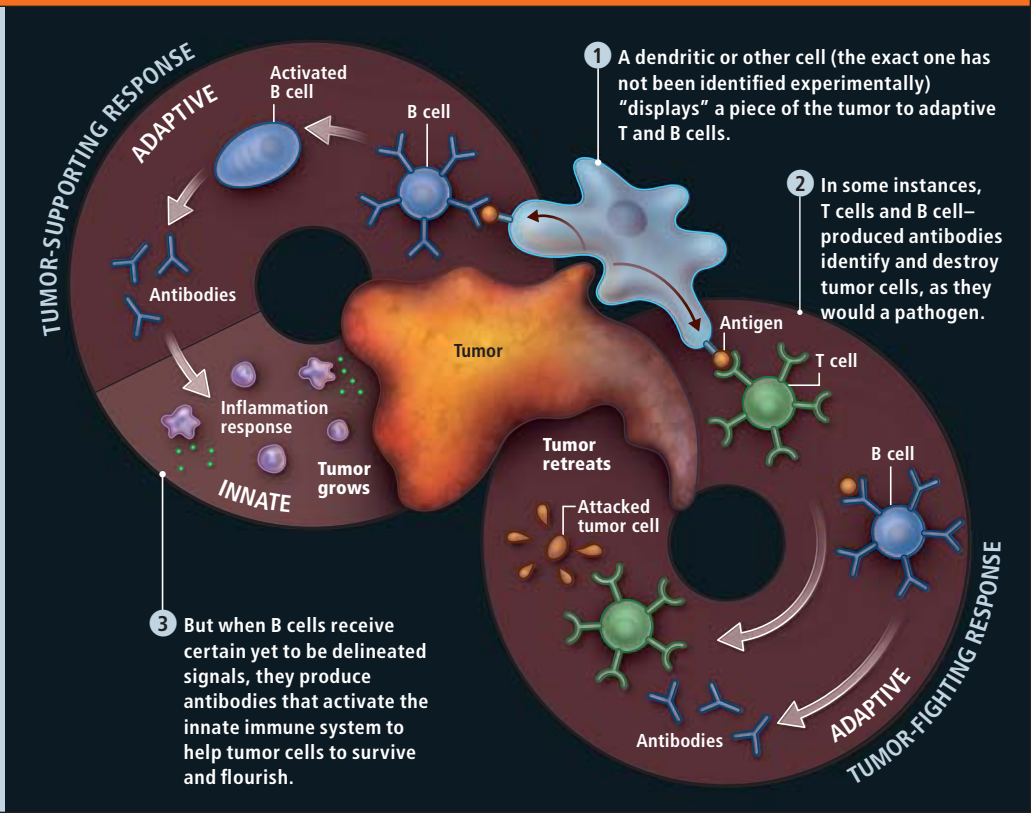
INITIATION
Hereditary mutations or exposure to chemicals or radioactivity results in genetic changes in one or more cells.

PROMOTION
Cells in premalignant tissue begin to proliferate, often in the presence of an inflammatory stimulus. Their appearance becomes increasingly abnormal.

PROGRESSION
Tumor cells begin to invade surrounding tissue and to spread to the blood and lymph nodes, at which point full malignancy develops. Metastases may establish themselves at distant sites.

THE IMMUNE PARADOX

Two arms of the immune system—the innate and the adaptive—are exquisitely well adapted for fighting pathogens, but their role in combating cancer is decidedly more paradoxical. The innate system furnishes an initial inflammatory response to a microbial insult by attacking any invading pathogen indiscriminately, whereas adaptive immunity furnishes a delayed response that homes in on a particular pathogen. In cancer, both systems may sometimes attack tumor cells. But a tumor protects itself by recruiting the innate system to enhance its development.



Genetic damage is the match that lights the fire of malignancy, and inflammation is the fuel that feeds the flames.

When looking for culprits, researchers have often focused their microscopes on macrophages, which occupy a meaningful spot among the white blood cells in the tumor microenvironment. The macrophages are capable of killing tumor cells or sending out an alarm to T cells of the adaptive immune system that something is amiss. But work by Pollard and other researchers has detailed how macrophages are "reeducated" by cancer cells to do their bidding. They become factories for cytokines and growth factors that nurture tumor development.

Turning the macrophages into traitors begins when tumor cells send out help signals that attract cells that become macrophages once they reach the tumors. Inside the tumors, proliferating cells grow so quickly that they begin to die for lack of oxygen. A combination of hypoxia and messages from the tumor cells initiates a process whereby the newly arrived macrophages assume their bad-body identity as tumor promoters. Cancer biologists give the name tumor-associated macrophages to these mutineers that congregate in and around the tumor.

Biologists have now been able to follow the inflammation link down to the level of individual signaling molecules, providing harder evidence for a connection to carcinogenesis. For example, nuclear factor-kappa B (NF-κB) is a complex of proteins that acts as a master switch for turning inflammation genes on and for controlling cell death. As biological pathways go, NF-κB's is world-famous, having been discovered and patented for use in drug development by scientific stars that include Nobelists David Baltimore and Phillip A. Sharp and having subsequently become the object of multimillion-dollar patent litigation.

In 2004 Yinon Ben-Neriah and Eli Pikarsky of the Hebrew University of Jerusalem and their colleagues reported that mice engineered to develop hepatitis (which can cause liver cancer) contracted precancerous lesions that did not progress to full malignancy when NF-κB was curtailed through a genetic alteration or when the proinflammatory TNF signaling molecule was shut off. In the latter group, a neutralizing antibody blocked TNF and prevented it from binding to a receptor on the premalignant liver cells; loss of the receptor prevented the TNF from triggering a molecular cascade that turns on the NF-κB master switch. Blocking NF-κB prompted the precancerous liver cells to initiate apoptosis, or programmed cell death. In a relat-

JEN CHRISTIANSEN

ed finding that year, Michael Karin and his collaborators at the University of California, San Diego, found that inhibiting NF-κB in mice engineered to develop colitis, which can lead to colon cancer, also promoted apoptosis. And shutting down the pathway in inflammatory cells, such as macrophages, deterred tumor development as well.

So far the clearest evidence of a link between cancer and inflammation is the data demonstrating that inflammation encourages the conversion of precancerous tissue to full malignancy for many cancers. But the biological response may also be involved in initiating the disease and in advancing metastasis. Infections with *Helicobacter pylori* bacteria induce inflammation that greatly increases the risk of gastric cancer, and the hepatitis C virus can bring on liver cancer, to name just two cancers. Pathogens may also generate free radicals, which can damage DNA. But although inflammation may be involved from the outset, few studies have shown yet that an inflammatory condition actually alters DNA to provide the initiating spark.

The case for a role in metastasis is stronger—and recent studies lend credence to this hypothesis. Karin's group reported in the April 5 *Nature* that inflammation, not genetic changes in cancer cells, spurs metastasis in mice engineered to acquire prostate cancer. The research suggests that a cytokine produced by inflammatory cells near a prostate tumor induces tumor cells to decrease production of a protein that blocks metastasis. This result, Karin notes, may explain the puzzling observation that cutting into tumors, such as for a prostate biopsy, sometimes seems to encourage metastasis. If he is correct, the inflammation generated by the intervention could be at fault. Around the same time, Pollard's group reported in *Cancer Research* on a study in mice that observed that macrophages accompany breast tumor cells in their migration

Immune System as Cancer Fighter

Tumors waylay the immune system to promote their own growth and survival. But the opposite also holds. The antibodies and killer T cells of the adaptive immune system can, at times, target and destroy cancer cells. Drug companies and scientists have tried to turn this knowledge into new therapies, with mixed results.

Among the most successful new biotechnology drugs are monoclonal antibodies—identical antibodies that are capable of attacking a cancer antigen, a molecular fragment found on the surface of a cancer cell. Monoclonals are generally a "passive" immunotherapy because they are produced in cell culture or in mice and injected into patients instead of relying on the patient's own immune system to produce antibodies.

In contrast, cancer vaccines—the object of a frustrating decades-long quest—are "active" therapies. A patient receives an injection of an antigen, usually along with another helper molecule, an adjuvant, that precipitates an immune response.

Cancer antigens are more difficult to identify than those for pathogens because cancer cells are mutant forms of the body's own cells. The adaptive immune system often does not see them as foreign—and a tumor can trick the body into turning off any immune response that does arise.

After hundreds of previous trials, and the absence of virtually any evidence from them that vaccines cause tumors to regress, the concept of the cancer vaccine has garnered its share of critics. "When you give cancer vaccines, sometimes you raise T cells against the vaccines, but they're just not powerful enough to keep the cancer from growing," notes Steven A. Rosenberg, chief of surgery at the National Cancer Institute. Rosenberg and his co-workers have pursued a different approach, adoptive cell transfer, in which T cells that target tumors are selected from white blood cells removed from the body. They are then multiplied in the laboratory and reinfused into patients whose immune systems have been chemically suppressed. In a 2005 study in the *Journal of Clinical Oncology,* about half of 35 melanoma patients saw their metastatic tumors regress at least partially.

In recent months, the picture for cancer vaccines has brightened somewhat. Early positive reports were presented at the American Association for Cancer Research in April for vaccines for breast, prostate, and head and neck cancers. But in May came more bad news: the Food and Drug Administration delayed approval of what would have been the first U.S. therapeutic cancer vaccine formulated by Seattle-based Dendreon for prostate cancer [see "Overcoming Self," by Gary Stix; SCIENTIFIC AMERICAN, July 2004].

Marshaling the patient's own immune system to fight cancer may still be possible. But meeting that goal may well depend on deepening the growing understanding of how the immune system serves as a two-edged sword that can either foster or block cancer progression. —*G.S.*

COMMON CAUSE

Chronic inflammation contributes to many diseases, not just cancer.

HEART DISEASE

Macrophages, stars of innate immunity, are key players. They ingest "bad" cholesterol (low-density lipoproteins), and then the cells are encased in a fibrous cap that forms arterial plaque, which can break off and create a clot that blocks an artery, leading to a heart attack.

DIABETES

When exposed to the metabolic stress that occurs from being obese, both innate immune cells and fat cells (adipocytes) manufacture signaling molecules called cytokines such as tumor necrosis factor. These molecules interfere with the normal function of insulin and can lead to diabetes.

ALZHEIMER'S DISEASE

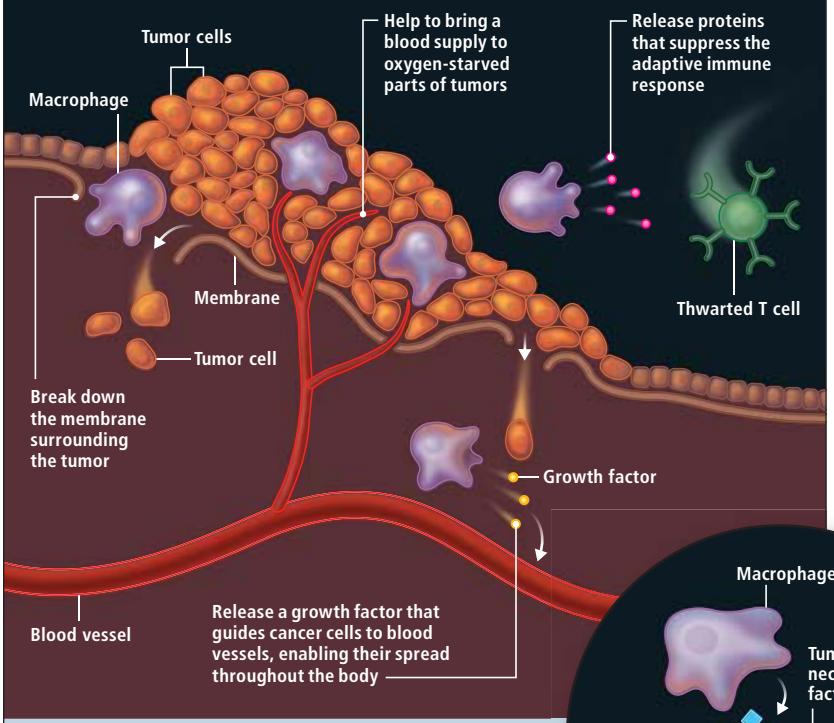
Microglial cells, the neural equivalent of macrophages, express cytokines and cell-damaging free radicals, while interacting with the beta-amyloid proteins that build up in the plaques that are characteristic of the disease. The resulting inflammation can damage neurons.

DEPRESSION AND SCHIZOPHRENIA

High levels of inflammatory molecules—interleukin-6 and C-reactive protein—have been found in depressed patients. Some evidence even suggests that elevated cytokines correlate with schizophrenia.

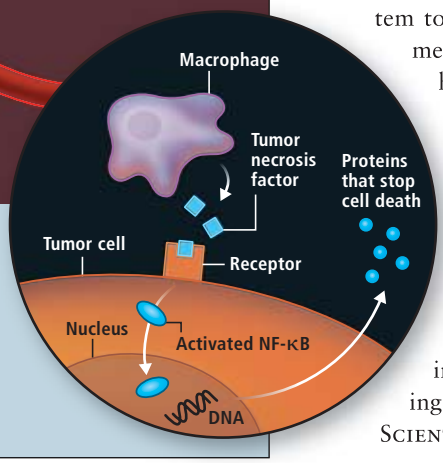
THE BIG EATERS

Macrophages, also known as big eaters, are inflammatory cells that coordinate many critical steps in cancer development, from nurturing the tumor to helping its cells spread to distant sites.



A MASTER SWITCH ▶

Macrophages produce inflammatory compounds, such as tumor necrosis factor, which can activate a gene switch, a complex of proteins called nuclear factor-kappa B (NF-κB), in a tumor cell. NF-κB enters the cell nucleus and turns on production of proteins that stop cell death and promote inflammation and cell proliferation.



toward blood vessels that will transport them to remote sites, all the while sending chemical messages to their partners.

The innate immune system has received the most attention in explorations of how inflammation might cause cancer. As with innate immunity, the adaptive immune system—the T cells and antibodies produced by B cells that target specific molecules on invading cells—contributes to pathology or may also fight against it. For decades, immunotherapies designed to enhance T cell responses against cancer have been explored, though often with disappointing results [*see box on preceding page*].

Furthermore, an emerging picture has begun to reveal an intricate cross talk between innate and adaptive immune cells that may participate in the promoting of malignant disease. Researchers working on cancer vaccines may need to take account of these interactions in designing their treatments if they are ever to prove effective. One study showed that ovarian tumors produce a signaling molecule that serves to attract regulatory T cells, a subclass of adaptive immune cells responsible for quieting other T cells [see "Subduing Suppressors," by Lisa Melton; Scientific American, December 2002].

Meanwhile Coussens and her colleagues at U.C.S.F. found in a 2005 study published in *Cancer Cell* that the removal of antibody-making B cells from mice engineered to be prone to skin cancer prevented the tissue changes and angiogenesis that are prerequisites for disease progression. In their normal role as pathogen fighters, B cell–produced antibodies circulate through the bloodstream and mark viruses and bacteria for destruction by innate immune cells. In response to a signal from precancerous tissue, however, the antibodies induce the innate system to collaborate in cancer development. An open research question is how this process starts. One possibility suggests that a cancer cell may send a message to innate immune cells, perhaps dendritic cells, that then activate B cells. Signaling may involve toll-like receptors, which have emerged as prominent intermediaries in innate immune messaging [see "Immunity's Early Warning System," by Luke A. J. O'Neill; Scientific American, January 2005].

Cancer Blockers

The recognition that cancer is more like an organ than just a clump of cells with DNA mutations in cell nuclei may also explain why some of the previous approaches to chemotherapy have met with limited success. "People have taken cells and then transformed them in culture and stuck them into animals," Pollard says. "They grow as little balls. They do certain things there. But they are not complex tissues, whereas a naturally occurring tumor is a very complex tissue."

Instead of just killing cancer cells—the goal of current drug therapies and radiation—new approaches may supplement existing drugs by slowing inflammation. Without the involvement of macrophages and other innate cells, the premalignant tissue would remain in check.

JEN CHRISTIANSEN

Cancer could, in essence, become a chronic disease akin to rheumatoid arthritis, another inflammatory condition. "Keep in mind almost no one dies of primary cancer," says Raymond DuBois, provost of the University of Texas M. D. Anderson Cancer Center and a researcher of anti-inflammatory agents for cancer. "A patient almost always dies from a metastasis."

A pharmaceutical against chronic inflammation represents a more alluring proposition than massacring malignant cells (and, unavoidably, healthy ones), a consequence of existing chemotherapies. Taken alone, such an agent might be benign enough to use every day as a preventive for high-risk patients. Epidemiological and clinical studies have shown some promise for the use of nonsteroidal anti-inflammatory drugs (NSAIDs) such as aspirin to stave off the onset of some solid tumors. Investigations continue on more selective blocking of the production of prostaglandins, the regulatory molecules that are curtailed by NSAIDs. In particular, drugs that inhibit production of prostaglandin E_2 may curb inflammation and tumor growth, while avoiding the cardiovascular side effects of drugs such as Vioxx and the gastrointestinal problems of the earlier class of NSAIDs [see "Better Ways to Target Pain," by Gary Stix; Scientific American, January 2007]. The anti-inflammatory effects of the ubiquitous statins used to lower cholesterol are also being contemplated.

Some treatment options already exist. The drug Avastin inhibits production of the angiogenesis-promoting VEGF, although oncologists must contend with other molecules in the tumor microenvironment that promote blood vessel growth. Drugs developed for more familiar inflammatory diseases may also fight cancer—and these medicines might be combined into HIV-like drug cocktails, that also include angiogenesis inhibitors and cell-killing agents.

Inhibitors of TNF have received approval for treatment of rheumatoid arthritis, Crohn's disease and other disorders and are now in clinical trials for both solid tumors and blood cancers. The drug Rituxan, a monoclonal antibody that represses B cells in rheumatoid arthritis and B cell lymphoma, might prevent the inflammatory response that fuels formation of solid tumors. Other cytokines and related molecules (IL-6, IL-8 and CCL2, among others) are also potential targets, as is NF-κB.

Some existing compounds, including NSAIDs and even one found in the spice turmeric, exert at least some of their effects by inhibiting NF-κB. But major pharmaceutical laboratories are investigating highly selective inhibitors of this molecular linchpin, many of them targeted at the enzymes (such as I-κB kinase) that regulate NF-κB activity.

A Chemical Trojan

One group is contemplating a radically ambitious treatment, a molecular Trojan horse of sorts. Claire Lewis and Munitta Muthana of the University of Sheffield in England and their colleagues have designed a drug delivery scheme that takes advantage of the natural attraction of macrophages to the oxygen-starved areas in tumors. They have engineered macrophages to deliver a therapeutic virus to hypoxic tumor regions, which respond poorly to conventional treatments such as chemotherapy and radiation because of an insufficient blood supply. Once the macrophages arrive in a tumor (grown in culture so far), each one releases thousands of copies of the virus, which then infect the cancer cells, after which a protein in those cells activates the therapeutic gene in each virus. This action then directs synthesis of a cell-killing toxin. "The macrophage is migrating into a site and doing what we want it to do rather than driving tumor development in a normal way," Lewis says.

The exact outlines of an anti-inflammatory strategy against cancer have yet to be elucidated. Tweaking immune cells that form a defensive barrier against pathogens bears its own risks. "It's a very complicated issue," DuBois notes. "If you magically shut down the immune system, you will have problems with opportunistic infections, just like with AIDS." Use of TNF blockers in other inflammatory disorders has been linked to tuberculosis and other infections, even potentially lymphoma. Moreover, inhibiting the NF-κB pathway can paradoxically promote cancer in some instances. Constraining NF-κB can at times lead to tissue damage and a process of abnormal regeneration of that tissue that can foster cancer.

Still, it seems likely that a new generation of anti-inflammatory agents will join the chemotherapeutic arsenal. Chronic diseases—and their underlying inflammatory conditions—are hallmarks of an aging population. "We're all a little bit overinflamed," Pollard observes. Treating the smoldering embers that surround the tumor rather than just mutant cells could make cancer a disease we can live with. ■

Instead of killing cancer cells—the goal of current drug therapies and radiation—new chemotherapies may supplement existing drugs by turning down inflammation.

MORE TO EXPLORE

Smoldering and Polarized Inflammation in the Initiation and Promotion of Malignant Disease. Frances Balkwill, Kellie A. Charles and Alberto Mantovani in *Cancer Cell,* Vol. 7, No. 3, pages 211–217; March 2005.

Distinct Role of Macrophages in Different Tumor Microenvironments. Claire E. Lewis and Jeffrey W. Pollard in *Cancer Research,* Vol. 66, No. 2, pages 605–612; January 15, 2006.

Paradoxical Roles of the Immune System during Cancer Development. Karin de Visser, Alexandra Eichten and Lisa M. Coussens in *Nature Reviews Cancer,* Vol. 6, No. 1, pages 24–37; January 2006.

The Evolution of CATS

Genomic paw prints in the DNA of the world's wild cats have clarified the cat family tree and uncovered several remarkable migrations in their past

By Stephen J. O'Brien and Warren E. Johnson

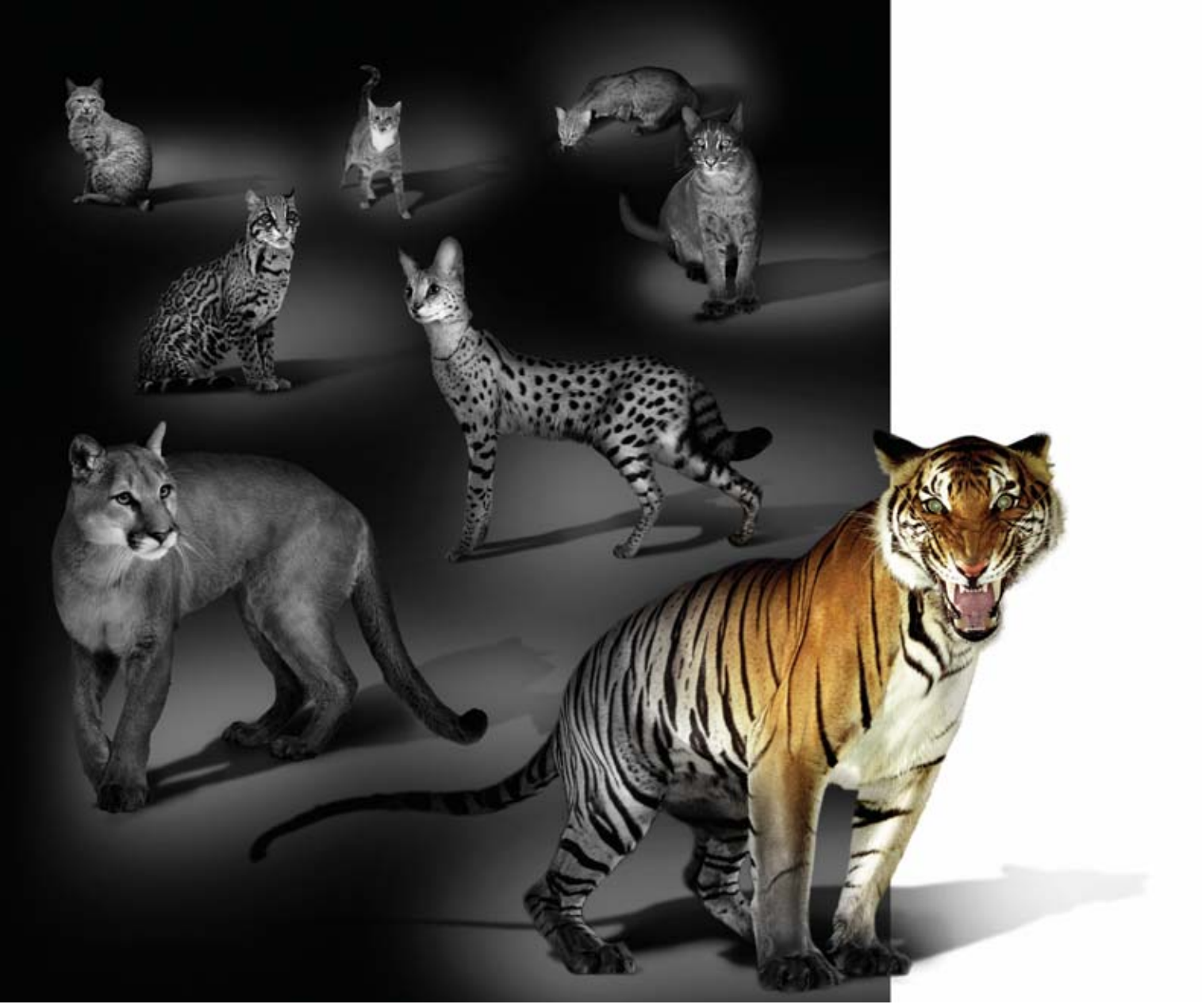
KEY CONCEPTS

- The family history of the cat has been murky because cat fossils are sparse and difficult to tell apart. But advances in the study of DNA have made it possible to construct the first clearly resolved family tree for cats.
- The DNA evidence shows that all living cats trace back to a pantherlike predator that lived in Southeast Asia 10.8 million years ago. The great roaring cats were the first to branch off; seven other lineages followed.
- As sea levels rose and fell, cats migrated to new continents and developed new species. A diminutive wildcat in the Near East was domesticated 8,000 to 10,000 years ago.
- Despite their evolutionary success, almost all wild cats are now threatened with extinction. —*The Editors*

Elegant and enigmatic, cats tantalize not only those of us who share our sofas with the smaller versions but scientists who have tried to puzzle out the origin and evolution of their larger cousins. Where did the modern cat family evolve? Why and when did they leave their homes and migrate across continents? How many species actually exist, and which ones are closely related?

Experts generally agree that there are 37 species in the family Felidae, but they have offered dozens of classification schemes, ordering cat species in as few as two to as many as 23 genera. Who could argue? Under the skin, one cat species appears pretty similar to another. They look like big cats, midsize cats and small cats. Distinguishing a lion's skull from a tiger's can be a challenge even for an expert, and genetic investigations that we have tried over the past two decades have failed to sort the cats into definitive groupings.

In recent years, however, a revolution in sequencing the genomes of various creatures, spearheaded by the Human Genome Project and by powerful technologies to probe DNA, has provided some extremely valuable new tools for inquiry. Drawing on



PHOTOILLUSTRATION BY JAMES PORTO; *left to right:* DULIC *Corbis (bobcat)*; RUSSELL GLENISTER *image100/Corbis (domestic cat)*; TERRY WHITTAKER *Frank Lane Picture Agency/Corbis (rusty-spotted cat)*; ZAINAL ZAHARI ZAINUDDIN *(Asian golden cat)*; GETTY IMAGES *(serval)*; DARRYL ESTRINE *Getty Images (tiger)*; DANIEL J. FOX *Corbis (puma)*; DAVE KING *Getty Images (ocelot)*

these novel techniques, the two of us, aided by colleagues at other institutions, have now constructed the first clearly resolved Felidae family tree. By comparing the same DNA sequences of 30 genes in each living cat species, we were able to determine the branches of the tree. Then, to arrive at the time each branch emerged, we used securely dated fossils and "molecular clock" analyses (which, based on the extent of differences in given genes, can estimate how long ago species diverged from one another). The result provided the first definitive look at how cats of all sizes are related to one another and led us to discern how and when these superb predators colonized five continents.

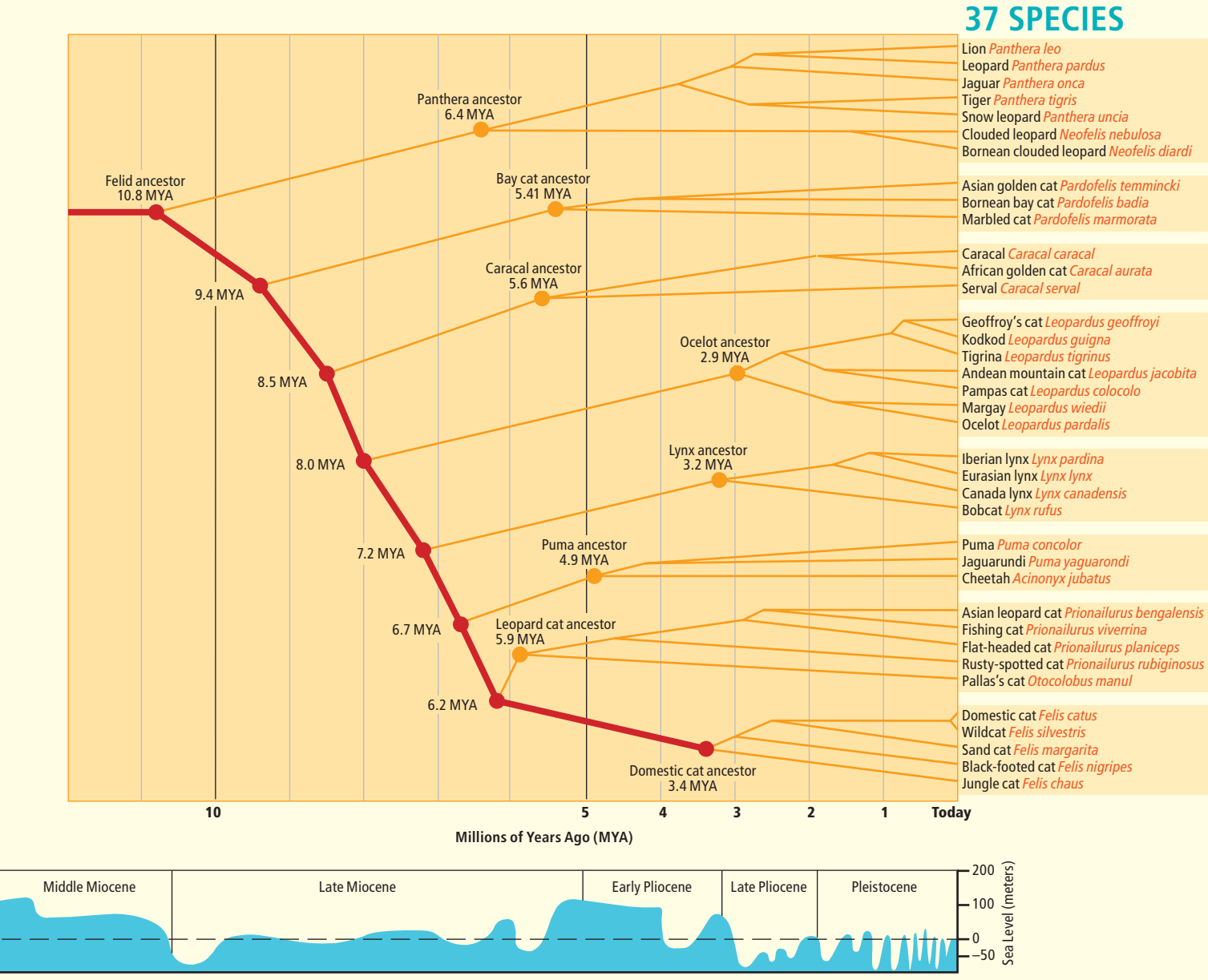
A Sense of Order

We immediately noticed that the DNA studies seemed to group the 37 species into eight distinct clusters, or "lineages." We were fascinated—and encouraged—to see that the eight groups defined exclusively by molecular analysis agreed with other kinds of observations, such as that species in one lineage often shared morphological, biological and physiological characteristics found only in their group. For example, one lineage contains all the great roaring cats (lion, tiger, leopard, jaguar and snow leopard). An incompletely ossified hyoid, a bone in the neck that supports the tongue, is what allows them to roar. Also in this group are the clouded leopard and the Bornean clouded leopard, little-known midsize cat species with a beautiful marbled coat; because they have a somewhat different bone structure in the neck, they cannot roar.

The comparison of gene sequences identified the lineages, the order of their emergence and, with the help of fossil calibrations, the time they appeared. Nevertheless, we needed two

THE CAT FAMILY TREE

Scientists compared DNA sequences in all 37 species of cats to determine the tree's branches. Fossils provided dates that indicate when major branching occurred.

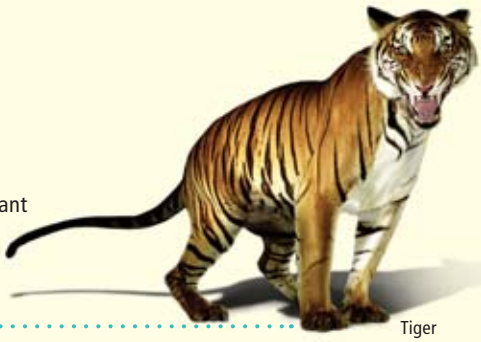


additional pieces of information to fill out our scenario and discern where cats first arose and how they came to have their current distribution around the world. First, we determined the present distribution of each cat species and where their ancestors occur in paleontological remains. Then we looked at the cats' world through the eyes of geologists who have interpreted the composition of sedimentary deposits to infer the rise and fall of sea levels. When sea levels were low, land bridges connected continents, allowing mammals to migrate to new domains. When sea levels rose again, animals on the continents were isolated once more. Studies of vertebrates show that isolation on continents, or on islands, provides just what is required for a population to drift apart so much genetically that eventually it can no longer breed with contemporary descendants of its former relatives—a reproductive distancing that is the hallmark of speciation. Armed with these pieces of the puzzle, we could construct a plausible sequence of migrations throughout the history of Felidae.

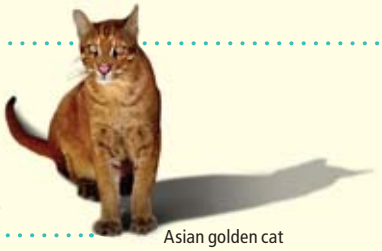
JANA BRENNING

8 LINEAGES

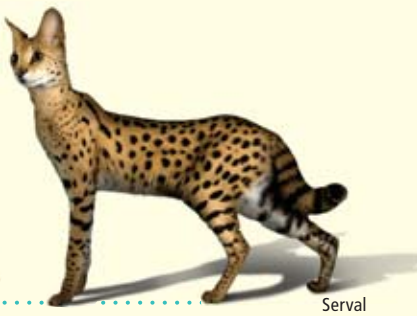
1 PANTHERA
These medium- to large-size cats (15 to 350 kilograms) are found throughout the world. They are the dominant predators in the ecosystems and on the continents that they inhabit, often specializing on large ungulate species. The lion, tiger, jaguar, leopard and snow leopard have an incompletely ossified hyoid, which allows them to roar. The two clouded leopard species do not roar.


Tiger

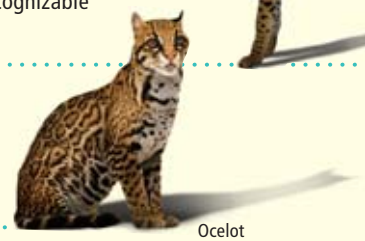
2 BAY CAT
This poorly known group of small- to medium-size cats (two to 16 kilograms) is restricted to forested habitats in tropical Southeast Asia. Before the authors' genetic analyses, taxonomists did not consistently group these species together.


Asian golden cat

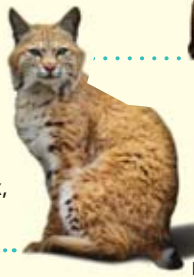
3 CARACAL
These medium-size cats (five to 25 kilograms), which are restricted to Africa, are distinctive and recognizable but were not typically grouped together before the authors' genetic work.


Serval

4 OCELOT
These small- to medium-size cats (1.5 to 16 kilograms) live in a broad range of habitats throughout Central and South America. They have a different number of chromosomes than other Felidae species do (36 instead of 38).


Ocelot

5 LYNX
These medium-size cats (six to 20 kilograms) all have short tails and pointed ears. They live in temperate climates of North America and Eurasia and tend to specialize on hare and rabbit. With the exception of the Iberian lynx, these species have been among the most widely exploited for their fur.


Bobcat

6 PUMA
These diverse cats, from the small jaguarundi (three to 10 kilograms) to the large African cheetah (21 to 65 kilograms), originated in North America but have spread widely across four continents and remain broadly distributed. Pumas can be locally common and are legally hunted in parts of their range.


Puma (mountain lion)

7 ASIAN LEOPARD CAT
These small cats (two to 12 kilograms) occupy a wide range of habitats in Asia, from mangrove forest to Mongolian steppe. The Asian leopard cat is the most common small cat in Asia.


Rusty-spotted cat

8 DOMESTIC CAT
These small cats (one to 10 kilograms), with the exception of the domestic cat, which is worldwide, have African and Eurasian distribution.


Domestic cat

PHOTOILLUSTRATION BY JAMES PORTO

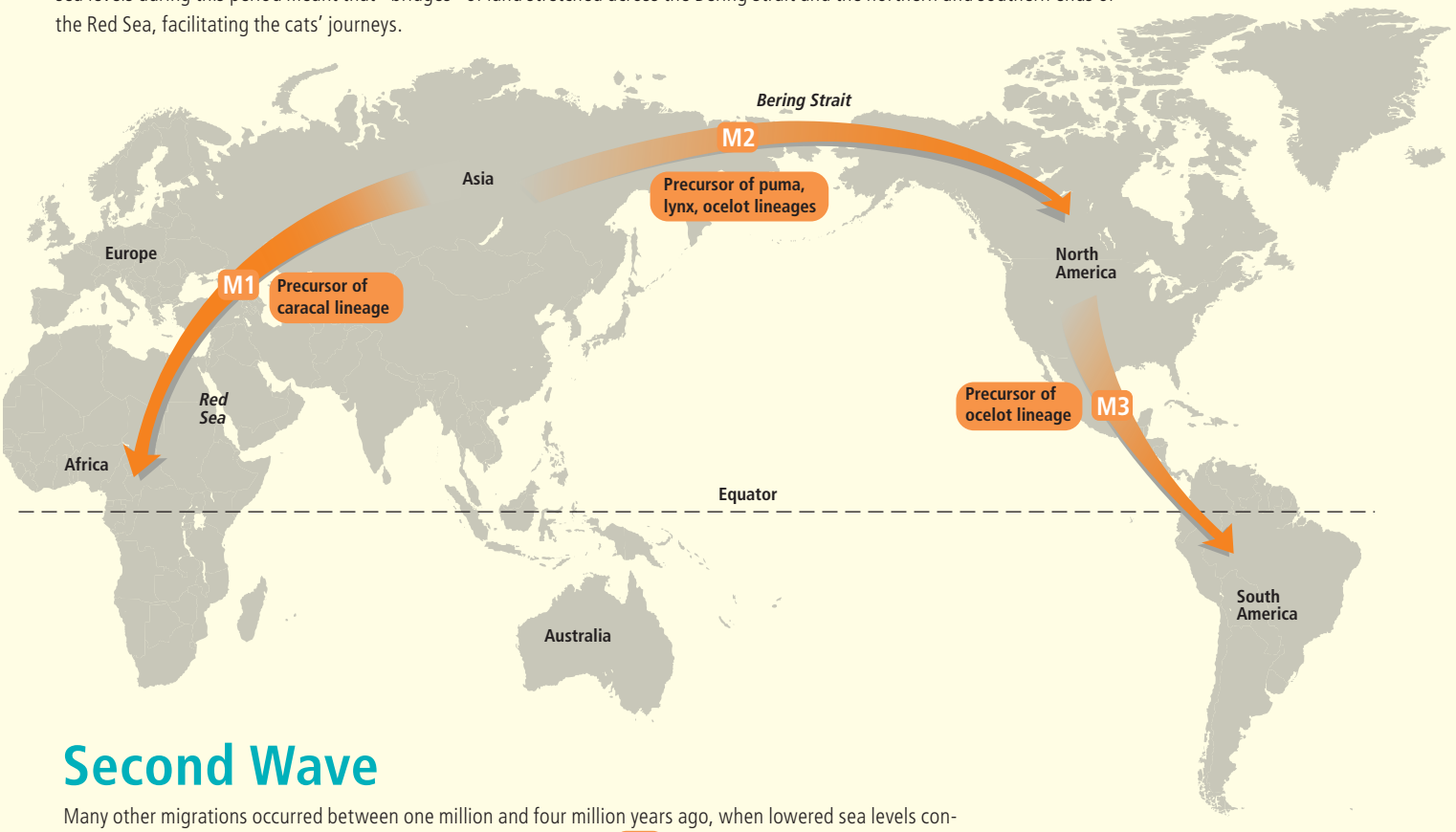
Based on the fossil record alone, most researchers have accepted a cat called *Pseudaelurus* that lived in Europe nine million to 20 million years ago as the last common ancestor of modern felids. (*Pseudaelurus* was not the first cat; large saber-toothed cats, called nimravids, reach back as far as 35 million years ago, but nearly all their descendants went extinct.) Our recent molecular investigations, however, suggest that all modern cats are descended from one of several *Pseudaelurus* species that lived in Asia some 11 million years ago. Although we are not certain which exact species this ancestral cat was, we do believe that the ancient group included the Adam and Eve of today's 37 species of Felidae.

On the Move

The first group branched off from this mysterious Asian cat approximately 10.8 million years ago, producing the panthera lineage **1** [*see table above*], which today includes the great roaring cats and the two species of clouded leopard. A second split about 1.4 million years

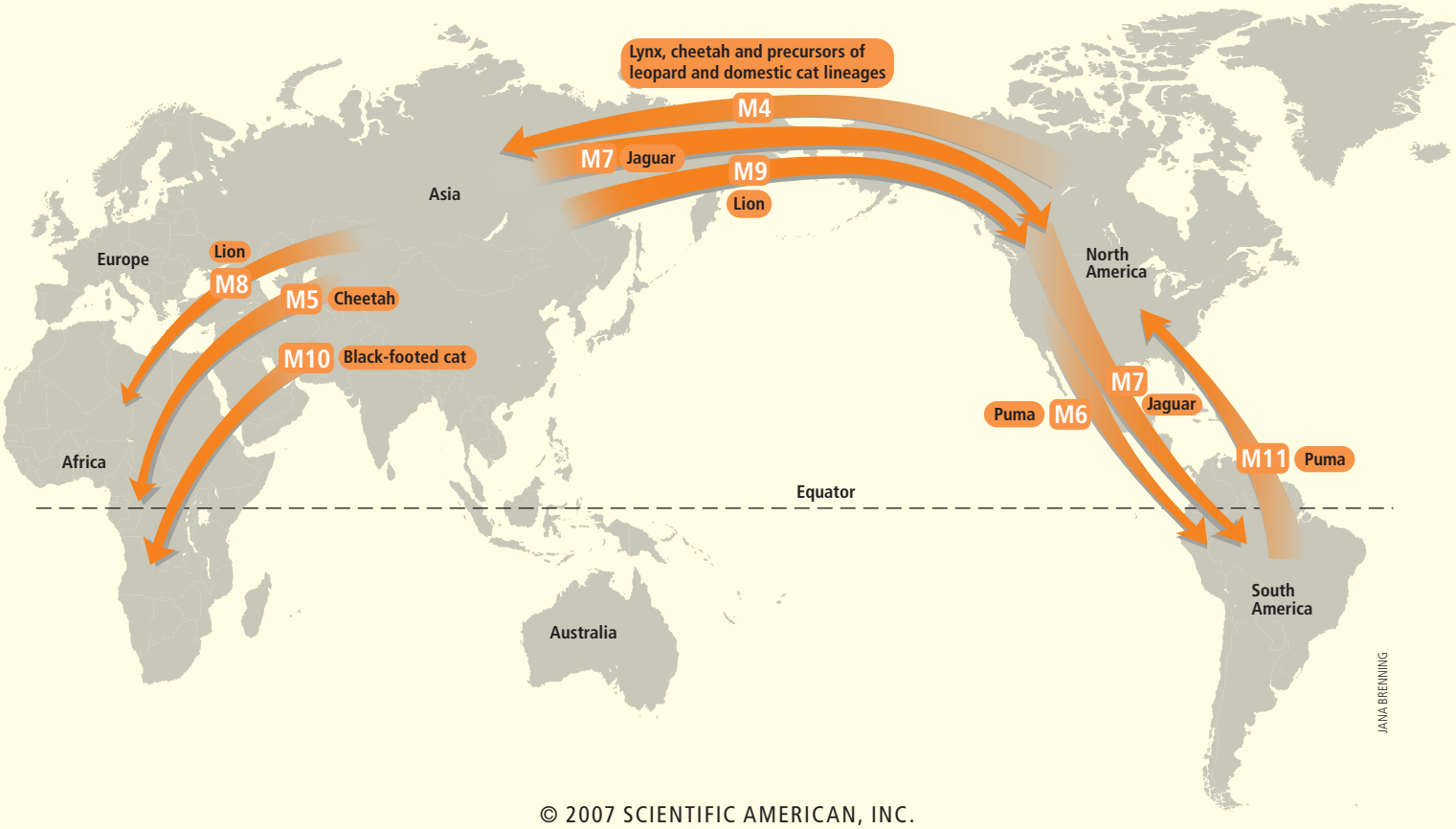
First Wave of Feline Migrations

Sometime around nine million years ago descendants of the pantherlike predator that is the ancestor of all modern cats began to migrate from its home in Asia to Africa M1 and North America M2 (and very much later to South America M3). Unusually low sea levels during this period meant that "bridges" of land stretched across the Bering Strait and the northern and southern ends of the Red Sea, facilitating the cats' journeys.



Second Wave

Many other migrations occurred between one million and four million years ago, when lowered sea levels connected the continents once again. The most recent puma migration M11 occurred 8,000 to 10,000 years ago.



JANA BRENNING

later, also in Asia, led to the Bornean bay cat lineage ❷, now composed of three small cats that evolved and still reside in Southeast Asia. The next split from the original group founded the caracal lineage ❸, today represented by three midsize species whose progenitors crossed into Africa eight million to 10 million years ago, embarking on the first intercontinental migration [*see upper map on opposite page*]. During this period, sea levels dropped to 60 meters below modern levels, connecting Africa and the Arabian Peninsula by land bridges at either end of the Red Sea and facilitating the migration to Africa.

Cats migrate because their hardwired behavior demands dispersal every generation. Once they reach adolescence, young males, and occasionally females, are forced to vacate their natal area. So, over time, growing cat populations require greater and greater territory for expansion. This behavior, together with the pressure to follow migrating prey species, probably explains why cats have been motivated to travel far and wide. They are also extremely skillful predators and quickly explore new regions as opportunities arise, so it is not surprising that they can move into unexploited areas successfully.

During the same interval in which Asian cats began to move into Africa, they also dispersed across Asia and traversed the Bering land bridge to Alaska. As cats now prowled Asia, Europe, Africa and North America, sea levels rose, separating continents, and with the isolation and changing habitats, a score of new species evolved. In North America, the ocelot ❹ and lynx ❺ lineages separated from the original migrants eight million and 7.2 million years ago, respectively, with the ocelot lineage ultimately dividing into two species there and the other group producing four species: three lynxes and the bobcat. The puma lineage ❻ diverged 6.7 million years ago, giving rise to the puma (also called cougar or mountain lion), jaguarundi and American cheetah. Fossil remains of all these species in American deposits nail down their origin in the Western Hemisphere.

Two million to three million years ago a new ice age caused the oceans to recede once again, enough, along with shifting landmasses, to connect the two American continents via the Isthmus of Panama. A few cats of this time grasped the opportunity to migrate, headed south and encountered a continent with no placental carnivores (no bears, dogs, cats, skunks, and so on). South America had been isolated from northern landmasses for tens of millions of years and was teeming with marsupial species, including several successful carnivorous varieties. But when

[THE AUTHORS]

After receiving a doctorate in genetics at Cornell University in 1971, Stephen J. O'Brien joined the National Cancer Institute as a postdoc. He is now chief of the NCI's Laboratory of Genomic Diversity, which he founded in the late 1980s. This is his fourth article for *Scientific American.* His most recent book is *Atlas of Mammalian Chromosomes* (Wiley, 2006). Warren E. Johnson earned his Ph.D. in animal ecology from Iowa State University in 1992 and joined the Laboratory of Genomic Diversity that same year.

WHERE THE CATS ARE TODAY

EUROPE
European wildcat ▲
Iberian lynx

NORTH ASIA
Asiatic wildcat
Chinese mountain wildcat
Eurasian lynx
Pallas's cat
Snow leopard ▲

NORTH AMERICA
Bobcat
Canada lynx ▲
Jaguar
Puma

TROPICAL ASIA
Asiatic golden cat
Asian lion
Bornean bay cat
Bornean clouded leopard
Clouded leopard
Fishing cat ▼
Flat-headed cat
Jungle cat
Leopard
Leopard cat
Marbled cat
Rusty-spotted cat
Sand cat
Tiger

SUB-SAHARAN AFRICA
African golden cat
African lion ▼
African wildcat
Black-footed cat
Caracal
Cheetah
Leopard
Serval

SOUTH AMERICA
Andean mountain cat
Geoffroy's cat
Jaguar ▼
Jaguarundi
Kodkod
Margay
Ocelot
Oncilla
Pampas cat
Puma

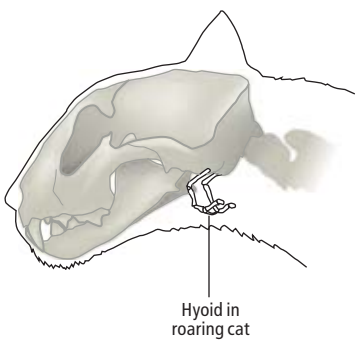
SHARON ANGLIN (*O'Brien, Johnson*); NORBERT ROSING *National Geographic Image Collection* (*European wildcat*); TOM BRAKEFIELD *Corbis* (*snow leopard*); JOE MCDONALD (*Canada lynx*); BEVERLY JOUBERT *National Geographic Image Collection* (*African lion*); TKOFOTO.COM (*fishing cat*); SA TEAM *Foto Natura/Minden Pictures* (*jaguar*)

FAST FACTS

There are 600 million domestic cats around the world.

Cat fossils are so similar that even experts struggle to tell a lion's skull from a tiger's.

Lions, tigers, jaguars, leopards and snow leopards are the only cats that can roar. An incompletely ossified bone in the throat called the hyoid makes these unusual vocalizations possible.



the cats arrived across Panama, they had already become the ultimate predators: large, fast, dexterous, ferocious and deadly. The more modest marsupial carnivores were no match for them. Nearly all resident marsupials were quickly replaced by migrant carnivores such as cats of the ocelot lineage, which diversified still further in their new home, creating seven species that still survive in South America.

As the last ice age wound down about 12,000 years ago, the thick ice sheets that covered all of Canada and the northern tier of the U.S. gradually melted, transforming the barren landscapes into the forested terrain and grassland prairies of North America. After the big thaw, a cataclysm abruptly extirpated 40 species of mammals from North America. The Pleistocene extinctions, as they are called, eliminated 75 percent of the large animals living there. Mammoths, mastodons, dire wolves, massive short-faced bears, giant ground sloths, American lions, saber-toothed cats, pumas and cheetahs would all disappear from North America. Cheetahs escaped extinction because several million years earlier, when seas were still low, a number of their ancestors had made their way back to Asia [*see lower map on page 72*] and then Africa. Pumas avoided annihilation in a South American refuge and restocked North America many generations later. The other species would never return.

The Journey Continues

At roughly the same time the cheetahs made their way back across the Bering Strait from America to Asia, the precursors of the leopard cat ❼ and the domestic cat ❽ lineages slipped from their American roots and crossed the Bering land bridge to Asia. Subsequently, the leopard cat lineage blossomed to produce the Asian leopard cat and four small species that today are found in India (rusty-spotted cat), Mongolia (Pallas's cat), Indonesia (flat-headed cat) and other scattered Asian locales (fishing cat).

Also in Asia during this period, the great roaring cats of the panthera lineage spread much more widely than before. Massive 320-kilogram tigers ranged throughout southern and eastern Asia (India, Indochina, the Sunda Shelf and China), whereas in northern and western Central Asia, the snow leopards adapted to high elevations in the Himalayas and Altai Mountains. Leopards dispersed not only across Asia but also into Africa, where they occur today. Lions and jaguars traveled to North America during the late Pliocene, roughly three million to four million years ago. Although the Pleistocene extinctions eliminated both species from North America, jaguars had escaped to South America, and lions, which had also dispersed to Africa, found a continent more hospitable than Europe, Asia or the Americas had been. The king of beasts clings to survival today in Africa, numbering fewer than 30,000 individuals. In Asia, lions are virtually extinct; only a tiny relict population of around 200 highly inbred Asiatic lions survives in the Gir Forest sanctuary in the Gujarat province of western India.

Our genetic analyses have also revealed a close call with extinction for tigers. Around 73,000 years ago the massive Toba volcanic eruptions on Borneo annihilated scores of mammal species in East Asia, including a widespread tiger population. A tiny group of tigers survived and repopulated a new race across the region, but the lack of genetic diversity in their modern descendants indicates the survivors passed through a population bottleneck at the time of the Toba eruption—leaving only a small group of animals to carry on the species. Like the cheetahs and pumas in North America, the tiger slipped through by a whisker.

Into Our Living Rooms

The final act in the cats' journey, from the jungle to our living rooms, began in the dense forests and vast deserts around the Mediterranean basin. There a handful of diminutive cat species (weighing less than 10 kilograms) had gradually emerged—the East Asian jungle cat, Middle Eastern sand cat, African black-footed cat and a ubiquitous wildcat species with four well-recognized subspecies (European, Central Asian, Near Eastern and Chinese). From one of these wildcat subspecies, one of the most successful experiments in history began—that of cat domestication. A wide-reaching molecular genetics study of the world's domestic cats and wildcats by graduate student Carlos Driscoll of the University of Oxford has brought this process into clear focus. All domestic cats carry genetic signatures matching Asian wildcats from Israel and the Near East.

We now believe that the cat was domesticated on several occasions, all within the Fertile Crescent 8,000 to 10,000 years ago, as nomadic human populations began to gather in small villages around the first agricultural settlements. These early farmers cultivated wheat and barley. Wildcats in the region, perhaps attracted by the

SKULLS UNLIMITED; MELISSA THOMAS (*hyoid*)

SOLVING THE CAT PUZZLE

Taxonomists have historically found it difficult to classify the cat family because the fossil record is sparse and it is hard to distinguish one fossil species from another. By analyzing the DNA of all 37 living species, the authors were able to sort the cat family into eight lineages. They obtained the DNA by collecting blood or tissue samples from each of the 37 species. Getting all the samples was not easy, because some of the species are rare and live in remote locations. They also analyzed seven "outgroup" species, close relatives of cats in the civet-mongoose family, Viverridae. The outgroup species provide a baseline for estimating the divergence dates within the Felidae family.

CINNAMON:
Her DNA was sequenced.

The scientists looked at DNA from the X and Y chromosomes and from the mitochondria (parts of the cell that generate energy and are passed along the maternal line). They focused on the DNA sequence of 30 different genes—in all, 22,789 nucleotide letters for each cat species. Nearly half of these sequences were variable across the range of species. The differences are what allowed investigators to determine which groups were most related and which were oldest. Genes accumulate changes over time. If these are not detrimental, they persist. So a species that emerged earliest would have had the most time for its genes to change and would show the most variation within any given gene, and one can safely assume that species whose genes share many of the same changes are most related.

Once the DNA analyses had allowed investigators to resolve the branching nodes, or "forks," in the cat family tree, they turned to fossils to estimate when the forks actually happened. Paleontologists have determined the age of dozens of fossils of ancient cats using radiocarbon-dating methods. Certain cat fossils considered as missing links (the most recent common ancestor of a group such as the great cats, lynxes or ocelots) provided 16 firm fossil dates for specific branch points on the tree. Then, mathematical computer scripts based on a steady cumulative molecular clock translated the genomic data into estimates of the time elapsed since each divergence node. (The molecular clock idea assumes that some evolutionary changes occur at a regular rate. Mutations, for example, may be incorporated in the DNA of genes at a steady rate over millions of years. Differences in the DNA, therefore, can act as a "clock" for measuring the date at which two lineages split from a common ancestor.)

The most recent addition to genome sequences is the complete set of genetic information in the DNA of an Abyssinian cat named Cinnamon. Cinnamon's full genome sequence, along with the sequence of 32 other species of mammals (including human, mouse, dog, cow, elephant and representatives of most mammalian orders), has given students of evolution an almost unlimited assemblage of genetic information across the 100-million-year-old history of modern mammals.

—The Editors

plentiful rodents in the grain stores, apparently offered themselves as cautious companions, earning their keep by dispatching the pesky rodents. The increasingly tame wildcats bred prolifically and linked their fortunes to those of the humans.

These animals ultimately undertook a new migration. It began on foot, then progressed in wagons, and eventually on oceanic vessels, ultimately spreading the domesticated cat companions across the globe. Some 600 million domestic cats live worldwide today, almost the only cat species not considered threatened or endangered by the world's conservation organizations. By the 19th century, cat owners were selectively mating their pet tabbies to produce fancy breeds. The American Cat Fanciers Association lists 41 official cat breeds, from Maine Coon to Siamese to Persian to Korat, all tracing their roots to the birth of human and feline civilization in the Fertile Crescent.

The evolutionary story that emerges from our studies of the cat family serves as a harbinger for the fledgling field of "genomic prehistory." Just as for the cats, the patterns of genomic variation carried by each species contain footprints of kinship, migrations, bottlenecks and expansions across the planet. ■

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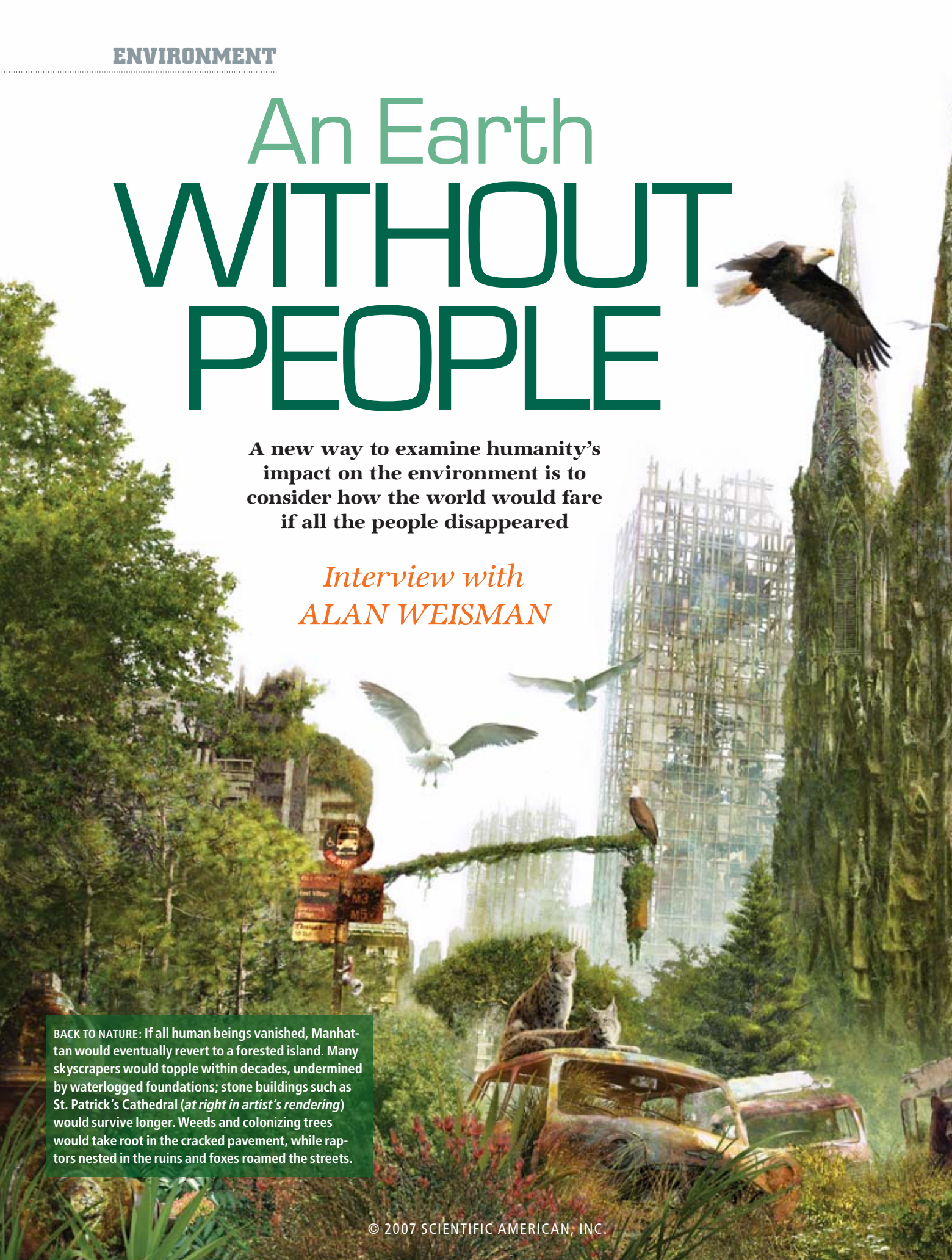
KRISTINA NARFSTRÖM

An Earth WITHOUT PEOPLE

A new way to examine humanity's impact on the environment is to consider how the world would fare if all the people disappeared

Interview with
ALAN WEISMAN



BACK TO NATURE: If all human beings vanished, Manhattan would eventually revert to a forested island. Many skyscrapers would topple within decades, undermined by waterlogged foundations; stone buildings such as St. Patrick's Cathedral (*at right in artist's rendering*) would survive longer. Weeds and colonizing trees would take root in the cracked pavement, while raptors nested in the ruins and foxes roamed the streets.

EDITORS' INTRODUCTION

It's a common fantasy to imagine that you're the last person left alive on earth. But what if *all* human beings were suddenly whisked off the planet? That premise is the starting point for *The World without Us,* a new book by science writer Alan Weisman, an associate professor of journalism at the University of Arizona. In this extended thought experiment, Weisman does not specify exactly what finishes off *Homo sapiens;* instead he simply assumes the abrupt disappearance of our species and projects the sequence of events that would most likely occur in the years, decades and centuries afterward.

According to Weisman, large parts of our physical infrastructure would begin to crumble almost immediately. Without street cleaners and road crews, our grand boulevards and superhighways would start to crack and buckle in a matter of months. Over the following decades many houses and office buildings would collapse, but some ordinary items would resist decay for an extraordinarily long time. Stainless-steel pots, for example, could last for millennia, especially if they were buried in the weed-covered mounds that used to be our kitchens. And certain common plastics might remain intact for hundreds of thousands of years; they would not break down until microbes evolved the ability to consume them.

SCIENTIFIC AMERICAN editor Steve Mirsky recently interviewed Weisman to find out why he wrote the book and what lessons can be drawn from his research. Some excerpts from that interview appear on the following pages.

WHO MIGHT

Nature, it is said, abhors a vacuum. If humans were to disappear, could another species evolve into a tool-making, crop-raising, language-using beast that would dominate the planet? According to Alan Weisman, baboons might have a reasonable shot. They have the largest brains of any primate besides *Homo sapiens,* and like us they adapted to living in savannas as forest habitats in Africa shrank. Writes Weisman in *The World without Us:* "If the dominant ungulates of the savanna—cattle—disappear, wildebeest will expand to take their place. If humans vanish, will baboons move into ours? Has their cranial capacity lain suppressed during the Holocene because we got the jump on them, being first out of the trees? With us no longer in their way, will their mental potential surge

If human beings were to disappear tomorrow, the magnificent skyline of Manhattan would not long survive them. Weisman describes how the concrete jungle of New York City would revert to a real forest.

"What would happen to all of our stuff if we weren't here anymore? Could nature wipe out all of our traces? Are there some things that we've made that are indestructible or indelible? Could nature, for example, take New York City back to the forest that was there when Henry Hudson first saw it in 1609?

"I had a fascinating time talking to engineers and maintenance people in New York City about what it takes to hold off nature. I discovered that our huge, imposing, overwhelming infrastructures that seem so monumental and indestructible are actually these fairly fragile concepts that continue to function and exist thanks to a few human beings on whom all of us really depend. The name 'Manhattan' comes from an Indian term referring to hills. It used to be a very hilly island. Of course, the region was eventually flattened to have a grid of streets imposed on it. Around those hills there used to flow about 40 different streams, and there were numerous springs all over Manhattan island. What happened to all that water? There's still just as much rainfall as ever on Manhattan, but the water has now been suppressed. It's underground. Some of it runs through the sewage system, but a sewage system is never as efficient as nature in wicking away water. So there is a lot of groundwater rushing around underneath, trying to get out. Even on a clear, sunny day, the people who keep the subway going have to pump 13 million gallons of water away. Otherwise the tunnels will start to flood.

"There are places in Manhattan where they're constantly fighting rising underground rivers that are corroding the tracks. You stand in these pump rooms, and you see an enormous amount of water gushing in. And down there in a little box are these pumps, pumping it away. So, say human beings disappeared tomorrow. One of the first things that would happen is that the power would go off. A lot of our power comes out of nuclear or coal-fired plants that have automatic fail-safe switches to make sure that they don't go out of control if no humans are monitoring their systems. Once the power goes off,

[THE INTERVIEWEE]

Alan Weisman is author of five books, including the forthcoming *The World without Us* (St. Martin's Press, 2007). His work has appeared in *Harpers,* the *New York Times Magazine,* the *Los Angeles Times Magazine, Discover,* the *Atlantic Monthly, Condé Nast Traveler, Orion* and *Mother Jones.* Weisman has been heard on National Public Radio and Public Radio International and is a senior producer at Homelands Productions, a journalism collective that produces independent public radio documentary series. He teaches international journalism at the University of Arizona.

PHOTOILLUSTRATION BY KENN BROWN AND PHOTOGRAPHY BY EMILY HARRISON (*preceding pages*); KENN BROWN AND EMILY HARRISON (*below left*); KENN BROWN (*below right*); PARK JONG-HAK (*Weisman*); DAVID KEATON/Corbis (*baboon*)

HUMANITY'S LONG FADE-OUT: A TIMELINE FOR THE FALL OF NEW YORK

2 DAYS AFTER THE DISAPPEARANCE OF HUMANS

Without constant pumping, New York City's subway system completely fills with water.

7 DAYS

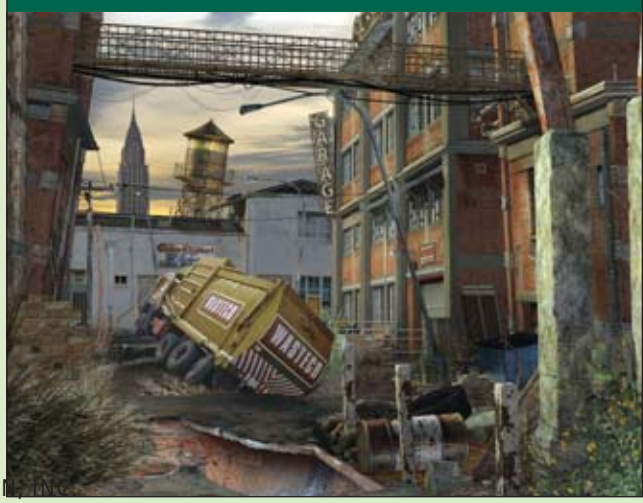
Nuclear reactors burn or melt down as their water-cooling systems fail.

1 YEAR

Street pavements split and buckle as water in the cracks freezes and thaws.

2 TO 4 YEARS

In New York and other cities, cracked streets become covered with weeds and, later, colonizing trees whose roots upheave sidewalks and wreak havoc with already damaged sewers.



REPLACE US?

to the occasion and push them into a sudden, punctuated evolutionary scramble into every cranny of our vacant niche?"

Hollywood, with its long series of *Planet of the Apes* movies, seems to agree with Weisman. A second out-of-Africa scenario could play out hundreds of thousands of years after the first. One wonders what the baboon archaeologists of the future would make of the extraordinary human artifacts—sculptures, cutlery, plastic bags—buried just beneath their feet. Weisman guesses that "the intellectual development of whatever creature digs them up might be kicked abruptly to a higher evolutionary plane by the discovery of ready-made tools." Even as ghosts, we could continue to shape the future.

—Edward Bell

the pumps stop working. Once the pumps stop working, the subways start filling with water. Within 48 hours you're going to have a lot of flooding in New York City. Some of this would be visible on the surface. You might have some sewers overflowing. Those sewers would very quickly become clogged with debris—in the beginning the innumerable plastic bags that are blowing around the city and later, if nobody is trimming the hedges in the parks, you're going to have leaf litter clogging up the sewers.

"But what would be happening underground? Corrosion. Just think of the subway lines below Lexington Avenue. You stand there waiting for the train, and there are all these steel columns that are holding up the roof, which is really the street. These things would start to corrode and, eventually, to collapse. After a while the streets would begin cratering, which could happen within just a couple of decades. And pretty soon, some of the streets would revert to the surface rivers that we used to have in Manhattan before we built all of this stuff.

"Many of the buildings in Manhattan are anchored to bedrock. But even if they have steel beam foundations, these structures were not designed to be waterlogged all the time. So eventually buildings would start to topple and fall. And we're bound to have some more hurricanes hitting the East Coast as climate change gives us more extreme weather. When a building would fall, it would take down a couple of others as it went, creating a clearing. Into those clearings would blow seeds from plants, and those seeds would establish themselves in the cracks in the pavement. They would already be rooting in leaf litter anyhow, but the addition of lime from powdered concrete would create a less acidic environment for various species. A city would start to develop its own little ecosystem. Every spring when the temperature would be hovering on one side or the other of freezing, new cracks would appear. Water would go down into the cracks and freeze. The cracks would widen, and seeds would blow in there. It would happen very quickly."

How would the earth's ecosystems change if human beings were out of the picture? Weisman says we can get a glimpse of this hypothetical world by looking at primeval pockets

KENN BROWN AND EMILY HARRISON

MORE TO EXPLORE

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Extinction: How Life on Earth Nearly Ended 250 Million Years Ago. Douglas H. Erwin. Princeton University Press, 2006.

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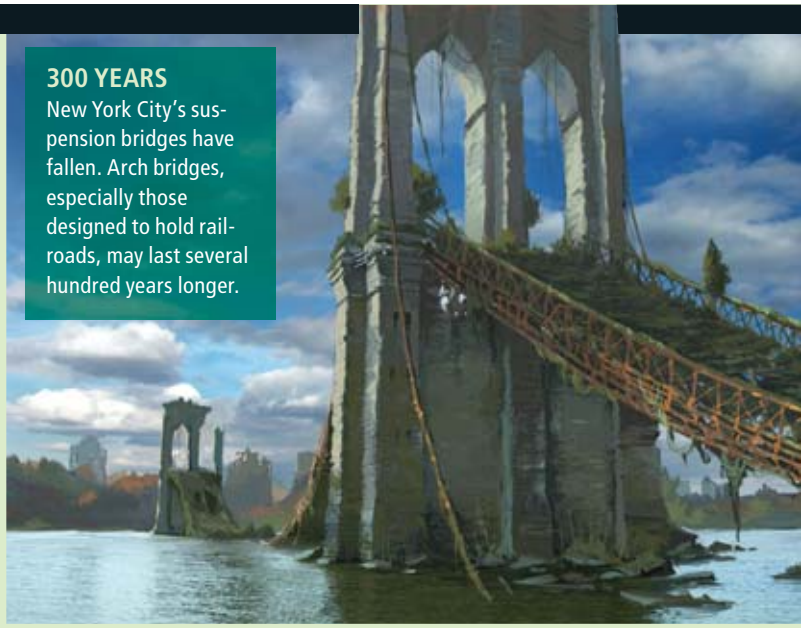
4 YEARS
Without heat, homes and office buildings fall victim to the freeze/thaw cycle and begin to crumble.

5 YEARS
Large parts of New York may be burned by now; a lightning strike on uncollected dead branches in Central Park could easily start a catastrophic fire.

20 YEARS
Dozens of streams and marshes form in Manhattan as collapsed streets fill with water.

100 YEARS
The roofs of nearly all houses have caved in, accelerating the deterioration of the structures.

300 YEARS
New York City's suspension bridges have fallen. Arch bridges, especially those designed to hold railroads, may last several hundred years longer.



500 YEARS Mature forests cover the New York metropolitan area.

5,000 YEARS
As the casings of nuclear warheads corrode, radioactive plutonium 239 is released into the environment.

15,000+ YEARS
The last remnants of stone buildings in Manhattan fall to advancing glaciers as a new ice age begins.

35,000 YEARS
Lead deposited in the soil from automobile emissions in the 20th century finally dissipates.

100,000 YEARS
The concentration of carbon dioxide in the atmosphere returns to preindustrial levels.

10 MILLION YEARS
Bronze sculptures, many of which still retain their original shape, survive as relics of the human age.

where humanity's footprint has been lightest.

"To see how the world would look if humans were gone, I began going to abandoned places, places that people had left for different reasons. One of them is the last fragment of primeval forest in Europe. It's like what you see in your mind's eye when you're a kid and someone is reading Grimm's fairy tales to you: a dark, brooding forest with wolves howling and tons of moss hanging off the trees. And there *is* such a place. It still exists on the border between Poland and Belarus. It was a game reserve that was set aside in the 1300s by a Lithuanian duke who later became king of Poland. A series of Polish kings and then Russian czars kept it as their own private hunting ground. There was very little human impact. After World War II it became a national park. You go in there and you see these enormous trees. It doesn't feel strange. It almost feels right. Like something feels complete in there. You see oaks and ashes nearly 150 feet tall and 10 feet in diameter, with bark furrows so deep that woodpeckers stuff pinecones in them. Besides wolves and elk, the forest is home to the last remaining wild herd of *Bison bonasus*, the native European buffalo.

"I also went to the Korean DMZ, the demilitarized zone. Here you have this little stretch of land—it's about 150 miles long and 2.5 miles wide—that has two of the world's biggest armies facing off against each other. And in between the armies is an inadvertent wildlife preserve. You see species that might be extinct if it weren't for this one little piece of land. Sometimes you'll hear the soldiers screaming at one another through loudspeakers or flashing their propaganda back and forth, and in the middle of all this tension you'll see the flocks of cranes that winter there.

"But to really understand a world without humans, I realized I would have to learn what the world was like before humans evolved. So I went to Africa, the place where humans arose and the only continent where there are still huge animals roaming around. We used to have huge animals on all the other continents and on many of the islands. We had enormous creatures in North and South America—giant sloths that were even bigger than the mammoths; beavers the size of bears. It's controversial as to what actually wiped them out, but a lot of indications point the finger at us. The extinctions on each landmass seemed to coincide with the arrival of humans. But Africa is the place where human beings and animals evolved together, and the animals there learned strategies to avoid our predation. Without humans, North America would probably become a giant deer habitat in the near term. As forests would become reestablished across the continent, eventually—in evolutionary time—larger herbivores would evolve to take advantage of all the nutrients locked up in woody species. Larger predators would evolve accordingly."

Thinking about an earth without humans

THE WINNERS...

Our demise would be good news for many species. Below is a small sample of the animals and plants that would benefit from the disappearance of humans.

BIRDS: Without skyscrapers and power lines to fly into, at least a billion birds would avoid breaking their necks every year.

TREES: In New York, oaks and maples, along with the invasive Chinese ailanthus, would claim the city.

MOSQUITOES: As extermination efforts cease and wetlands rebound, great clouds of the insects would feed on other wildlife.

FERAL HOUSE CATS: They would probably do well dining on small mammals and birds in the posthuman world.

KENN BROWN (*above left*); JEAN-FRANCOIS PODEVIN (*above right*); RUSSELL GLENISTER *image100/Corbis (cat)*

1 BILLION+ YEARS
As the sun brightens, the earth heats dramatically, but insects and other animals may adapt.

5 BILLION YEARS
The earth vaporizes as the dying sun expands and consumes all the inner planets.

TRILLIONS OF YEARS
Broadcasts of *The Twilight Zone* and other television shows, faint and fragmented, still travel outward through space.

can have practical benefits. Weisman explains that his approach can shed new light on environmental problems.

"I'm not suggesting that we have to worry about human beings suddenly disappearing tomorrow, some alien death ray taking us all away. On the contrary, what I'm finding is that this way of looking at our planet—by theoretically just removing us—turns out to be so fascinating that it kind of disarms people's fears or the terrible wave of depression that can engulf us when we read about the environmental problems that we have created and the possible disasters we may be facing in the future. Because frankly, whenever we read about those things, our concern is: Oh, my God, are we going to die? Is this going to be the end? My book eliminates that concern right at the beginning by saying the end has already taken place. For whatever reason, human beings are gone, and now we get to sit back and see what happens in our absence. It's a delicious little way of reducing all the fear and anxiety. And looking at what would happen in our absence is another way of looking at, well, what goes on in our presence.

"For example, think about how long it would take to wipe out some of the things we have created. Some of our more formidable inventions have a longevity that we can't even predict yet, like some of the persistent organic pollutants that began as pesticides or industrial chemicals. Or some of our plastics, which have an enormous role in our lives and an enormous presence in the environment. And nearly all of these things weren't even here until after World War II. You begin to think there's probably no way that we are going to have any kind of positive outcome, that we are looking at an overwhelming tide of geologic proportions that the human race has loosed on the earth. I raise one possibility toward the end of the book that humans can continue to be part of the ecosystem in a way that is much more in balance with the rest of the planet.

"It's something that I approach by first looking at not just the horrible things that we have created that are so frightening—such as our radioactivity and pollutants, some of which may be around until the end of the planet—but also some of the beautiful things that we have done. I raise the question, Wouldn't it be a sad loss if humanity was extirpated from the planet? What about our greatest acts of art and expression? Our most beautiful sculpture? Our finest architecture? Will there be any signs of us at all that would indicate that we were here at one point? This is the second reaction that I always get from people. At first they think, This world would be beautiful without us. But then they think, Wouldn't it be sad not to have us here? And I don't think it's necessary for us to all disappear for the earth to come back to a healthier state." ■

... AND THE LOSERS

No doubt about it: our parasites and livestock would miss us. Below is a list of species that would probably suffer as a result of our disappearance.

DOMESTICATED CATTLE: They would become a delicious steak dinner for mountain lions, coyotes and other predators.

RATS: Bereft of our garbage, they would either starve or be eaten by raptors nesting in fallen buildings.

COCKROACHES: Without heated buildings to help them survive the winter, they would disappear from temperate regions.

HEAD LICE: Because these insects are so specifically adapted to humans, our demise would lead to their extinction.

SCI AM

To listen to a podcast of the interview with Alan Weisman, log on to
www.SciAm.com/ontheweb

PAT RAWLINGS (*above left*); RON MILLER (*above center*); EVERETT COLLECTION (*above right*); PER-ERIC BERGLUND Getty Images (*rat*)

BROADBAND
ROOM SERVICE BY LIGHT

Encoded light transmissions can provide the wireless devices in a room with multimedia Web services such as videoconferencing, movies on demand and more **By Mohsen Kavehrad**

KEY CONCEPTS

- Wireless delivery of multimedia Internet services to multiple users indoors may best be accomplished using light beams rather than radio waves.
- Optical wireless local-area networks employ encoded invisible infrared or visible light rays to transmit broadband data to mobile and fixed users inside homes and offices.
- Unlike the radio waves used by Wi-Fi, WiMAX and other similar networks, light photons offer a broader bandwidth that lets many users operate simultaneously. In addition, photons do not interfere with one another, nor do they pass through walls, thereby preventing eavesdropping.

—The Editors

Electronics engineers have long dreamed of ubiquitous connectivity—wireless data delivery for everyone and everything, everywhere, all the time. And they have made significant strides toward their goal: more than two billion people today have cell phones, and hundreds of millions send and receive messages and files via laptops, handhelds and other digital devices using Wi-Fi, the radio-frequency-based wireless local-area network ("hot spot") technology.

In addition, more and more Wi-Fi users enjoy the convenience of employing wireless mobile devices anywhere indoors. At the same time, manufacturers are installing wireless communications capabilities in traditionally stationary electronic devices and appliances to enable consumers to communicate with them remotely. Increasingly, these users also want to access broadband services without the fixed wire links they typically must have to receive them. But because of the limited availability of radio bandwidth in desired frequency ranges, Wi-Fi suffers from insufficient transmission speed and channel capacity, which slows the wireless access of Web-based multimedia services such as Internet browsing and video conferencing, as well as television and movies on demand. And even the new higher-speed, wide-area radio systems, such as WiMAX, are not well suited to wireless broadband communications inside structures because they can handle only a few users in a confined space and, more important, cannot provide secure communications.

An intriguing alternative is optical wireless technology. Rather than transmitting radio waves, optical wireless local-area networks send data in coded beams of white or infrared light—the latter being the same invisible wavelengths found in TV remote controls. Optical systems can connect wireless digital devices to a data port in a room, which in turn can be hooked into whatever high-speed broadband data network serves the house or building. This fast-developing technology offers several benefits: its focused, interference-free cells (or basic service areas) afford almost limitless bandwidth for multiple users. It also provides near-total security because, unlike radio waves, light does not pass through walls. And optical wireless is especially appropriate for large business spaces with many high-bandwidth users in close prox-

LIGHT WAVES can bring broadband data to and from mobile digital devices indoors at high speed no matter where the user moves.

imity, such as a factory floor or an office with many reconfigurable cubicles.

Data via Light

You may have heard of the "last mile" problem—the high cost of delivering broadband services from the nation's high-speed data infrastructure to fixed users. Optical wireless technology, in contrast, addresses the "last few feet" problem—the difficulty of sending broadband traffic from the terminus of the hardwired information backbone to wireless devices indoors.

Researchers have investigated the concept of indoor optical communications since the early 1980s, when engineers at IBM Zurich built the first working system. The technology languished for a decade because the Internet was still in its infancy and demand for wireless broadband systems did not yet exist. With the astounding growth of the Web in recent years, however, all that has changed.

Engineers describe infrared and white light-emitting diode (LED) wireless local-area networks as "optical" systems because they transmit data via invisible and visible light waves (or photons) rather than longer radio waves or microwaves. Current optical wireless systems use very low intensity infrared radiation—the "optical" segment of the electromagnetic spectrum with wavelengths longer than those of visible light but shorter than those of radio waves—which people cannot sense. When infrared light is emitted at higher intensities, we feel it as heat.

Optical links operate best when the transmitter aims directly at the receiver, as they do in the familiar point-and-shoot systems of TV remotes and digital cameras. But this arrangement would be impractical when connecting up an entire office or providing network access in a public place such as an airport or a restaurant. To get full coverage in a room, optical networks disperse their data-containing beams throughout the space [*see box on page 85*]. Encoded infrared beams can bounce off all the surfaces—the walls,

20 MILLION+

WIRELESS BROADBAND USERS BY 2010

will access high-speed data via WiMAX and other radio-based wide-area networks, according to Visant Strategies, a market research firm. Optical wireless systems may better serve indoor users.

JOHN STILL

[HOW THEY STACK UP]

RADIO VS. INFRARED

Nondirected (or diffuse) infrared systems, which disperse coded light beams by reflecting them off room surfaces, offer advantages over radio-frequency-based systems for delivering wireless broadband data indoors.

TRANSMISSION SPEED

Radio: Ensuring safe power levels that do not hurt indoor occupants limits the maximum data-transfer rate to several hundred megabits per second.

Infrared: Gigabit-per-second data-transfer speeds.

Infrared TV remote

BANDWIDTH LIMITATION

Radio: Because radio signals sent at the same frequency interfere with one another, the Federal Communications Commission regulates transmission bands, which curbs available bandwidth.

Infrared: Photons do not interfere with one another. Usable bandwidth is limited by the maximum rate at which the receiver's photodiodes can register incoming data and prepare to receive more.

SECURITY

Radio: Radio waves pass through walls, opening up chances for eavesdroppers.

Infrared: Light waves cannot pass through walls, preventing others from snooping.

MULTIPATH FADING

Radio: As coded radio waves bounce off conductive surfaces, they often arrive at different times. Sometimes the reflections are sufficiently out of phase so that the troughs line up with the rises, canceling one another out.

Wi-Fi router

Infrared: Destructive interference is impossible with light waves. The sensors on the active area of a photodiode absorb the waves separately and then average out the incoming energy, so no canceling can result.

PRINCIPAL NOISE SOURCE

Radio: Co-channel interference from other users transmitting on the same frequency slows transmission speed.

Infrared: Spurious signals from ambient light sources—sun, lamps, and so forth—slow transmission speed.

the desk, the coffee machine, even occupants' faces. The resulting reflections scatter around the interior, so receivers can point in any direction. Although some commercially available infrared networking products already use this method, the ricocheting beams create something akin to echoes, which complicates the signal receiver technology's determination of whether it is capturing accurate data. The echoes can lead to loss of data and can significantly limit the network's data-transmission speed.

Making Infrared Work

To address the echo issue, my research team at Pennsylvania State University developed an optical wireless system that sends out multiple copies of the data as an array, or grid, of pencil-thin infrared beams that fill the volume of an interior space [*see box on page 86*]. The low-power beams, each repeating the same signals, connect an access port, which is wired to the high-speed data infrastructure, to all the digital devices in the room fitted with infrared receivers. Repetition of the coded beam permits users to move around the room and still stay hooked up to the system because they can link to new beams as they lose connection with others. Because a device receives multiple identical data streams simultaneously, it can perform error checking by simply comparing the data from several beams to ensure the data's accuracy. The grid of pencil beams enables rapid signal transmission—a gigabit per second, several hundred times as much data as a DSL modem—with few transmission errors. Such a system can make indoor wireless broadband access a breeze.

We create the light grid by sending the encoded infrared signal out through a so-called beam former—a special holographic filter—that disperses the beams in the desired directions. To make the holographic filter, we first illuminate an inexpensive photosensitive plastic sheet with an image of a grid from two directions. To accomplish this task, we split the image-containing beam into two with a half-silvered mirror and then recombine them using a couple of beam directors. This setup lights the photosensitive sheet with the same grid image from different angles, creating a three-dimensional, or volumetric, image. When the infrared wireless transmitter sends a coded light beam through the holographic filter, many copies of the beam emerge in a three-dimensional grid pattern.

The beam pattern we use depends on the configuration of the room; different areas can be illuminated as needed—with a fan shape, a rectangular grid shape, concentric circles, and so forth. For instance, whereas general-use spaces such as offices and factories usually have uniform lighting, an art museum typically requires lights to be focused on the paintings and the sculptures. In the same way, optical wireless installations can be optimized so that the beams are concentrated in areas where many broadband users labor and less so where there are fewer workers.

A room's infrared wireless receiver is fitted with a similar so-called fly-eye holographic filter that helps to collect the "reply," or return-path, beams emitted by digital devices. The filter funnels the signals received from many directions into separate photodetectors and improves reception by combining the energies of the beams.

GETTY IMAGES (*remote*); D-LINK CORPORATION (*router*)

White LED Wireless

These infrared-based optical wireless systems will most likely be supplanted at some point by local-area networks based on white LEDs, which offer still more bandwidth, along with other benefits. LED technology is increasingly being seen as a replacement for conventional lighting, and it could provide an additional broadband function at the same time.

White LEDs combine the low power consumption and long life of fluorescent bulbs with the pleasing light spectrum of incandescent bulbs. According to industry experts, within a few years these white light–creating silicon chips will be mass-produced using traditional integrated-circuit fabrication techniques cheaply enough to allow them to overtake compact fluorescents, the currently favored low-energy lighting option. What is not yet widely appreciated, though, is that the same white LED technology that could one day brighten rooms and other interior spaces very inexpensively and efficiently could simultaneously provide all the suitably equipped digital devices inside those spaces with wireless digital broadband access. When you turn on a white LED lamp, your wireless device could simultaneously receive broadband transmissions via the same white light that illuminates the room.

A white LED lamp could transmit broadband via the same light that illuminates the room.

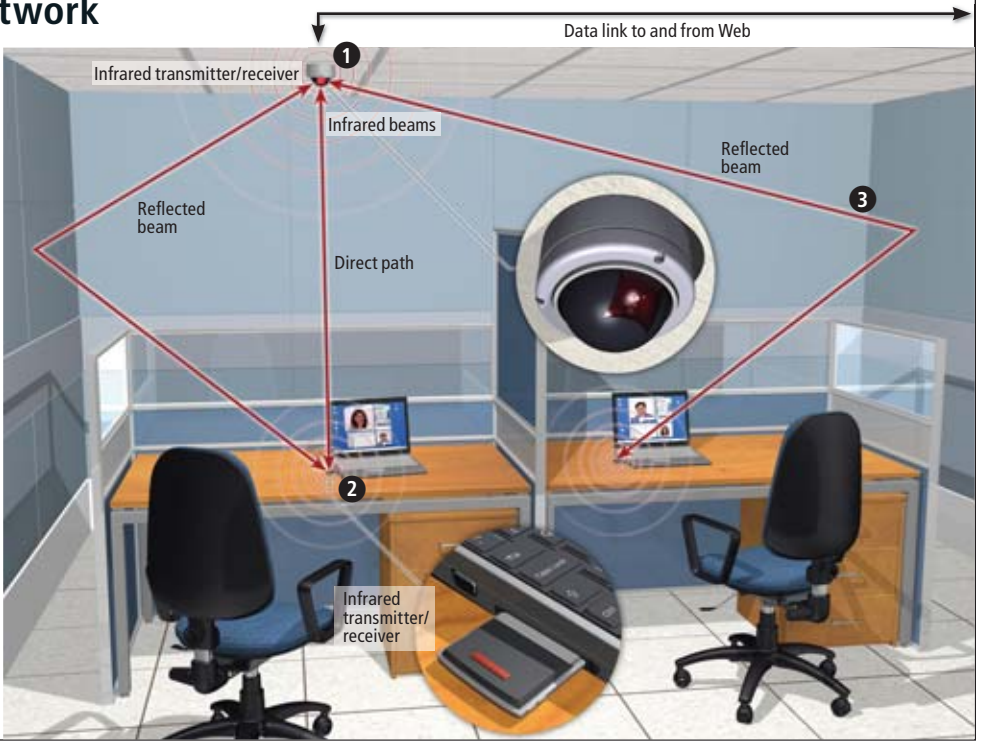
Unlike other existing lighting sources, an LED can be readily adapted to operate as a visible-light wireless communications transmitter, a concept first suggested a few years ago by a team of researchers at Keio University in Japan. The LED's rapid on-and-off response time (a kind of high-tech semaphore operating in the millions of cycles per second, or megahertz, range) enables it to modulate visible light for encoding wireless communications. According to my research group's preliminary experimental results, a commercially available white LED element can be modulated for signaling by up to about 100 megahertz. This high-frequency semaphore is far too fast for the human eye to see.

White LEDs offer a number of advantages for indoor wireless communications over Wi-Fi and even infrared networks. Because white LEDs may end up providing interior lighting in the future, installation of a wireless system based on them would probably be easier than setting up most other wireless systems. Plus, signal degradation caused by everyday objects in rooms blocking point-to-point transmissions—known as the shadowing effect—would be minimal because white LED light fixtures would typically be distributed throughout a room. Ceiling installations would be particularly useful because the beams would be less likely to be obstructed.

[HOW IT WORKS]

Optical Wireless Network

In contrast to radio-wave-based technology, such as Wi-Fi or the new WiMAX systems, optical wireless networks can connect multiple indoor portable devices to the Internet at broadband speeds using infrared light. Inexpensive infrared transmitters/receivers beam signals into a room ❶ to link with devices fitted with plug-in cards that can both receive and transmit the coded infrared light ❷. Because light signals do not interfere with one another—as radio signals can—and offer greater bandwidth, many more devices can share the optical network. Barriers such as partitions do not halt reception because beams reflect off room surfaces ❸. Engineers are working on similar systems that use white LED lamps, flickering in code faster than the human eye can detect.



SW INFOGRAPHICS

[THE AUTHOR]

Mohsen Kavehrad is W. L. Weiss Endowed Chair Professor of Electrical Engineering and founding director of the Center for Information and Communications Technology Research at Pennsylvania State University. Before entering academics, Kavehrad worked for Bell Laboratories. He received his Ph.D. in electrical engineering from the Polytechnic University of New York in 1977. Kavehrad, a fellow of the Institute of Electrical and Electronics Engineers, enjoys reading and writing poetry.

As with all optical systems, white LED technology is not susceptible to interference from light signals of other colors and offers a huge communications bandwidth.

It is important to note that room occupants will be able to shut off the lights at night and still use their laptops and other devices, because even when LEDs are "off" and dark, a low-current power supply could still allow them to release enough so-called residual photons to communicate wirelessly. An alternative approach would be to design white LED systems to include low-cost light sources that emit invisible frequencies to accomplish this function when the room lights are switched off.

Researchers need to resolve several remaining concerns with white LED wireless local-area network technology. A key step will be the design of the return, or uplink, signal systems by which the wireless devices communicate with the white LEDs and thus the backbone infrastructure. Engineers could, for instance, equip devices with emitters (on plug-in cards for retrofitting) that produce a different, invisible (perhaps infrared) wavelength. These light sources would send coded beams to white LED lamps fitted with small photodiode receivers. Or the system could operate on a single visible wavelength and take advantage of the fact that LEDs are pulsed at very high frequencies (they are "occulted," or mostly on with very brief off periods). The return signals from wireless devices could be transmitted to receivers during the LEDs' predetermined off cycles. Engineers call this technique "split time," or time-division duplex. Whatever the eventual solution, the added equipment will raise the cost of the system somewhat.

Developers of white LED systems will also have to account for the possible and still uninvestigated negative effects of natural and artificial light entering through windows and other sources. And before engineers can formulate practical designs, they must conduct additional simulations and experiments to determine the optimal balance between indoor illumination and communications. Finally, researchers will have to produce effective visual-spectrum encoding, decoding, modulation, and diversity-combining techniques that are compatible with both illumination and communications functions.

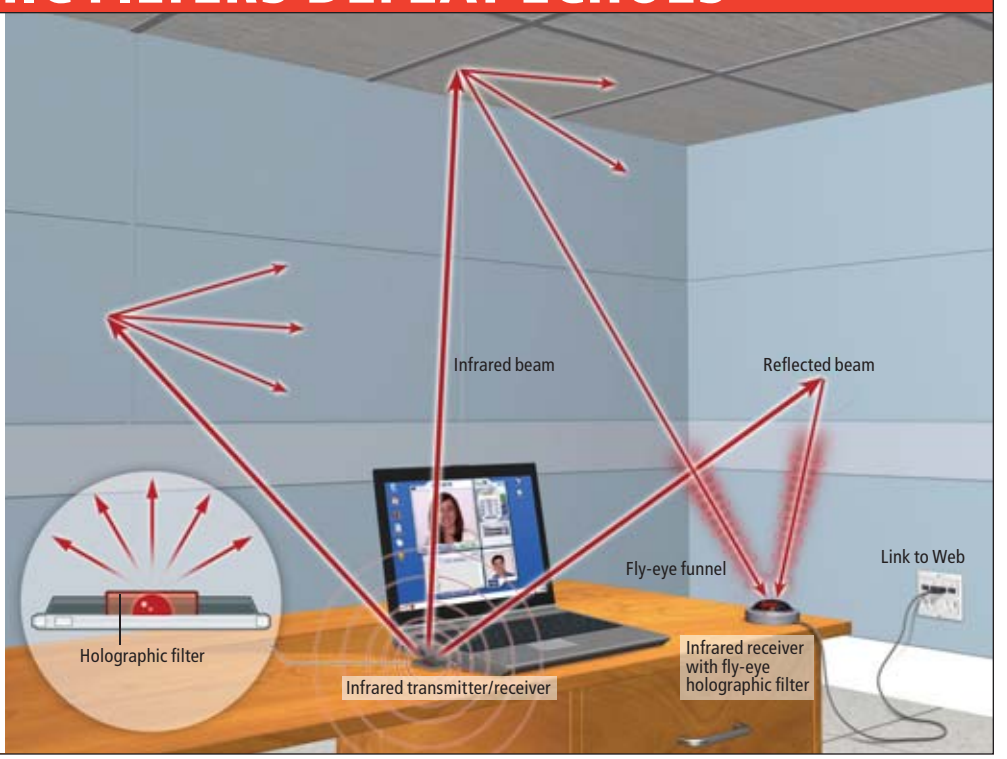
Power-Line Broadband

Adoption of both variants of optical wireless technology would benefit greatly from of an up-and-coming way to deliver broadband access over the last mile to fixed users—broadband

[AUTHOR'S INNOVATION]

HOLOGRAPHIC FILTERS DEFEAT ECHOES

Existing optical wireless systems bounce infrared beams off room surfaces, scattering the reflections around the interior. Because the scattered beams travel unequal path lengths, they arrive at the receiver at slightly different times, creating an effect similar to echoes. The coded beams thus overlap randomly, making it difficult for the network to recognize incoming data accurately. Information loss and speed reduction result. One solution is to place a special holographic filter on the transmitter; the filter multiplies each encoded beam into many identical copies in a wide-ranging grid pattern that fills the entire room. A similar holographic "fly-eye" filter (*lower right*) on the receiver funnels signals from various sectors into separate sensors on the active area of the photodiode, which makes it easy to verify one beam-borne data stream against another.

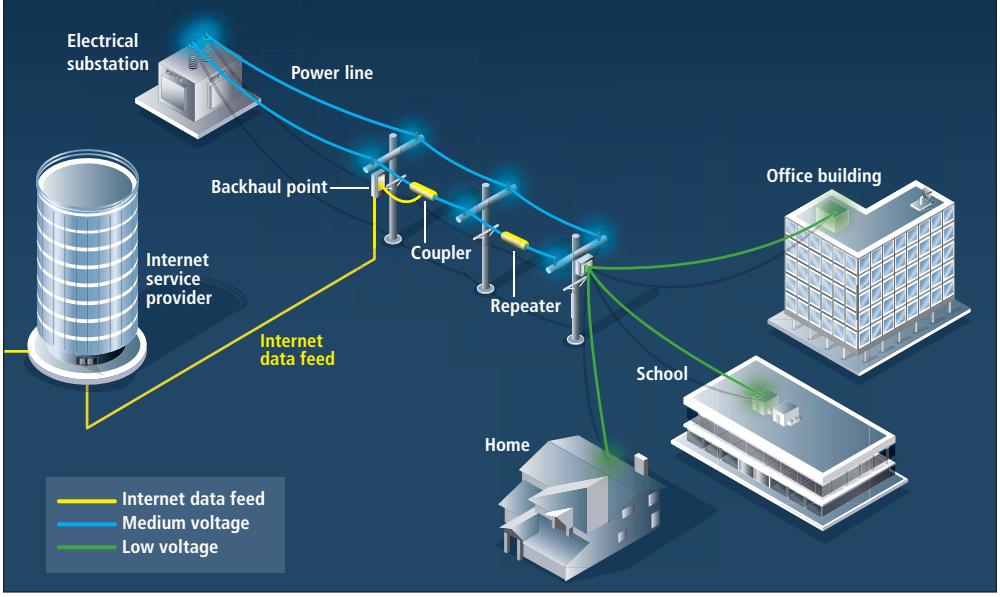


DEPARTMENT OF PUBLIC INFORMATION, PENNSYLVANIA STATE UNIVERSITY (*Kavehrad*); SW INFOGRAPHICS (*illustration*)

[THE NEXT STEP]

BROADBAND VIA THE WALL PLUG

Optical wireless becomes more practical if the broadband data travel the "last mile" over electric power lines, via a new technology that can deliver data at rates between 500 and 50,000 kilobits per second—equivalent to the performance of DSL or cable. An Internet service provider feeds high-speed data to a backhaul point, a gateway to the local medium-voltage grid. Afterward, a coupler injects the data signal into the electric current flowing in the power line. Repeaters amplify the data at various points as the current makes its way to customers. Inexpensive "broadband over power lines" modems plugged into wall sockets in homes, schools and offices then convert the electrical signals into a form suitable for digital devices.



over power lines (BoPL) technology, which sends high-speed data over medium- or low-voltage electric power grids to room wall sockets [*see box above*]. BoPL exploits the existing power network to piggyback broadband information on the same wires that bring electricity to consumers [see "The Network in Every Room," by W. Wayt Gibbs; SCIENTIFIC AMERICAN, February 2002]. Utilities in Ohio, Texas, and elsewhere in the U.S. already offer BoPL service to consumers at rates comparable to that of DSL. And many users receive Internet services via BoPL in Europe and Asia (in Spain, Sweden, Norway, the Netherlands, South Korea and Japan, for instance), where the grid architecture makes it easier to adapt the existing power grid technology for this purpose. The optical wireless application of this broadband "bridge" emerges when users plug into electrical wall sockets small, inexpensive adapters that can deliver data via embedded infrared transmitters to any digital device in the room equipped with an optical receiver. In buildings illuminated by white LEDs, adapters would not be necessary.

My research team has shown that a white LED system for lighting and high-data-rate wireless communications, coupled with BoPL technology, could provide data-transmission capacities as high as a gigabit (a billion bits) per second, which surpasses those offered by conventional DSL (two to four megabits, or millions of bits, per second at the maximum) or cable (about 50 megabits per second on average). This maximum rate is limited only by optical path differences within a room of a particular shape and size, which can contribute to signal distortions. Multiple receptions of the same message, if not properly processed, cause such problems. If engineers design a system appropriately, however, they can keep this distortion to acceptable levels or even exploit the multiple copies to provide a better quality of delivery of broadband service to the end users.

Whether their system uses infrared or visible light, operators of wireless digital devices indoors will soon have a new way to ride the broadband wave into the future. Optical wireless technology is well equipped to be the bridge that can bring this digital access across the last few feet to where we live and work. ■

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SW INFOGRAPHICS

Should SCIENCE Speak to FAITH?

By Lawrence M. Krauss and Richard Dawkins

Two prominent defenders of science exchange their views on how scientists ought to approach religion and its followers

[THE AUTHOR]

Lawrence M. Krauss is Ambrose Swasey Professor and director of the Center for Education and Research in Cosmology and Astrophysics at Case Western Reserve University. Author of seven popular books and dozens of commentaries for national publications, radio and television, he also lectures widely on science and public policy. Among his many scientific honors, he has the unique distinction of having received the highest awards from all three U.S. physics societies. In his spare time, he has performed *The Planets* with the Cleveland Orchestra, served as a Sundance Film Festival judge and written four articles for *Scientific American*.

EDITORS' INTRODUCTION

Although the authors are both on the side of science, they have not always agreed about the best ways to oppose religiously motivated threats to scientific practice or instruction. Krauss, a leading physicist, frequently steps into the public spotlight to argue in favor of retaining evolutionary theory in school science curricula and keeping pseudoscientific variants of creationism out of them. An open letter he sent to Pope Benedict XVI in 2005, urging the pontiff not to build new walls between science and faith, led the Vatican to reaffirm the Catholic Church's acceptance of natural selection as a valid scientific theory.

Dawkins, an evolutionary biologist, prolific author and lecturer, is also an eloquent critic of any attempt to undermine scientific reasoning. He has generally shown less interest than Krauss, however, in achieving a peaceful coexistence between science and faith. The title of Dawkins's best-selling book *The God Delusion* perhaps best summarizes his opinion of religious belief.

These two allies compared notes from the front lines during breaks at a conference devoted to discussing clashes between science and religion held at the Salk Institute for Biological Studies in San Diego late last year. In a dialogue they re-create here, the authors explained their respective tactics for engaging the enemy and tackled some of the questions that face all scientists when deciding whether and how to talk to the faithful about science: Is the goal to teach science or to discredit religion? Can the two worldviews ever enrich one another? Is religion inherently bad? In an extended version of their conversation available at www.SciAm.com/ontheweb, the authors also delve into whether science can ever test the "God Hypothesis."

Krauss: Both you and I have devoted a substantial fraction of our time to trying to get people excited about science, while also attempting to explain the bases of our current respective scientific understandings of the universe. So it seems appropriate to ask what the primary goals of a scientist should be when talking or writing about religion. I wonder which is more important: using the contrast between science and religion to teach about science or trying to put religion in its place? I suspect that I want to concentrate more on the first issue, and you want to concentrate more on the second.

I say this because if one is looking to teach people, then it seems clear to me that one needs to reach out to them, to understand where they are coming from, if one is going to seduce them into thinking about science. I often tell teachers,

MATT COLLINS (*illustrations*); JOHN BOSWELL (*photograph*)

for example, that the biggest mistake any of them can make is to assume that their students are interested in what they are about to say. Teaching *is* seduction. Telling people, on the other hand, that their deepest beliefs are simply silly—even if they *are*—and that they should therefore listen to us to learn the truth ultimately defeats subsequent pedagogy. Having said that, if instead the primary purpose in discussing this subject is to put religion in its proper context, then perhaps it is useful to shock people into questioning their beliefs.

Dawkins: The fact that I think religion is bad science, whereas you think it is ancillary to science, is bound to bias us in at least slightly different directions. I agree with you that teaching is seduction, and it could well be bad strategy to alienate your audience before you even start. Maybe I could improve my seduction technique. But nobody admires a dishonest seducer, and I wonder how far you are prepared to go in "reaching out." Presumably you wouldn't reach out to a Flat Earther. Nor, perhaps, to a Young Earth Creationist who thinks the entire universe began after the Middle Stone Age. But perhaps you would reach out to an Old Earth Creationist who thinks God started the whole thing off and then intervened from time to time to help evolution over the difficult jumps. The difference between us is quantitative, only. You are prepared to reach out a little further than I am, but I suspect not all that much further.

Krauss: Let me make clearer what I mean by reaching out. I do not mean capitulating to misconceptions but rather finding a seductive way to demonstrate to people that these are indeed misconceptions. Let me give you one example. I have, on occasion, debated both creationists and alien abduction zealots. Both groups have similar misconceptions about the nature of explanation: they feel that unless you understand everything, you understand nothing. In debates, they pick some obscure claim, say, that in 1962 some set of people in Outer Mongolia all saw a flying saucer hovering above a church. Then they ask if I am familiar with this particular episode, and if I say no, they invariably say, "If you have not studied every such episode, then you cannot argue that alien abduction is unlikely to be happening."

I have found that I can get each group to think about what they are saying by using the other group as a foil. Namely, of the creationists I ask, "Do you believe in flying saucers?" They inevitably say "no." Then I ask, "Why? Have you studied all of the claims?" Similarly, to the alien abduction people I ask, "Do you believe in Young Earth Creationism?" and they say "no," wanting to appear scientific. Then I ask, "Why? Have you studied every single counterclaim?" The point I try to make for each group is that it is quite sensible to base theoretical expectations on a huge quantity of existing evidence, without having studied absolutely every single obscure counterclaim. This "teaching" technique has worked in most cases, except those rare times when it has turned out that I was debating an alien abduction believer who was also a creationist!

Dawkins: I like your clarification of what you mean by reaching out. But let me warn you of how easy it is to be misunderstood. I once wrote in a *New York Times* book review, "It is absolutely safe to say that if you meet somebody who claims not to believe in evolution, that person is ignorant, stupid or insane (or wicked, but I'd rather not consider that)." That sentence has been quoted again and again in support of the view that I am a bigoted, intolerant, closed-minded, intemperate ranter. But just look at my sentence. It may not be crafted to seduce, but you, Lawrence, know in your heart that it is a simple and sober statement of fact.

Ignorance is no crime. To call somebody ignorant is no insult. All of us are ignorant of most of what there is to know. I am completely ignorant of baseball, and I dare say that you are as completely ignorant of cricket. If I tell somebody who believes the world is 6,000 years old that he is ignorant, I am paying him the compliment of assuming that he is not stupid, insane or wicked.

Krauss: I have to say that I agree completely with you about this. To me, ignorance is often the problem, and, happily, ignorance is most easily addressed. It is not pejorative to suggest that someone is ignorant if they misunderstand scientific issues.

Dawkins: In exchange, I am happy to agree with you that I could, and probably should, have put it more tactfully. I should have reached out more seductively. But there are limits. You would stop short of the following extreme:

[THE AUTHOR]

JOHN BOSWELL

Richard Dawkins is Charles Simonyi Professor of the Public Understanding of Science at the University of Oxford. His nine books have earned him honorary doctorates in literature and science, and he is a Fellow of both the Royal Society and the Royal Society of Literature. His many prizes include the Cosmos International Prize, the Nakayama Prize for Human Science and the Shakespeare Prize for Distinguished Contributions to British Culture. In 2006 he created the Richard Dawkins Foundation for Reason and Science. New British school guidelines encourage students to play the roles of such figures as Galileo, Darwin and Dawkins while debating science and creationism.

"Dear Young Earth Creationist, I deeply respect your belief that the world is 6,000 years old. Nevertheless, I humbly and gently suggest that if you were to read a book on geology, or radioisotope dating, or cosmology, or archaeology, or history, or zoology, you might find it fascinating (along with the Bible of course), and you might begin to see why almost all educated people, including theologians, think the world's age is measured in billions of years, not thousands."

Let me propose an alternative seduction strategy. Instead of pretending to respect dopey opinions, how about a little tough love? Dramatize to the Young Earth Creationist the sheer magnitude of the discrepancy between his beliefs and those of scientists: "6,000 years is not just a little bit different from 4.6 billion years. It is so different that, dear Young Earth Creationist, it is as though you were to claim that the distance from New York to San Francisco is not 3,400 miles but 7.8 yards. Of course, I respect your right to disagree with scientists, but perhaps it wouldn't hurt and offend you too much to be told—as a matter of deductive and indisputable arithmetic—the actual magnitude of the disagreement you've taken on."

Krauss: I don't think your suggestion is "tough love." In fact, it is precisely what I was advocating, namely, a creative and seductive way of driving home the magnitude and nature of such misconceptions. Some people will always remain deluded, in spite of facts, but surely those are not the ones we are trying to reach. Rather it is the vast bulk of the public who may have open minds about science but simply don't know much about it or have never been exposed to scientific evidence. In this regard, let me pose another question, about which you may feel even more strongly: Can science enrich faith, or must it always destroy it?

The question came to me because I was recently asked to speak at a Catholic college at a symposium on science and religion. I guess I was viewed as someone interested in reconciling the two. After agreeing to lecture, I discovered that I had been assigned the title Science Enriching Faith. In spite of my initial qualms, the more I thought about the title, the more rationale I could see for it. The need to believe in a divine intelligence without direct evidence is, for better or worse, a fundamental component of many people's psyches. I do not think we will rid humanity of religious faith any more than we will rid humanity of romantic love or many of the irrational but fundamental aspects of human cognition. While orthogonal from the scientific rational components, they are no less real and perhaps no less worthy of some celebration when we consider our humanity.

BATTLEGROUND OF BELIEFS

In a 2005 survey of U.S. National Science Teachers Association members:

- 30% said they felt pressure to omit evolution from their lessons
- 31% said they felt pressure to include nonscientific alternatives to evolution in their classes

In the 2006 Baylor Religion Survey of 1,721 U.S. adults:

- 69% thought prayer should be allowed in schools
- 25% thought some UFO sightings are probably spaceships from other worlds
- 88% rejected the idea that God favors any particular political party
- 69% rejected the idea that God favors the U.S. in worldly affairs

In a 2007 *Newsweek* poll of 1,004 U.S. adults:

- 48% thought that God created humans in their present form in the past 10,000 years
- 30% thought that humans evolved from simpler life-forms, with God guiding the process
- 48% thought the theory of evolution is well supported by evidence, but 39% thought the theory is not well supported.

Dawkins: As an aside, such pessimism about humanity is popular among rationalists to the point of outright masochism. It is almost as though you and others at the conference where this dialogue began positively relish the idea that humanity is perpetually doomed to unreason. But I think irrationality has nothing to do with romantic love or poetry or the emotions that lie so close to what makes life worth living. Those are not orthogonal to rationality. Perhaps they are tangential to it. In any case, I am all for them, as are you. Positively irrational beliefs and superstitions are a different matter entirely. To accept that we can never be rid of them—that they are an irrevocable part of human nature—is manifestly untrue of you and, I would guess, most of your colleagues and friends. Isn't it therefore rather condescending to assume that humans at large are constitutionally incapable of breaking free of them?

Krauss: I am not so confident that I am rid of irrational beliefs, at least irrational beliefs about myself. But if religious faith is a central part of the life experience of many people, the question, it seems to me, is not how we can rid the world of God but to what extent can science at least moderate this belief and cut out the most irrational and harmful aspects of religious fundamentalism. That is certainly one way science might enrich faith.

In my lecture to the Catholic group, for instance, I took guidance from your latest book and described how scientific principles, including the requirement not to be selective in choosing data, dictate that one cannot pick and choose in one's fundamentalism. If one believes that homosexuality is an abomination because it says so in the Bible, one has to accept the other things that are said in the Bible, including the allowance to kill your children if they are disobedient or validation of the right to sleep with your father if you need to have a child and there are no other men around, and so forth.

Moreover, science can directly debunk many such destructive literal interpretations of scripture, including, for example, the notion that women are simple chattels, which stands counter to what biology tells us about the generic bi-

ological roles of females and the intellectual capabilities of women and men in particular. In the same sense that Galileo argued, when he suggested that God would not have given humans brains if "he" did not intend people to use them to study nature, science definitely can thus enrich faith.

Still another benefit science has to offer was presented most cogently by Carl Sagan, who, like you and me, was not a person of faith. Nevertheless, in a posthumous compilation of his 1985 Gifford Lectures in Scotland on science and religion, he makes the point that standard religious wonder is in fact too myopic, too limited. A single world is too puny for a real God. The vast scope of our universe, revealed to us by science, is far grander. Moreover, one might now add, in light of the current vogue in theoretical physics, that a single universe may be too puny and that one might want to start thinking in terms of a host of universes. I hasten to add, however, that enriching faith is far different than providing supporting evidence for faith, which is something that I believe science certainly does not do.

Dawkins: Yes, I love that sentiment of Sagan's, and I'm so glad you picked it out. I summed it up for the publishers of those lectures on the book jacket: "Was Carl Sagan a religious man? He was so much more. He left behind the petty, parochial, medieval world of the conventionally religious; left the theologians, priests and mullahs wallowing in their small-minded spiritual poverty. He left them behind, because he had so much more to be religious about. They have their Bronze Age myths, medieval superstitions and childish wishful thinking. He had the universe." I don't think there is anything I can add in answering your question about whether science can enrich faith. It can, in the sense you and Sagan mean. But I'd hate to be misunderstood as endorsing faith.

Krauss: I want to close with an issue that I think is central to much of the current debate going on among scientists regarding religion: Is religion inherently bad? I confess here that my own views have evolved over the years, although you might argue that I have simply gone soft. There is certainly ample evidence that religion has been responsible for many atrocities, and I have often said, as have you, that no one would fly planes into tall buildings on purpose if it were not for a belief that God was on their side.

"Enriching faith is far different than providing supporting evidence for faith."

—*L.M.K.*

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Lawrence M. Krauss's home page: www.phys.cwru.edu/~krauss/

As a scientist, I feel that my role is to object when religious belief causes people to teach lies about the world. In this regard, I would argue that one should respect religious sensibilities no more or less than any other metaphysical inclinations, but in particular they should not be respected when they are wrong. By wrong, I mean beliefs that are manifestly in disagreement with empirical evidence. The earth is not 6,000 years old. The sun did not stand still in the sky. The Kennewick Man was not a Umatilla Indian. What we need to try to eradicate is not religious belief, or faith, it is ignorance. Only when faith is threatened by knowledge does it become the enemy.

Dawkins: I think we pretty much agree here. And although "lie" is too strong a word because it implies intention to deceive, I am not one of those who elevate moral arguments above the question of whether religious beliefs are true. I recently had a televised encounter with the veteran British politician Tony Benn, a former minister of technology who calls himself a Christian. It became very clear in the course of our discussion that he had not the slightest interest in whether Christian beliefs are true or not; his only concern was whether they are moral. He objected to science on the grounds that it gave no moral guidance. When I protested that moral guidance is not what science is about, he came close to asking what, then, was the use of science. A classic example of a syndrome the philosopher Daniel Dennett has called "belief in belief."

Other examples include those people who think that whether religious beliefs are true or false is less important than the power of religion to comfort and to give a purpose to life. I imagine you would agree with me that we have no objection to people drawing comfort from wherever they choose and no objection to strong moral compasses. But the question of the moral or consolation value of religion—one way or the other—must be kept separate in our minds from the truth value of religion. I regularly encounter difficulties in persuading religious people of this distinction, which suggests to me that we scientific seducers have an uphill struggle on our hands. ■

The conversation between Lawrence M. Krauss and Richard Dawkins continues in an extended version at **www.SciAm.com/ontheweb**

A Little Privacy, Please

Computer scientist Latanya Sweeney helps to save confidentiality with "anonymizing" programs, "deidentifiers" and other clever algorithms. Whether they are enough, however, is another question BY CHIP WALTER

Latanya Sweeney attracts a lot of attention. It could be because of her deep affection for esoteric and cunning mathematics. Or maybe it is the black leather outfit she wears while riding her Honda VTX 1300 motorcycle around the sedate campus of Carnegie Mellon University, where she directs the Laboratory for International Data Privacy. Whatever the case, Sweeney suspects the attention helps to explain her fascination with protecting people's privacy. Because at the heart of her work lies a nagging question: Is it possible to maintain privacy, freedom and safety in today's security-centric, databased world where identities sit ripe for the plucking?

Several years ago Scott McNealy, chairman of Sun Microsystems, famously quipped, "Privacy is dead. Get over it." Sweeney couldn't disagree more. "Privacy is definitely not dead," she counters; those who believe it is "haven't actually thought the problem through, or they aren't willing to accept the solution."

Certainly privacy is under siege, and that, she says, is bad. Debates rage over the Patriot Act and data mining at the federal level, and states have a hodgepodge of reactive laws that swing between ensuring privacy and increasing security. Although identity theft began a slow decline in 2002, one recent study revealed that 8.4 million U.S. adults still suffered some form of identity fraud in 2006. "The problem grows as technologies explode," Sweeney says, and every problem requires a different solution, which is another way of saying that it is impossible to predict where new forms of privacy invasion will arise.

All this has kept Sweeney and her team busy the past six years wrestling some of today's thorniest confidentiality issues to the mat—identity theft, medical privacy and the rapid expansion of camera surveillance among them. Other academic labs tend to attack issues at a theoretical level; the 47-year-old Sweeney states that her group operates as a kind of digital detective agency staffed with a dedicated squad of programmers devising some seriously clever software. The researchers' approach is to technically fillet systems and then suggest ingenious but pragmatic solutions.

For example, Sweeney's Identity Angel program scours the Internet and quickly gathers thousands of identities by linking names in one database with addresses, ages and Social Security numbers scattered throughout others. Those four pieces of information are all anyone needs to

LISA KYLE

LATANYA SWEENEY

PRIVACY IS NOT DEAD: Runs the Data Privacy Laboratory at Carnegie Mellon University, which develops software to maintain privacy.

ATTENTION, ENGINEERS: Advocates that new technology be designed with privacy in mind: "If the technology is built without controls, it forces us to either accept the benefits of the technology without controls or cripple it by adding them later."

HER RIDE: A V2 engine on two wheels.

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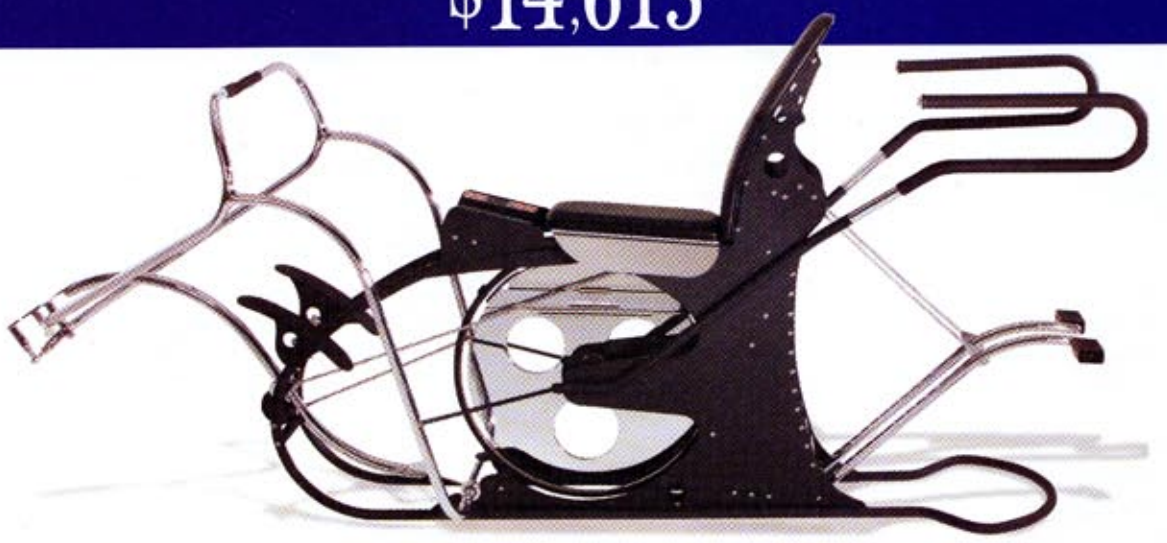

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3. Reading the ROM literature and reluctantly understanding it.
4. Taking a leap of faith and renting a ROM for 30 days.
5. Being highly impressed by the results and purchasing a ROM.
6. Becoming a ROM enthusiast and trying to persuade friends.
7. Being ignored and ridiculed by the friends who think you've lost your mind.
8. After a year of using the ROM your friends admiring your good shape.
9. You telling them (again) that you only exercise those 4 minutes per day.
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snatch an identity and open a credit-card account. The lab routinely alerts vulnerable people so they can fix the problem.

Another program "anonymizes" identities. It was originally developed for the Department of Defense after the 9/11 attacks to help locate potential terrorists while still protecting the privacy of innocent citizens. The program prevents surveillance cameras from revealing an identity until authorities show they need the images to prosecute a crime. Unlike other software, the program does not pixelate or black out an individual's features but actually fabricates a new facial image from other faces in the database, making it impossible for humans or machines to identify.

The clever algorithms at the heart of Sweeney's lab go back to her days growing up in Nashville, when she would daydream about ways to create an artificially intelligent black box that she could talk to. "I spent hours fantasizing about that box," she recalls. Ten years later she parlayed her talent for mathematics and early fascination with artificial intelligence into scholarships that helped to pay her way to the Massachusetts Institute of Technology, a bastion in both fields. It would have seemed the perfect place to pursue her grade school dream of creating a smart machine. The problem was that Sweeney had just departed the polite world of a prim New England all-girls high school and was suddenly immersed in M.I.T.'s male-dominated geek culture, a transition that took her off guard. That, coupled with her experiences with a racially insensitive professor whom she never seemed able to please, led Sweeney to drop out and start up her own software consulting business.

"DEIDENTIFIER" melds two real faces (*left*) to create an unidentifiable composite (*right*) in surveillance footage. The actual face would be revealed only if authorities had cause.

CARNEGIE MELLON DATA PRIVACY LAB

After a decade in the business world, Sweeney returned to college, completing her undergraduate degree at Harvard University. She then earned her master's and doctorate in computer science at M.I.T., the first African-American woman to do so. "When I came back, I told them I didn't plan on taking any more crap," she laughs.

It was on her return to M.I.T. that Sweeney first fell into the orbits of privacy and security. She had won a fellowship at the National Library of Medicine, and to show her appreciation, she volunteered to help several Boston hospitals improve protec-

tion of their medical records, a concern that was surfacing as the Internet ballooned in the mid-1990s. Sweeney wrote a program called Scrub System that tapped her expertise in artificial intelligence to ingeniously search patient records, treatment notes and letters between physicians. Standard search-and-replace software had generally found 30 to 60 percent of personal, identifying information. Scrub System "understands" what constitutes a name, address or phone number and eliminates 99 to 100 percent of the revealing data.

The software won accolades from medical associations. "Her research was highly influential," says Betsy Humphreys, deputy director of the National Library of Medicine. "A lot of people didn't see how different life was [in the Internet age].... Latanya's work raised their awareness." With Scrub System, "I thought I had solved the privacy problem," Sweeney says sheepishly. But the truth was, "I really didn't understand a thing about privacy."

This realization hit home when one day she reviewed the medical history of a young woman. "At age two this girl was sexually molested, at age three she stabbed her sister with scissors, at four her parents got divorced, at five she set fire to her home," Sweeney recounts. Clearly, "removing the explicit identifiers wasn't what [privacy] was about." It was about the bread crumbs of information we leave behind in records strewn all over the Internet—in medical forms, credit applications, resumes and other documents. Nothing specifically identified the girl in the report, but the scraps of information were unique, and Sweeney was pretty sure she could use them to reidentify her—and almost anyone else.

Programs such as Identity Angel have proved Sweeney correct, and she has spent plenty of time finding ways to invade privacy, sometimes getting the jump on the bad guys, sometimes not. She tells the story of a banker indicted in Maryland who cross-referenced information in publicly available hospital discharge records with his own client list to see if any of his clients had cancer. If they did, he called in their loans. In a project using data from the state of Illinois, Sweeney's lab found a way to reidentify patients with Huntington's disease even after all information about the patients had been deleted from their records. Huntington's is caused by the repetition of a short sequence of DNA. The more this sequence repeats, the earlier the age of onset. Sweeney's lab combined those data with hospital discharge records, which included patients' ages, to accurately link 90 percent of the Huntington's patients with DNA records on file. Abuses may be rare, Sweeney admits, but both cases show how ugly things can get if one database is used to leverage the information in another.

The real solution, Sweeney says, does not lie in her lab or in any other. Ultimately engineers and computer scientists will have to weave privacy protection into the design and usability of their new technologies, up front. If they do, "society can [then] decide how to turn those controls on and off," Sweeney remarks. Otherwise we might all need to ride a motorcycle to get a few private moments. ■

Chip Walter is author of Thumbs, Toes, and Tears: And Other Traits That Make Us Human *(Walker & Company, 2006). A Q&A version of his interview with Sweeney is at* **www.SciAm.com/ontheweb**

In or Out?

By Mark Fischetti

A new participant has taken center court at major tennis tournaments: Hawkeye, a tracking system that sees whether a ball lands inside, outside or partly on a line.

Hawkeye's 10 video cameras feed 24 gigabytes of data to video-processing software that tracks the real-time position of every serve and shot. Television broadcasters began using the system in 2002 to enhance commentary. In March 2006 the NASDAQ-100 Open became the first tournament on the professional circuit to allow players to challenge an umpire's line call, with the final decision settled by a review official after consulting Hawkeye.

This year all Grand Slam and Masters tournaments not played on clay are using this arrangement. Each player is allowed two challenges per set of play. Some stadiums show a computer-generated replay from Hawkeye during an umpire's review, engaging the crowd. Thus far Hawkeye has overturned 33 to 40 percent of challenged calls, according to Paul Hawkins, who invented the system and founded Hawkeye Innovations in Winchester, England.

Hawkins, an engineer with a doctorate in artificial intelligence who specializes in visual processing, first developed the system for cricket. TV commentators use it to analyze pitches toward the batsman. But cricket organizations have not adopted the system for challenges. "It's a cultural issue," Hawkins says, adding that Major League Baseball also has not shown interest because a home-plate umpire's calling of balls and strikes is so central to the game.

Many top tennis players say they like Hawkeye because it makes calls more accurate. Umpires say it takes a little pressure off them as serves and other shots get faster and faster. Fans seem to like the drama that challenges create. Setup and operation of Hawkeye can run from $40,000 to $50,000 a week per court, but stadium owners are attracting companies such as Canon and Sony to sponsor the amenity.

With a few adjustments, Hawkeye could call every shot live, eliminating line umpires altogether by sounding a tone when a ball lands out of bounds. "But no one is asking for that because they are concerned it would make the game too sterile," Hawkins says. "As a sports fan, I would have to say it would be bad for the game. At the moment, we have a nice balance between the human and the technical." ■

BALL POSITION
Cameras are installed at 10 positions around a court. Each one monitors half the court and sends video to its own computer in a control booth. Four more computers there combine the information streams.

SINGLE FRAME
Each camera's computer determines the two-dimensional position of a ball in a single frame.

DID YOU KNOW...

CYCLOPS: Certain tournaments have used the Cyclops system to determine if a served ball lands beyond the service line. A small unit resting on the side of a court sends infrared beams across the service line to a receiver on the opposite side. If the ball breaks the beams, Cyclops sounds a tone indicating the serve was long. Hawkeye, which monitors all lines, is taking over this function at major events. "Cyclops was a great piece of technology," inventor Paul Hawkins says, "but it has come to the end of its life cycle."

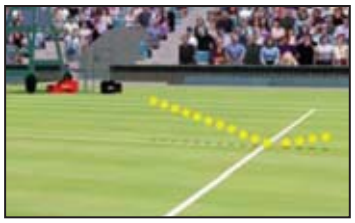
CLAY: Hawkeye has been installed on grass and hard courts. Organizers of clay tournaments have passed because they say the ball leaves a clear mark umpires can examine. But independent tests show that the ball mark can be larger than the compressed ball's footprint because a forceful impact can displace surrounding clay particles.

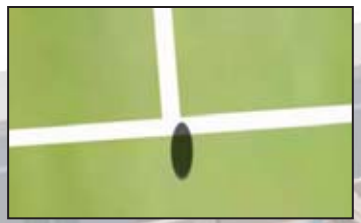
ADVANTAGE: Broadcasters sometimes brand Hawkeye with their own labels: ESPN, for example, calls it ShotSpot. A Toronto firm markets a competing camera-based system called Auto-Ref that has not received much attention. All kinds of innovations in tennis technology are reviewed at the International Tennis Federation's annual International Congress on Tennis Science and Technology, held this year in London in September.

5W INFOGRAPHICS (*main illustration*); HAWKEYE INNOVATIONS (*insets*)

TRAJECTORY

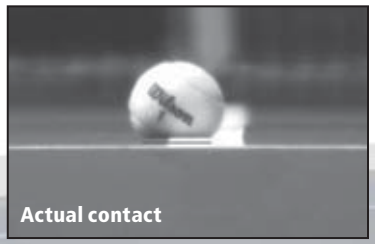
Machine-vision software combines the references from single frames (*bottom of opposite page*) to determine the ball's three-dimensional position. Computers process frame positions through time to track the ball's trajectory and determine where it contacts the court.





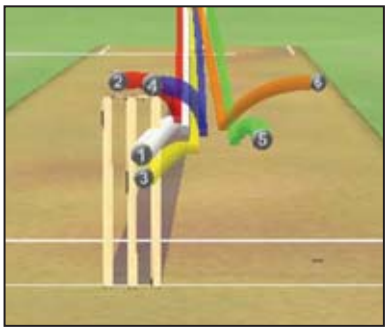
BALL MARK

Whether a ball touches a line depends on how it compresses. High-speed cameras show that for a typical cross-court shot, 44 millimeters of a ball contact the ground. But the ball leaves a mark only 35 millimeters wide, because its outside edge does not touch forcefully enough to scuff the surface. For years, umpires have looked for ball marks to help decide close calls; Hawk-eye calculates actual compression.



CRICKET

Television commentators use Hawkeye to show the position of a bowler's pitches (*all*), as well as whether balls hit by the batsman would have struck the wicket (*1, 3*).



SEND IDEAS *to workingknowledge@SciAm.com*
Topic suggested by readers Stan Gedrich and Gordon Wood.

Justifying Mistakes ▪ Getting Better ▪ Tracking the Anasazi

BY MICHELLE PRESS

BETTER: A SURGEON'S NOTES ON PERFORMANCE

by Atul Gawande. Henry Holt, 2007 ($24)

Gawande is a Boston-area surgeon, a staff writer for the *New Yorker* and a MacArthur Fellow. His first book, *Complications: A Surgeon's Notes on an Imperfect Science,* was a finalist for the 2002 National Book Award. In this collection of 12 original and previously published essays adapted from the *New England Journal of Medicine* and the *New Yorker,* Gawande focuses on performance. "What does it take to be good at something?" he asks. In response, he gives three core requirements for success in medicine or any field that involves risk and responsibility: diligence, ingenuity and "doing right." He illustrates each of these qualities with dramatic stories, from hand washing in hospitals to inoculating four million Indian children against polio. (Gawande is master of the telling anecdote—no small thing.) He concludes that it is the human qualities that are most important: monitoring and improving clinical performance would do more to save lives than advances in laboratory knowledge.

MISTAKES WERE MADE (BUT NOT BY *ME*): WHY WE JUSTIFY FOOLISH BELIEFS, BAD DECISIONS, AND HURTFUL ACTS

by Carol Tavris and Elliot Aronson. Harcourt, 2007 ($25)

Social psychologists Tavris and Aronson answer the question they pose in the title by examining cognitive dissonance, "the hardwired psychological mechanism that creates self-justification and protects our certainties, self-esteem, and tribal affiliations." They elaborate on how self-justification can increase prejudice, distort memory, perpetuate injustice, warp love. And they go on to give the "good news": understanding how this mechanism works is the first step toward finding solutions that will defeat the wiring. The goal is to become aware of the two dissonant cognitions that are causing distress and to find a way to resolve them or learn to live with them. They quote as an example then prime minister of Israel Shimon Peres, who, when Ronald Reagan did something that disappointed him, said: "When a friend makes a mistake, the friend remains a friend, and the mistake remains a mistake."

EXCERPT

HOUSE OF RAIN: TRACKING A VANISHED CIVILIZATION ACROSS THE AMERICAN SOUTHWEST

by Craig Childs. Little, Brown & Company, 2006 ($24.99)

Childs, a naturalist and writer, draws on scholarly research and his own years of exploration in the Southwest to trace the disappearance of the Anasazi, the native people who in the 11th century built a flourishing cultural center in what is now New Mexico that vanished abruptly two centuries later. He writes passionately about his search:

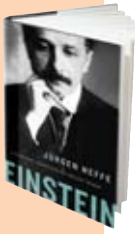
"At first I saw only a high stack of rocks, obviously set by someone's hand into a crack. As I looked closer, I began to see the concealed outline of a tidy masonry structure that had been tucked behind a leaning flake of cliff....

"I immediately started for it, climbing hand over hand up the cliff base.... I had found a secret. In past travels I had seen many [such storerooms] belonging to the Anasazi, but they had all been broken open, emptied by archaeologists, by pot-hunters, by erosion, or even, perhaps, by the residents themselves returning many centuries later....

"This was no casual find. I had been looking for this for a long time, traveling untrailed desert for most of my adult life, poking into canyons and caves hoping to find intact signs of people here long before me. Their presence gave context to my brief life, to my civilization."

SALADO POT from the 14th century

NEW AND NOTABLE BIOGRAPHIES



1 **Einstein: A Biography**
by Jürgen Neffe, translated by Shelley Frisch. Farrar, Straus and Giroux, 2007 ($30)

2 **Einstein on Politics: His Private Thoughts and Public Stands on Nationalism, Zionism, War, Peace, and the Bomb**
edited by David E. Rowe and Robert Schulmann. Princeton University Press, 2007 ($29.95)

3 **Einstein: His Life and Universe**
by Walter Isaacson. Simon and Schuster, 2007 ($32)

4 **Aldo Leopold's Odyssey: Rediscovering the Author of a Sand Country Almanac**
by Julianne Lutz Newton. Island Press, 2006 ($35)

5 **The Gentle Subversive: Rachel Carson, *Silent Spring,* and the Rise of the Environmental Movement**
by Mark H. Lytle. Oxford University Press, 2007 ($20)

6 **The Man Who Stopped Time: The Illuminating Story of Eadweard Muybridge—Pioneer Photographer, Father of the Motion Picture, Murderer**
by Brian Clegg. Joseph Henry Press, 2007 ($27.95)

7 **Brilliant!: Shuji Nakamura and the Revolution in Lighting Technology**
by Bob Johnstone. Prometheus Books, 2007 ($28)

8 **The Death of Sigmund Freud: The Legacy of His Last Days**
by Mark Edmundson. Bloomsbury, 2007 ($25.95)

9 **Freud's Wizard: Ernest Jones and the Transformation of Psychoanalysis**
by Brenda Maddox. Da Capo Press, 2007 ($26)

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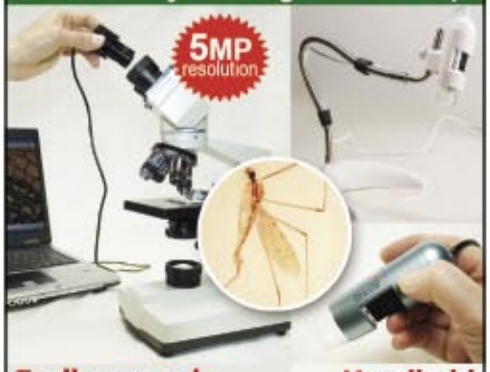

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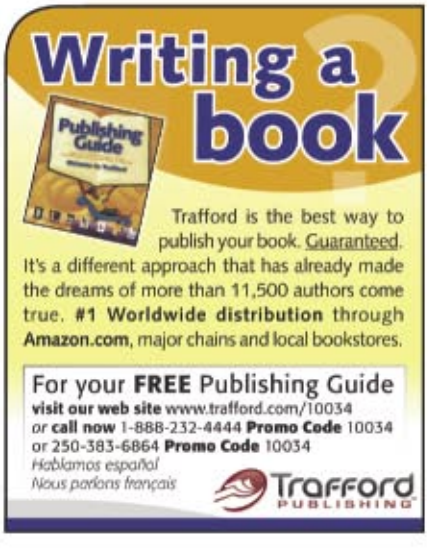

Q *Why do the* ***ice cubes*** *in my freezer often develop* ***stalagmitelike*** *spikes?*

Stephen Morris, a professor of experimental nonlinear physics at the University of Toronto, explains:

Water is one of those rare materials that expand while they freeze. If a crust of ice with a small hole in it forms over liquid water, the crust can trap the liquid below, leaving it no room to expand. So as the water begins to solidify, it is forced up through the hole and starts to freeze around the edge, forming a hollow, water-filled "ice spike."

Water keeps moving up the spike—creating a little self-made chimney, which can grow quite long and thin. Eventually all the water freezes and the spike becomes solid. The energy needed to lift the water up into the spike comes entirely from its expansion during freezing.

Some features that govern the way water crystallizes play important roles in the spike formation process. The form of the ice crystals depends on the cooling rate and therefore on the air temperature. Spikes typically form when the ambient air is well below zero degrees Celsius, allowing for rapid freezing—an air temperature of about –7 degrees C (roughly 20 degrees Fahrenheit) turns out to be optimal.

Fast cooling favors the formation of sheetlike crystals, which quickly cover the surface. Some sheets hang down into the water like curtains; these crystallites tend to join to one another at 60-degree angles, much like the arms of a snowflake do. They typically leave triangular holes in the surface; hence, spikes often have a triangular base. The sides of the spike are sometimes a continuation of preexisting crystallites below the surface of the freezing water, which explains why some spikes can extend from the surface at steep angles. It is also possible to get structures that look like little inverted pyramids, or "ice vases," if the water happens to drain out before completely freezing.

Pure water works best for spike formation, as does a container with vertical sides, such as the ice tray in your freezer. People often see spikes in birdbaths or pet drinking dishes that are left outside overnight, and they can sometimes form on falling sleet pellets. But it is rather rare for them to form elsewhere in nature—on the surface of lakes or ponds, for instance—because usually the cooling rate of natural bodies of water is not fast enough.

Q *Does* ***sleeping*** *after a meal lead to* ***weight gain****?*

Jeremy Barnes, a professor of health promotion at Southeast Missouri State University, offers this answer:

Although it is difficult to provide a definitive answer without knowing all the aspects of an individual's lifestyle and genetics, it is true that going for a brisk walk rather than, say, taking an afternoon nap will burn more calories.

Sleeping itself, however, is not the cause of weight gain. The real key to weight control is energy balance (the balance between calorie, or energy, intake and expenditure) over extended periods. When energy intake is greater than energy expenditure, the body will store excess energy as fat, regardless of whether those extra calories came from fat, carbohydrate, protein or even alcohol. Unfortunately, in the U.S. many people consume more energy than their body is using, which has led to a situation of epidemic proportions where about one third of all adults are now obese and another third are overweight.

Interestingly, a few recent studies indicate that individuals who suffer from sleep deprivation or get only limited amounts of sleep actually may be more susceptible to weight gain than those who get adequate sleep. But this phenomenon seems to be attributable primarily to sleep-triggered changes in the levels of hormones that increase or decrease hunger rather than the amount of sleep itself. ■

KENNETH LIBBRECHT (*left*); IMAGE SOURCE/CORBIS (*right*)

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The New Science of Love with a little wizardry thrown in.

In every great fairy tale, the sorcerers take a little science and throw in a little magic to create the perfect brew that brings two lovers together. Romance is all about chemistry and these seven brilliant stones can add just the right magical fire to raise the temperature of your secret potion. In today's most important design called the "River of Love", this pendant of 2 carats t.w. of graduated Diamond*Aura* stones is the perfect blend of science and sorcery. Our Gemologists have broken the code to create an impeccable stone with even more fire and better clarity than mined diamonds. Of course, the Diamond*Aura* stones are hard enough to cut glass and they are so clear and white that they rival a "D Flawless" diamond in terms of color and clarity. In the laboratory, we have found a way to match the brilliance and stunning reflective qualities of a diamond by using science and thus we avoid the outrageous price.

Perfection from the laboratory. We will not bore you with the details of the ingenious process, but will only say that it involves the use of rare minerals heated to an incredibly high temperature of over 5000°F. This can only be accomplished inside some very modern and expensive laboratory equipment. After cutting and polishing, scientists finally created a faultless marvel that's optically brighter and clearer with more flashes of color. According to the book *Jewelry and Gems–the Buying Guide* the technique used in Diamond*Aura* offers, *"The best diamond simulation to date, and even some jewelers have mistaken these stones for mined diamonds."*

Compare For Yourself at 2 carats		
	Mined Flawless Diamond	Diamond*Aura* Compares to:
Hardness	Cuts Glass	Cuts Glass
Cut (58 facets)	Brilliant	Brilliant
Color	"D" Colorless	"D" Colorless
Clarity	"IF"	"F" Faultless
Dispersion/Fire	0.044	0.066
2 ct tw necklace	$20,000+	$129

The 4 Cs. Our Diamond*Aura* jewelry retains every important specification: color, clarity, cut, and carat weight. In purely scientific measurement terms, ***the fire is actually superior to that of a diamond***. Fire is the dispersion of white light into a rainbow of color. Our team of cutters and polishers artistically performs the symmetrically brilliant, 58-facet cut to maximize the light reflection and refraction.

Buying naturally mined diamonds can be a dangerous journey. Prices are high and often fixed, quality is subjective and the origins of the stones may be in doubt. Do you really want to worry about that or do you just want a look that is spectacular.

The "River of Love" is for that love of a lifetime. If you're looking for the most fire, carat weight, brilliance and clarity for a magnificent price, the 2 carat Diamond*Aura* "River of Love" 7 stone necklace is mounted in 18k gold fused over sterling silver for only $129.00! Just to make the magic more tempting, we will include the .86 total carat weight Diamond*Aura* stud earrings for FREE! If you are not thrilled with the brilliant romance of the Diamond*Aura* "River of Love" necklace, return it within 30 days for a refund of your purchase price and keep the stud earrings as our gift.

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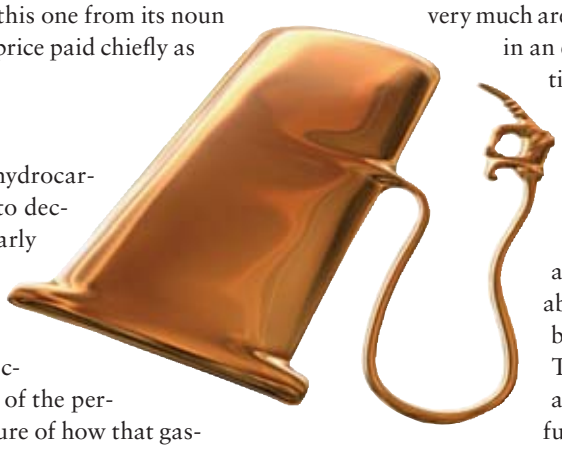
Does Premium Gasoline Deliver Premium Benefits to Your Car?

BY DAVID BIELLO

Premium gasoline must be called "premium" because it is better for your automobile. After all, one of that adjective's definitions is "a high value or a value in excess of that normally or usually expected," according to *Merriam-Webster's Collegiate Dictionary*. But is that common assumption safe? The answer to this question lies in the process of refining gasoline from oil, the dynamics of the typical internal-combustion engine and another definition of "premium"—this one from its noun form: "a sum over and above a regular price paid chiefly as an inducement or incentive."



High Octane, Low Knock

All gasoline is a brew of many different hydrocarbon molecules, ranging from heptane to decane and beyond. The hydrocarbon clearly identified on the pump—and the one many consumers associate with gasoline quality—is octane: eight carbon atoms and 18 hydrogens. The familiar octane number, though, is not a measure of the percentage of octane in the gas but a measure of how that gasoline compares with a pure mixture of octane and heptane. At special laboratories across the globe, chemists concoct such reference fuels and compare gasoline varieties to them in a one-cylinder engine following a standard protocol. "The American Society of Testing and Materials has this thick document on how you determine octane rating with this specialized one-cylinder engine," explains Joseph Shepherd, a mechanical engineer at the California Institute of Technology. "The higher the number, the harder it is to have knock."

Premium Fights Knock

"Knock"—an unregulated explosion in a chamber designed for highly regulated combustion—is the bane of an internal-combustion engine. During the four-stroke cycle of a typical car motor, the piston drops in the cylinder, allowing it to fill with a mixture of gasoline and air. The piston then moves up again, compressing the fuel mix; when it reaches the top, the spark plug ignites the explosive vapor, driving the piston down again. As the piston returns to the top of the cylinder, it expels what remains of the spent fuel through the exhaust valves and the entire process starts again. Knock occurs when the compression of the fuel-and-air mixture alone, and not the spark plug, sets off an explosion.

Each hydrocarbon molecule in gasoline behaves differently under pressure, but octane best resists the temptation to explode. "You rate the gasoline on how it knocks compared with this reference mixture," explains William H. Green, a chemist at the Massachusetts Institute of Technology. "Ones that don't knock very much are the premium." That is, they behave in an engine as if they have a high proportion of octane, even if they don't.

The Rub: Today's Engines Are Knock-Free

Most modern cars are designed to employ a specific compression ratio, a measure of how much room is available to the fuel when the piston is at the bottom and the top of the cylinder. This compression ratio—typically around 8 to 1—tolerates lower octane fuels (such as 87-octane regular gasoline) without knocking. "The compression ratio is fixed by the designer of the engine," Green says. "The regular fuel will burn properly and the premium fuel will burn properly, and therefore there is no reason you should pay the extra money." High-performance engines in some sports cars or engines in older, heavier automobiles, however, can boast much higher compression ratios and so require higher octane gasoline.

Such high compression ratios could be turned to efficiency rather than speed, Green notes, especially if put into the engines of lighter cars. And other automotive fuels, such as ethanol, can offer high octane ratings. But for standard cars on the road today, purchasing premium gasoline is simply paying a premium for a fuel that delivers no added benefits. "If you think you need it," Green says, "you're being very eccentric." ■

David Biello is an associate editor of ScientificAmerican.com.

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MATTHIAS KULKA *zefa/Corbis*

Pros Magaga and her daughter tend their newly-expanded shop in Kampala, Uganda

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