SCIENTIFIC AMERICAN

SEPTEMBER 2010 $5.99 WWW.SCIENTIFICAMERICAN.COM

SPECIAL ISSUE

the end.

Or is it?

The eternal fascinations—and surprising upsides—of endings

INSIDE:

Cheating Death
How Far Science Can Go

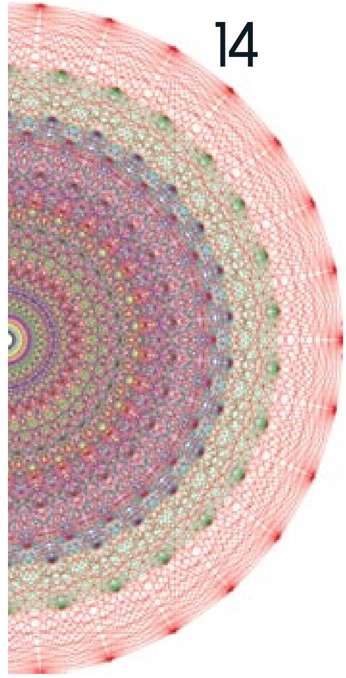
The Paradox of Time
Why It Can't Stop but Must

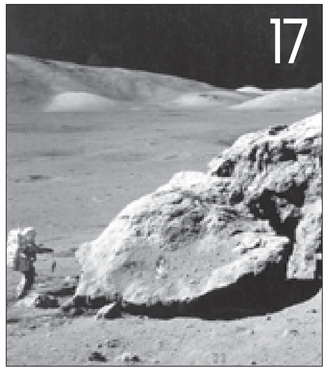
What Comes Next
Experts Predict the Future

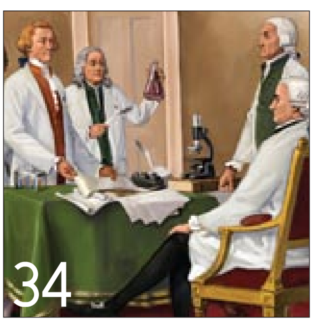
SPECIAL ISSUE

the end

CONTENTS DEPARTMENTS







GO TO SCIENTIFICAMERICAN.COM

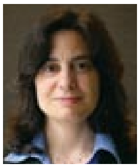
The Future of Cars
How will the automobile keep pace with a changing world? In an in-depth report, we look toward next-generation fuels, crashless cars, and the steadily proceeding integration of personal technology and personal transportation.

More at **www.ScientificAmerican.com/sep2010**

COURTESY OF NG CONNECT PROGRAM

Scientific American (ISSN 0036-8733), Volume 303, Number 3, September 2010 published monthly by Scientific American, a trading name of Nature America, Inc., 75 Varick Street, 9th Floor, New York, N.Y. 10013-1917. Periodicals postage paid at New York, N.Y., and at additional mailing offices. Canada Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40012504. Canadian BN No. 127387652RT; QST No. Q1015332537. Publication Mail Agreement #40012504. Return undeliverable mail to Scientific American, P.O. Box 819, Stn Main, Markham, ON L3P 8A2. **Individual Subscription rates:** 1 year $39.97 (USD), Canada $49.97 (USD), International $61 (USD). **Institutional Subscription rates:** Schools and Public Libraries: 1 year $69 (USD), Canada $74 (USD), International $81 (USD). Businesses and Colleges/Universities: 1 year $299 (USD), Canada $304 (USD), International $311 (USD). POSTMASTER: Send address changes to Scientific American, Box 3187, Harlan, Iowa 51537. **Reprints available:** write Reprint Department, Scientific American, 75 Varick Street, 9th Floor, New York, N.Y. 10013-1917; fax: 646-563-7138; reprints@SciAm.com. **Subscription inquiries: U.S. and Canada (800) 333-1199; other (515) 248-7684. Send e-mail to sacust@sciam.com.** Printed in U.S.A.

Start of the End



After waiting in the long customs queue at JFK airport in New York City a few years ago, I found myself before an agent with a dour expression. He wondered: What kind of work, exactly, requires a trip to Europe and back in less than three days? As I drew breath to explain my job as an editor at *Scientific American,* his eyes dropped to the slim volume in my hand, and he suddenly beamed. "Oh, I read that book, and it was terrific." He handed me back my passport. "Welcome home."

The book? *Stiff: The Curious Lives of Human Cadavers* (W. W. Norton, 2003), by Mary Roach. I'd heard it was witty and thought it would be diverting for a long international flight. It was. In fact, I was well into the chapter on what happens to bodies during airplane crashes before I noticed I'd been reading it at 35,000 feet over the Atlantic Ocean. After a pause (in which I confess I thought about the wisdom of tempting fate), I read on. I was rewarded with fascinating scientific information and, more than that, a good story.

You just never know when a willingness to engage with possibly uncomfortable topics might have an upside. Now that you have reached the beginning of "The End," our annual special single-topic issue, we hope it will provide similar benefits. As you read, you may come to appreciate, as I have, how an apparent finish can often be just another way to open a new door. Turn to page 38 for a thoughtful introduction to the feature section by staff editor Michael Moyer, who organized the issue.

That is not to say it is always easy to take a hard look at finales. When it comes to contemplating our own mortality, the nature of our consciousness actually makes it impossible to imagine the world without us. Consider, as Jesse Bering, director of the Institute of Cognition and Culture at Queen's University Belfast, wrote in our sister publication, *Scientific American Mind,* that you will never know you have died: "You may feel yourself slipping away, but it isn't as though there will be a 'you' around who is capable of ascertaining that, once all is said and done, it has actually happened."

Partly for this reason—the difficulty and possible discomfort about some of the topics we wanted to cover—the editors have mulled and then put aside this issue annually for the past few years. How would people react? Would it "die" on the newsstand? (Ouch, I know.) For my part, I find contemplating the future fascinating, whether it is my own, the planet's or even the universe's: this issue explores all three and then looks at what comes after the end in many related areas as well. The topic also seems the perfect alpha-and-omega bookend to our single-themed issue last year, "Origins."

When you're done with this issue, you can find more on the home page of www.ScientificAmerican.com, including a special interactive package about the feature article starting on page 74, "How Much Is Left?" which was developed with Zemi. And during the week of August 23, you can listen to several of the editors and other experts in interviews and related stories on WNYC's national morning radio news program "The Takeaway" (more at www.ScientificAmerican.com/TheEnd). As always, let us know what you think. ■

MARIETTE DiCHRISTINA
editor in chief

ETHAN HILL (*DiChristina*)

EXPO

ON THE NATIONAL MALL

& SURROUNDING AREAS

OCTOBER 23 & 24, 2010, 10AM-5:30PM

1500 FUN, HANDS-ON SCIENCE & ENGINEERING ACTIVITIES

A FREE EVENT FOR THE ENTIRE FAMILY

USASCIENCEFESTIVAL.ORG

THANKS TO OUR SPONSORS

LOCKEDIUM

FESTIVAL HOST

Lockheed Martin

LIFETECHIUM

Life Technologies Foundation

DISCOVERYCIUM

K&L GATESIUM

K&L Gates

AMERICIUM

CTSI

Popular Science

Science Illustrated

NOBELIUM

Larry and Diane Bock

EE Times

NewScientist

Scientific American

Popular Mechanics

ScienceBlogs

EINSTEINIUM

Farrell Family Foundation

ResMed Foundation

Alexandria

Northrop Grumman

Technology Review

The Epoch Times

motorola foundation

EarthSky

KRYPTON

Agilent Technologies

Amgen

illumina

Celgene

Dow

Forbes Wolfe

The Kavli Foundation

intel

WAMU 88.5 FM American University Radio

C&EN

Engineering.com

PBS

physics today

PLATINUM

Vertex

Genentech

PLTW

nvtc Northern Virginia Technology Council

Sandia National Laboratories

Family Magazine

Baxter

MedImmune

Sigma Xi

Celestron

Cisco

PALLADIUM

NuVasive Inc.
FEI Company
Case Western Reserve University
Biogen Idec Foundation
LifeStraw®
Microsoft
Draper Laboratory
Colella Photography
Dassault Systèmes SolidWorks Corp.

TITANIUM

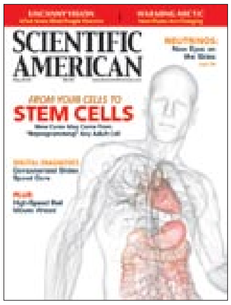
Bechtel Corporation
SpaceX
National Radio Astronomy Observatory
SciVee
Research In Motion
SchoolTube
Thirty Meter Telescope Project
Virginia Commonwealth University School of Engineering
Astronomy Outreach Foundation
Rochester Institute of Technology
National Math and Science Initiative
SpringBoard: A Program of the Juneau Economic Development Council

Letters to the Editor

Scientific American
75 Varick Street, 9th Floor,
New York, NY 10013-1917
or editors@SciAm.com

Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article at **www.ScientificAmerican.com/sciammag**

Pathology ▪ High-Speed Rail ▪ Blindsight



MAY 2010

> **"The proposed 'high-speed' rail link between Cincinnati and Cleveland should be covered in Anti Gravity."**
> —*John Day* COLUMBUS, OHIO

Digital Revolution

Pathologists are traditionally seen as being detached from everyday clinical practice, which explains why we were so pleasantly surprised when we came across the interesting article "A Better Lens on Disease," by Mike May. Even before the digital revolution, pathologists had developed rudimentary ways (mainly photographs) to capture histological images and submit them to one another for a second opinion. Nowadays such a procedure is adopted usefully at small hospitals in developing countries to refer unusual or difficult cases to internationally recognized European or U.S. pathology departments.

The crucial role of histology in driving targeted therapies (both in cancer and in other diseases) calls for global efforts to ensure consistent histological assessments, and circulating images is fundamental to establishing solid diagnostic criteria. Pathology laboratories have basically changed very little in the past 100 years, and we welcome the digital revolution: it will make it easier for pathologists to conduct a worldwide discussion of their diagnoses and will result in more consistent diagnostic assessments. But the digitized lens is just a tool. It still takes the eyes of a well-trained pathologist to provide the biological rationale for 21st-century personalized therapies.

Matteo Fassan and Massimo Rugge
Department of Medical Diagnostic Sciences and Special Therapies
University of Padua, Italy

Really High-Speed?

In "Revolutionary Rail," Stuart F. Brown writes that maglev is "the only way fast trains could pass through much of the western U.S.'s jagged terrain." But existing rail lines do go through these areas, and so could high-speed lines. A grade of 3 percent should not be thought of as a maximum for high-speed rail: the French TGV and German ICE high-speed trains have maximum grades higher than the 3 percent mentioned in the article. Long tunnels such as in the European Alps are also possible. Moreover, in discussing a Los Angeles to Las Vegas high-speed line, the article states that any high-speed line would have to scale grades of up to 7 percent. There are many route options where much lower maximum grades could be used. Furthermore, snow and ice can be more of a problem with maglev than conventional rail because maglev does not have contact pressure between wheel and rail that can cut through accumulated snow and ice.

Louis T. Cerny
Railroad consultant
Gaithersburg, Md.

Brown typically stresses the technological wonders of high-speed rail and blames the backwardness of the U.S. on "passenger trains [not having been] a federal priority for quite some time." But there is a far more fundamental reason: with few exceptions, the population density of the U.S. is far lower than that of the regions of the world where high-speed rail has been suc-


The more twists and turns, the better the tale.
The new 2011 Legacy. A novel take on driving. A SUBARU BOXER® engine provides balance. Symmetrical All-Wheel Drive provides grip. The result is an unparalleled, dynamic drive with an endearing 31 mpg.* After that first corner, you'll never want the story to end. **Love. It's what makes a Subaru, a Subaru.**
SUBARU.
Legacy.® Well-equipped at $19,995†
*EPA-estimated hwy mpg for 2.5i CVT models. Actual mileage will vary. †MSRP excludes destination and delivery charges, tax, title and registration fees. Dealer sets actual price. Legacy 2.5GT Limited pictured has an MSRP of $31,395.

cessful. For example, the very successful Shinkansen lines of Japan connect points in a country with a population of 127 million. California, with about the same land area, has about one third as many people. On the other hand, such lines do attract dense populations. As a "refugee" from the Boston-Washington corridor, I'm not sure I want to see its density re-created on the West Coast.

Lawrence S. Lerner
Professor Emeritus
College of Natural Sciences and Mathematics
California State University, Long Beach

JAPAN'S TOKKAIDO SHINKANSEN bullet trains carry 150 million passengers every year.

The proposed half-billion-dollar "high-speed" rail link between Cincinnati and Cleveland should be covered in the Anti Gravity column. The system will require substantial subsidies, have an average speed of 39 (no typo!) miles per hour, offer poor frequency of service, and serve only a very limited number of cities. There is virtually no chance to increase speeds substantially without building completely new dedicated tracks. Buses today, operating without subsidy, offer dramatically shorter travel times, comparable fares, twice the frequency of service, and service to more communities. [*Editors' note: The proposal is for a project that would cost $400 million, not quite half a billion.*]

John Day
Columbus, Ohio

Trout Awareness

Beatrice de Gelder's article "Uncanny Sight for the Blind" raises fascinating evolutionary questions about consciousness. Given that sight slowly evolved from the first light-sensing structures to today's sophisticated ability to perceive, focus on and be aware of the world around us, when did conscious awareness get paired with sight? Presumably a plant that turns toward the sun has no awareness of doing so. What about insects, reptiles or fish? Is a trout aware that the dark disturbance on the water's surface is a bug that it can eat, or is its swift rising to consume the insect simply a nonaware response to a perception that is more akin to "blindsight" than it is to our awareness? Perhaps this line of research will help us to know which species have consciousness that is akin to human awareness.

Joseph Ossmann
Carmichael, Calif.

Ancient Geeks

Steve Mirsky's "140-Character Study" [Anti Gravity] is humorous and enjoyable, but the illustration's attempt to render the word "Tweet" as a Greek inscription on a statue is an abject failure. Any classicist worth their bow tie and suede jacket would tell you that the only way to render the /w/ sound in ancient Greek is through the oft-overlooked digamma, uppercase F, lowercase ϝ. Your artist used an omega, which many Greek fonts link with the W on our keyboard but which was nothing more than a long O-sound.

Matthew Chaldekas
Los Angeles

ERRATA Konrad Hochedlinger's "Your Inner Healers" has two references to "smooth muscular atrophy"; it should have said "spinal muscular atrophy."

Because of an editing error, "Breeding Cassava to Feed the Poor," by Nagib Nassar and Rodomiro Ortiz, stated that lysine is a sulfur-containing amino acid; it contains no sulfur.

"Through Neutrino Eyes," by Graciela B. Gelmini, Alexander Kusenko and Thomas J. Weiler, says that particle detectors can identify the type, or flavor, of a neutrino with "25 percent confidence." It should have read "25 percent uncertainty": statistically, an experimenter misidentifies the flavor one quarter of the time.

In "Society and Science" [From the Editor], Mariette DiChristina writes: "Several years ago the Bush administration limited research to then existing stem cell lines"; the limits applied only to federally funded research.

SCIENTIFIC AMERICAN®
Established 1845

PRESIDENT: Steven Inchcoombe
EXECUTIVE VICE PRESIDENT: Michael Florek
VICE PRESIDENT, OPERATIONS AND ADMINISTRATION: Frances Newburg

MANAGING DIRECTOR, CONSUMER MARKETING: Christian Dorbandt
ASSOCIATE DIRECTOR, CONSUMER MARKETING: Anne Marie O'Keefe
SENIOR MARKETING MANAGER/RETENTION: Catherine Bussey
SENIOR MARKETING MANAGER/ACQUISITION: Patricia Elliott

VICE PRESIDENT AND PUBLISHER: Bruce Brandfon
VICE PRESIDENT, MARKETING AND SALES DEVELOPMENT: Michael Voss
DIRECTOR, GLOBAL MEDIA SOLUTIONS: Jeremy A. Abbate
MANAGER, INTEGRATED MEDIA SALES: Stan Schmidt
SALES DEVELOPMENT MANAGER: David Tirpack
PROMOTION MANAGER: Diane Schube
MARKETING RESEARCH DIRECTOR: Rick Simone
SALES REPRESENTATIVES: Jeffrey Crennan, Chantel Arroyo

DIRECTOR, ANCILLARY PRODUCTS: Diane McGarvey

How to Contact Us

SUBSCRIPTIONS
For new subscriptions, renewals, gifts, payments, and changes of address: U.S. and Canada, 800-333-1199; outside North America, 515-248-7684 or www.ScientificAmerican.com

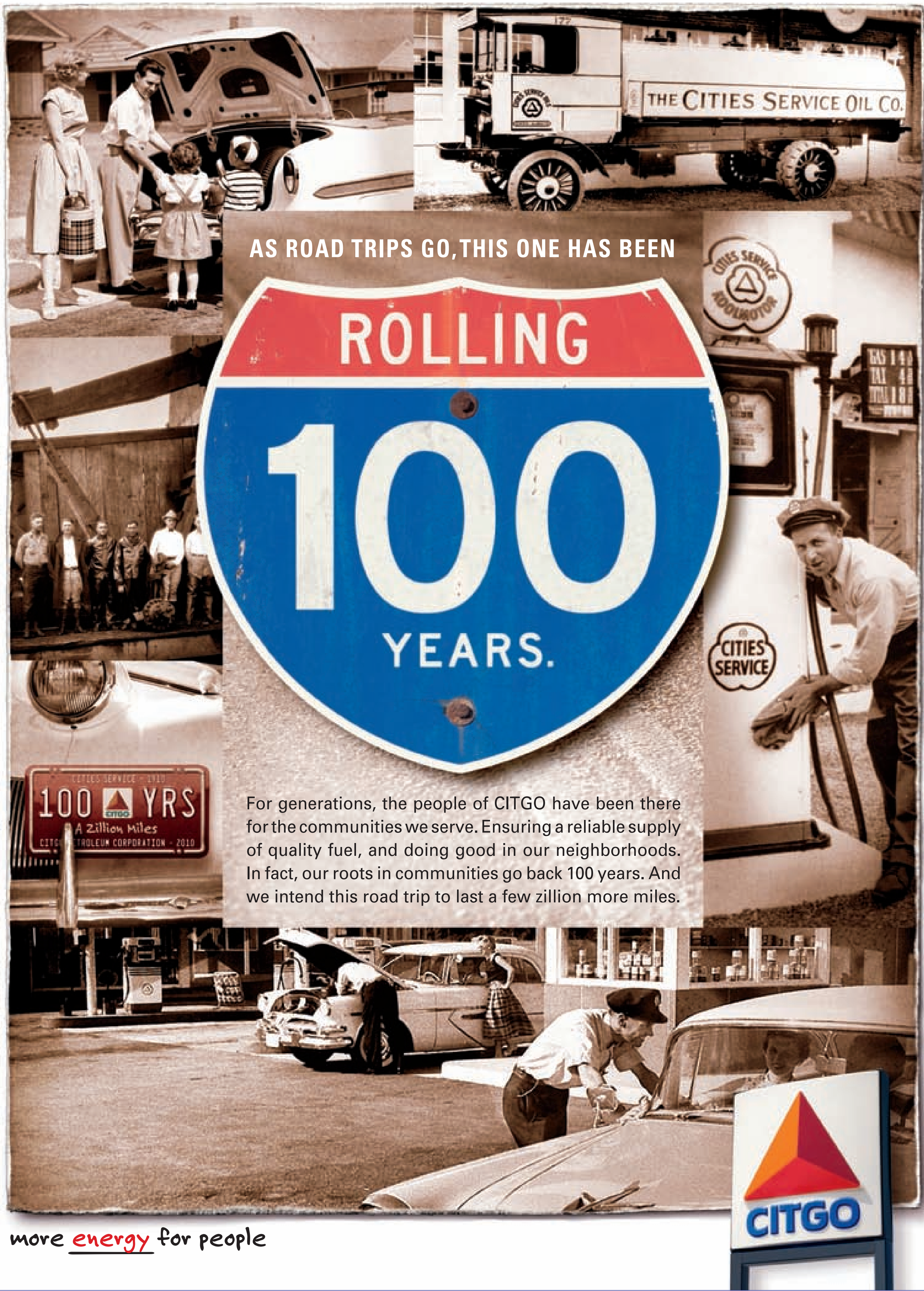
SUBMISSIONS
To submit article proposals, follow the guidelines at www.ScientificAmerican.com. Click on "Contact Us." We cannot return and are not responsible for materials delivered to our office.

REPRINTS
To order bulk reprints of articles (minimum of 1,000 copies): Reprint Department, Scientific American, 75 Varick Street, 9th Floor, New York, NY 10013-1917; 212-451-8877; reprints@SciAm.com.
For single copies of back issues: 800-333-1199.

PERMISSIONS
For permission to copy or reuse material: Permissions Department, Scientific American, 75 Varick Street, 9th Floor, New York, NY 10013-1917; 212-451-2810; randp@SciAm.com; www.ScientificAmerican.com/permissions.
Please allow three to six weeks for processing.

ADVERTISING
www.ScientificAmerican.com has electronic contact information for sales representatives of Scientific American in all regions of the U.S. and in other countries.

TOSHIYUKI AIZAWA *Getty Images*



THE CITIES SERVICE OIL CO.
AS ROAD TRIPS GO, THIS ONE HAS BEEN
ROLLING
100
YEARS.
CITIES SERVICE KOOLMOTOR
CITIES SERVICE
CITIES SERVICE · 1910
100 YRS
A Zillion Miles
For generations, the people of CITGO have been there for the communities we serve. Ensuring a reliable supply of quality fuel, and doing good in our neighborhoods. In fact, our roots in communities go back 100 years. And we intend this road trip to last a few zillion more miles.
CITGO
more energy for people

Adapt Your Environment ▪ Uganda Sickness ▪ Horrified Whalers

Compiled by Daniel C. Schlenoff

SEPTEMBER 1960

EVOLUTION OF MAN—"Mutation, sexual recombination and natural selection led to the emergence of *Homo sapiens*. The creatures that preceded him had already developed the rudiments of tool-using, toolmaking and cultural transmission. But the next evolutionary step was so great as to constitute a difference in kind from those before it. There now appeared an organism whose mastery of technology and of symbolic communication enabled it to create a supraorganic culture. Other organisms adapt to their environments by changing their genes in accordance with the demands of the surroundings. Man and man alone can also adapt by changing his environments to fit his genes. His genes enable him to invent new tools, to alter his opinions, his aims and his conduct, to acquire new knowledge and new wisdom. —Theodosius Dobzhansky"

SEPTEMBER 1910

SLEEPING SICKNESS—"Prior to the nineties, sleeping sickness was unknown in Uganda and its introduction is attributed to the entry of Emin Pasha [Eduard Schnitzer] and his 10,000 followers who were brought from the edge of the Congo territory, the center of the disease. The point arose as to how the parasite was distributed. It was known that the tsetse fly was responsible for the terrible rinderpest among cattle in south Africa, and a biting insect which thrives in great numbers on the shores of the lake was suspected. This is a member of the tsetse species, and is known as *Glossina palpalis*, recognized by the native authorities as the kivu. A map of where tsetse flies were collected was compared with another on which the area of the sleeping sickness was indicated: the territories coincided."

FOUNTAIN—"A sanitary drinking fountain for use in schools and other public places has been invented. As shown in the illustration, a series of tubes, which may be bent to any ornamental design, are trained to deliver the water to a common center. The impact of the water at this central point produces a geyser-like jet over which the drinker can apply his mouth, while unused water falls to the base of the fountain."

FOUNTAIN OF KNOWLEDGE—or at least of hygiene, 1910

SEPTEMBER 1860

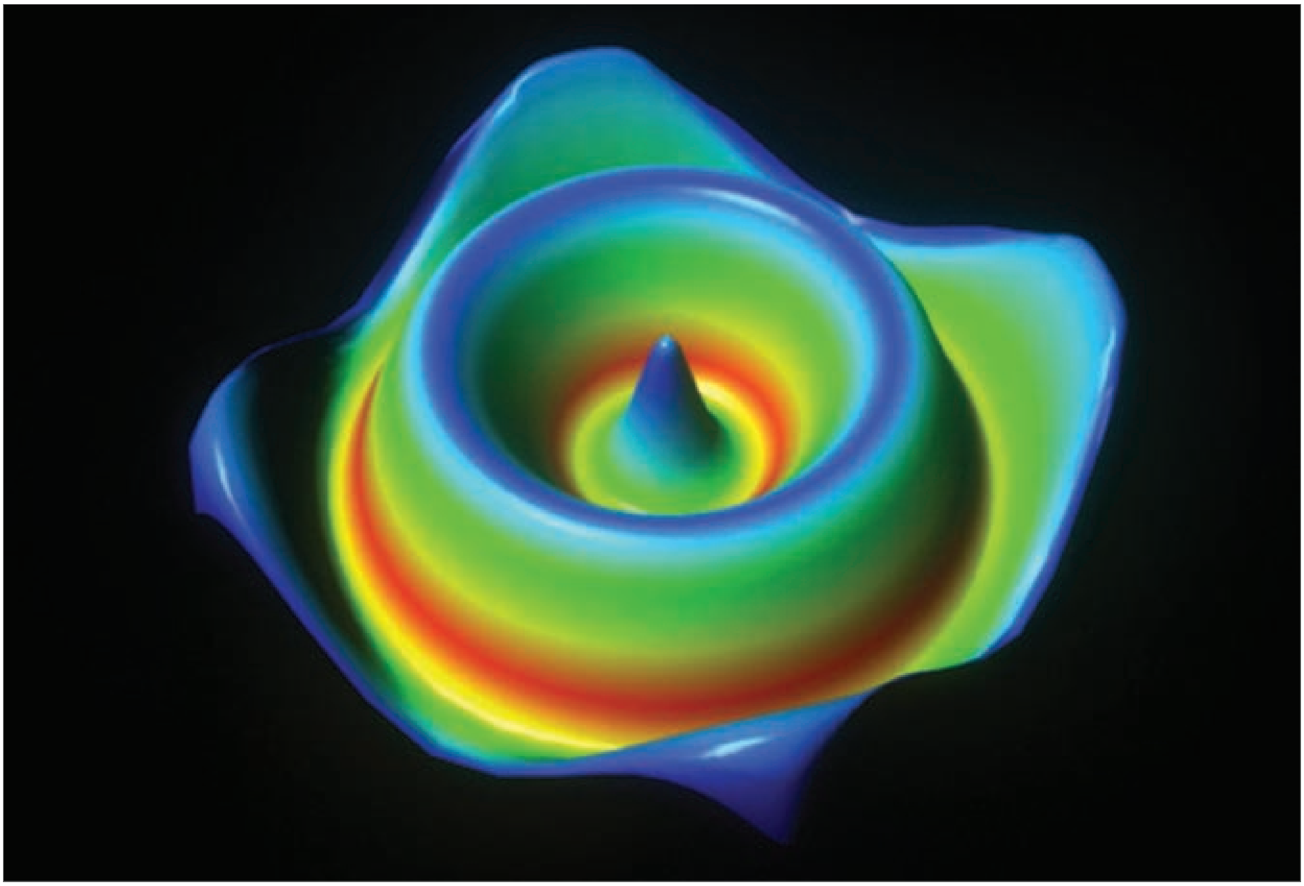
POISON FISHING—"A paper has just been published (in England) on the capture of whales by the means of poison, the agent being hydrocyanic or prussic acid. The subtle poison was contained in glass tubes, in quantity about two ounces, secured to a harpoon. Messrs. W. and G. Young sent a quantity of these harpoons to one of their ships engaged in the Greenland fishery, and on meeting with a fine whale the harpoon was skillfully and deeply buried in his body; the leviathan immediately 'sounded,' or dived perpendicularly downwards, but in a very short time the rope relaxed, and the whale rose to the surface quite dead. The men were so appalled by the terrific effect of the poisoned harpoon that they declined to use any more of them."

INTERNAL COMBUSTION—"A Parisian, by the name of Étienne Lenoir, is creating a sensation among his countrymen by the exhibition of a caloric engine. Lenoir's little shop, in a bye street, is every day besieged by a crowd of curious people from all classes—the Imperial downwards. According to *Cosmos*, and other French papers, the age of steam is ended—Watt and Fulton will soon be forgotten. This is the way they do such things in France. Lenoir's engine is an explosion engine, in which air, mixed with hydrogen or illuminating gas, is exploded in the cylinder by an electric spark; the piston is thus shot forward and back. The practical objections to such motors are the jerks of its action and the accumulation of heat. Gas, although much dearer (as fuel) than coal, is so cleanly and manageable, that it will some day come into use for the multitude of small engines which will be found useful for driving sewing and other light machines."

[NOTE: Lenoir's engine is considered to be the first commercially practical internal-combustion engine.]

GAS WORKS—"A lady in an omnibus at Washington espied the great unfinished dome of the capitol (which don't look much like a dome at present), and said, innocently, 'I suppose those are the gas-works?' 'Yes, Madam, for the *nation*,' was the reply of a fellow-passenger."

SCIENTIFIC AMERICAN, VOL. CIII, NO. 13; SEPTEMBER 24, 1910



RESEARCH & DISCOVERY

Rummaging for a Final Theory

Unifying gravity and particle physics may come down to an old approach from the 1960s BY ZEEYA MERALI

TURNING THE CLOCK BACK by half a century could be the key to solving one of science's biggest puzzles: how to bring together gravity and particle physics. At least that is the hope of researchers advocating a back-to-basics approach in the search for a unified theory of physics.

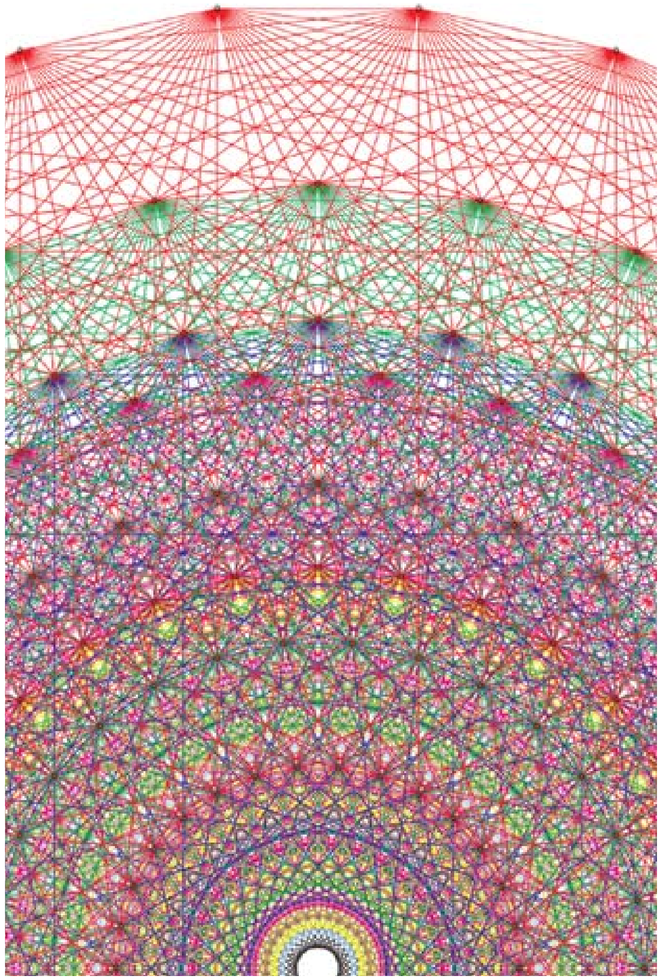
In July mathematicians and physicists met at the Banff International Research Station in Alberta, Canada, to discuss a return to the golden age of particle physics. They were harking back to the 1960s, when physicist Murray Gell-Mann realized that elementary particles could be grouped according to their masses, charges and other properties, falling into patterns that matched complex symmetrical mathematical structures known as Lie ("lee") groups. The power of this correspondence was cemented when Gell-Mann mapped known particles to the Lie group SO(3), exposing a vacant position indicating that a new particle, the soon to be discovered "Omega-minus," must exist.

During the next few decades, the strategy helped scientists to develop the Standard Model of particle physics, which uses a combination of three Lie groups to weave together all known elementary particles and three fundamental forces: electromagnetism; the strong force, which holds atomic nuclei together; and the weak force, which governs radioactivity. It seemed like it would only be a matter of time before physicists found an overarching Lie group that could house everything, including gravity. But such attempts came unstuck because they predicted phenomena not yet seen in nature, such as the decay of protons, says physicist Roberto Percacci of the International School for Advanced Studies in Trieste, Italy.

The approach fell out of favor in the 1980s, as other candidate unification ideas, such as string theory, became more popular. But inspired by history, Percacci developed a model with Fabrizio Nesti of the University of Ferrara in Italy and presented it at the meeting. In the model, gravity is contained within a large Lie group, called SO(11,3), alongside electrons, quarks, neutrinos and their cousins, collectively known as fermions. Although the model cannot yet explain the behavior of photons or other force-carrying particles, Percacci believes it is an important first step.

One fan of Percacci's work is A. Garrett Lisi, an independent researcher with a Ph.D. in physics from the University of California, San Diego. Lisi hit the headlines in 2007 with his own attempt to embed a "theory of everything" in the most complex and elegant Lie group, called E8. Percacci's work, Lisi says, "provides a nice unification of gravity and the Standard Model."

Lisi's ideas revived mathematicians' interest in this historical approach to physics, which led to the Banff meeting, says Gregg J. Zuckerman, an expert on E8 at Yale University. Lisi's attempt,



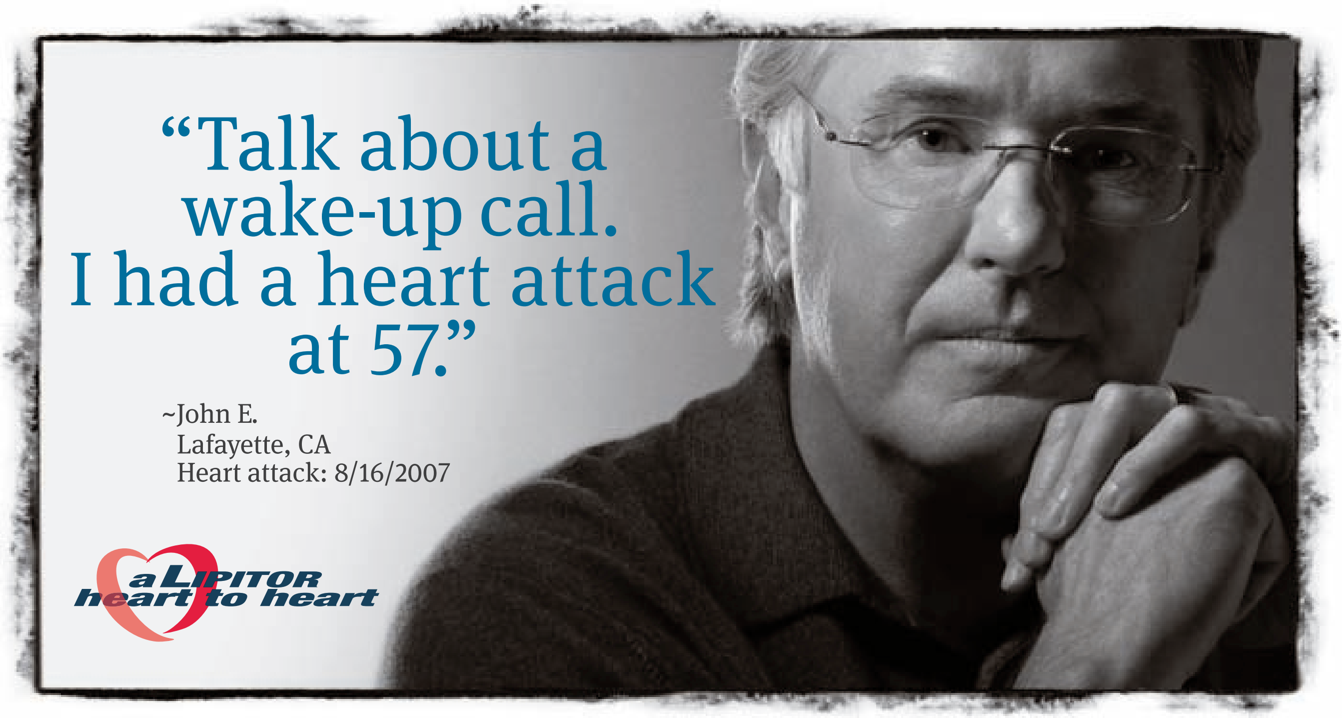
MATHEMATICAL WEB: **Visual representation of the Lie group E8. Such complex symmetrical mathematical structures could help researchers weave together the physics of particles and forces.**

COURTESY OF JOHN STEMBRIDGE AND PETER MCMULLEN

he adds, "represents a more general ideal about returning to Lie groups as a way to unify gravity with the Standard Model."

Others are taking this ideal forward in different ways. Rather than thinking of Lie groups as boxes that can hold forces and particles, mathematician Tevian Dray and physicist Corinne Manogue of Oregon State University are tearing them apart and examining one of their mathematical building blocks—an eight-dimensional number system called octonions. (Everyday real numbers are one-dimensional, whereas complex numbers, which have both real and imaginary parts, are two-dimensional.)

Many mathematicians shy away from octonions because they



"I should have been doing more for my high cholesterol. I learned the hard way. Now I trust my heart to Lipitor." Talk to your doctor about your risk and about Lipitor.

- When diet and exercise are not enough, adding Lipitor may help. Lipitor is FDA-approved to reduce the risk of heart attack and stroke in patients who have heart disease or risk factors for heart disease, including family history of early heart disease, high blood pressure, low good cholesterol, age and smoking.
- Lipitor has been extensively studied with over 18 years of research. And Lipitor is backed by over 400 ongoing or completed clinical studies.

IMPORTANT SAFETY INFORMATION:
LIPITOR is not for everyone. It is not for those with liver problems. And it is not for women who are nursing, pregnant or may become pregnant.

If you take LIPITOR, tell your doctor if you feel any new muscle pain or weakness. This could be a sign of rare but serious muscle side effects. Tell your doctor about all medications you take. This may help avoid serious drug interactions. Your doctor should do blood tests to check your liver function before and during treatment and may adjust your dose.

Common side effects are diarrhea, upset stomach, muscle and joint pain, and changes in some blood tests.

INDICATION:
LIPITOR is a prescription medicine that is used along with a low-fat diet. It lowers the LDL ("bad" cholesterol) and triglycerides in your blood. It can raise your HDL ("good" cholesterol) as well. LIPITOR can lower the risk for heart attack, stroke, certain types of heart surgery, and chest pain in patients who have heart disease or risk factors for heart disease such as age, smoking, high blood pressure, low HDL, or family history of early heart disease.

LIPITOR can lower the risk for heart attack or stroke in patients with diabetes and risk factors such as diabetic eye or kidney problems, smoking, or high blood pressure.

Please see additional important information on next page.

LIPITOR®
atorvastatin calcium
tablets

Have a heart to heart with your doctor about your risk. And about Lipitor.
Call 1-888-LIPITOR (1-888-547-4867) or visit www.lipitor.com/john

You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.fda.gov/medwatch or call 1-800-FDA-1088.

IMPORTANT FACTS

LIPITOR atorvastatin calcium tablets (LIP-ih-tore)

LOWERING YOUR HIGH CHOLESTEROL

High cholesterol is more than just a number, it's a risk factor that should not be ignored. If your doctor said you have high cholesterol, you may be at an increased risk for heart attack and stroke. But the good news is, you can take steps to lower your cholesterol.

With the help of your doctor and a cholesterol-lowering medicine like LIPITOR, along with diet and exercise, you could be on your way to lowering your cholesterol.

Ready to start eating right and exercising more? Talk to your doctor and visit the American Heart Association at www.americanheart.org.

WHO IS LIPITOR FOR?

Who can take LIPITOR:

- People who cannot lower their cholesterol enough with diet and exercise
- Adults and children over 10

Who should NOT take LIPITOR:

- Women who are pregnant, may be pregnant, or may become pregnant. LIPITOR may harm your unborn baby. If you become pregnant, stop LIPITOR and call your doctor right away.
- Women who are breast-feeding. LIPITOR can pass into your breast milk and may harm your baby.
- People with liver problems
- People allergic to anything in LIPITOR

BEFORE YOU START LIPITOR

Tell your doctor:

- About all medications you take, including prescriptions, over-the-counter medications, vitamins, and herbal supplements
- If you have muscle aches or weakness
- If you drink more than 2 alcoholic drinks a day
- If you have diabetes or kidney problems
- If you have a thyroid problem

ABOUT LIPITOR

LIPITOR is a prescription medicine. Along with diet and exercise, it lowers "bad" cholesterol in your blood. It can also raise "good" cholesterol (HDL-C).

LIPITOR can lower the risk of heart attack, stroke, certain types of heart surgery, and chest pain in patients who have heart disease or risk factors for heart disease such as:

- age, smoking, high blood pressure, low HDL-C, family history of early heart disease

LIPITOR can lower the risk of heart attack or stroke in patients with diabetes and risk factors such as diabetic eye or kidney problems, smoking, or high blood pressure.

POSSIBLE SIDE EFFECTS OF LIPITOR

Serious side effects in a small number of people:

- **Muscle problems** that can lead to kidney problems, including kidney failure. Your chance for muscle problems is higher if you take certain other medicines with LIPITOR.
- **Liver problems**. Your doctor may do blood tests to check your liver before you start LIPITOR and while you are taking it.

Call your doctor right away if you have:

- Unexplained muscle weakness or pain, especially if you have a fever or feel very tired
- Allergic reactions including swelling of the face, lips, tongue, and/or throat that may cause difficulty in breathing or swallowing which may require treatment right away
- Nausea, vomiting, or stomach pain
- Brown or dark-colored urine
- Feeling more tired than usual
- Your skin and the whites of your eyes turn yellow
- Allergic skin reactions

Common side effects of LIPITOR are:

- Diarrhea
- Upset stomach
- Muscle and joint pain
- Changes in some blood tests

HOW TO TAKE LIPITOR

Do:

- Take LIPITOR as prescribed by your doctor.
- Try to eat heart-healthy foods while you take LIPITOR.
- Take LIPITOR at any time of day, with or without food.
- If you miss a dose, take it as soon as you remember. But if it has been more than 12 hours since your missed dose, wait. Take the next dose at your regular time.

Don't:

- Do not change or stop your dose before talking to your doctor.
- Do not start new medicines before talking to your doctor.
- Do not give your LIPITOR to other people. It may harm them even if your problems are the same.
- Do not break the tablet.

NEED MORE INFORMATION?

- Ask your doctor or health care provider.
- Talk to your pharmacist.
- Go to **www.lipitor.com** or call **1-888-LIPITOR**.

Pfizer

Manufactured by Pfizer Ireland Pharmaceuticals, Dublin, Ireland

Printed in the USA.

Distributed by Parke-Davis, Division of Pfizer Inc.
New York, NY 10017 USA
June 2009

Rx only

do not obey all the standard laws of algebra, Dray observes, so the order in which you perform mathematical operations can give you different answers. Dray and Manogue have turned this seemingly unpalatable asymmetry to their advantage to describe the biased properties of some particles. For instance, octonions naturally reproduce neutrinos' puzzling "left-handedness"—that is, their intrinsic quantum "spin" is always oriented in one sense relative to their motion.

Octonions also seem tailor-made for performing calculations in 10 dimensions, Dray explains, making them potentially useful for string theorists, who posit that our universe contains six extra compact dimensions. String theorists have not been able to pinpoint one unique mechanism that describes how these extra dimensions collapse down, but Dray and Manogue have found that choosing one particular octonion to concentrate on performs this feat simply and automatically.

"We are starting to get glimmers of the properties that a final theory must have," says Dray, who emphasizes that much work remains to be done to obtain a fully working octonion model. What is encouraging, he adds, is that many researchers are getting tantalizing hints, using differing approaches, that Lie groups are the right path to take. These hints are strong enough to stimulate mathematicians, such as Jeffrey Adams of the University of Maryland, to lend their expertise to physicists pursuing the Lie group approach. "I'd be disappointed if there's not something like this that works," Adams says.

Not everyone shares this optimism. Skip Garibaldi, a mathematician at Emory University, says that E8-inspired nostalgia is misguided. Working with physicist Jacques Distler of the University of Texas at Austin, Garibaldi has shown that Lisi's theory predicts the existence of unwanted particles, whose interactions are the mirror image of regular fermions. Such particles would most likely have already exerted a noticeable effect on known particles, Garibaldi argues. "There is no way to shove gravity inside E8 without also predicting something that has nearly been ruled out by experiment," he says.

Lisi, who posted the latest version of his theory on the Internet in June and presented it at the meeting, concedes that mirror fermions are an issue but adds that E8 theory is a work in progress and that mirror fermions could have evaded notice if they are heavier than commonly thought. They could even show up in the Large Hadron Collider, he says.

It is too early to judge whether the back-to-basics program will ultimately pay off, Zuckerman remarks. But he undoubtedly speaks for many when he says, "I can tell you that the literature is very exciting to me."

Zeeya Merali writes frequently about physics from London.

Lunar Pencil Lead

Impact-delivered graphite discovered in Apollo moon rock BY JOHN MATSON

HUMANS HAVE NOT SET FOOT on the moon since *Apollo 17* in 1972, but those missions are still producing surprises. An analysis of a collected rock has produced the first solid evidence for graphite, the form of carbon commonly used as pencil lead, in a lunar sample.

Andrew Steele, an astrobiologist at the Carnegie Institution of Washington, and his colleagues reported in the July 2 *Science* that they found dozens of graphite particles in a small, dark patch on the sample—a region just 0.1 square millimeter in area—as well as seven needle-shaped rolls of carbon called graphite whiskers. Other samples have yielded traces of the element implanted by the solar wind or locked up in carbide compounds, but discrete pockets of graphite of this relatively large size appear to be a unique find.

The researchers surmise that the graphite inclusions stem from a meteorite strike, probably during a period of intense impacts about four billion years ago known as the late heavy bombardment. The graphite fragments, Steele says, "are a remnant of basically a carbon-rich dust after an impact from a meteorite containing carbon, or the carbon may have condensed from a gas" released by an impact. If the former scenario proves to be the case, the graphite flecks and whiskers may be intact fragments of the meteorite that excavated the giant Serenitatis impact basin near the *Apollo 17* landing site.

Paul D. Spudis of the Lunar and Planetary Institute in Houston agrees that the graphite "probably is a remnant of some impactor," but he says that the impactor may not have been the same one that carved out the Serenitatis Basin. He and a colleague hypothesized in 1981 that the impact-melted rocks collected during *Apollo 17* may stem from multiple impact events.

GETTY IMAGES

ROCK ON: **Harrison Schmitt of *Apollo 17,* the last manned lunar mission, brought back samples in 1972 that still yield surprises today.**

Whatever the case, the scientific resources gleaned from the Apollo program are clearly far from exhausted. The development of ever more sensitive microscopy and chemical-analysis techniques will continue to produce new insights from existing samples—good news, considering that no nation appears to be close to returning humans to the lunar surface.

MEDICINE & HEALTH

Undifferentiated Ethics

Stem cells from adult skin are as morally fraught as the embryonic kind BY SALLY LEHRMAN

SAN FRANCISCO—When researchers first demonstrated in 2007 that human skin cells could be reprogrammed to behave like stem cells that can fully differentiate into other cells, scientists and politicians alike rejoiced. All the potential of embryonic stem cells might be harnessed with the new techniques—without the political and moral controversy associated with destroying a fertilized egg.

That optimism, however, may be misplaced; these transformed cells, known as induced pluripotent stem cells (iPS cells), actually present equally troubling ethical quandaries, according to bioethicists who met at the International Society for Stem Cell Research annual meeting in June. Not only do many of the ethical challenges posed by embryonic stem cells remain, but the relative ease and low cost of iPS techniques, combined with the accessibility of cells, accelerate the need to address futuristic-sounding possibilities such as creating gametes for reproduction. Scientists have already reported progress in growing precursor cells for eggs and sperm from both iPS and embryonic stem cell lines.

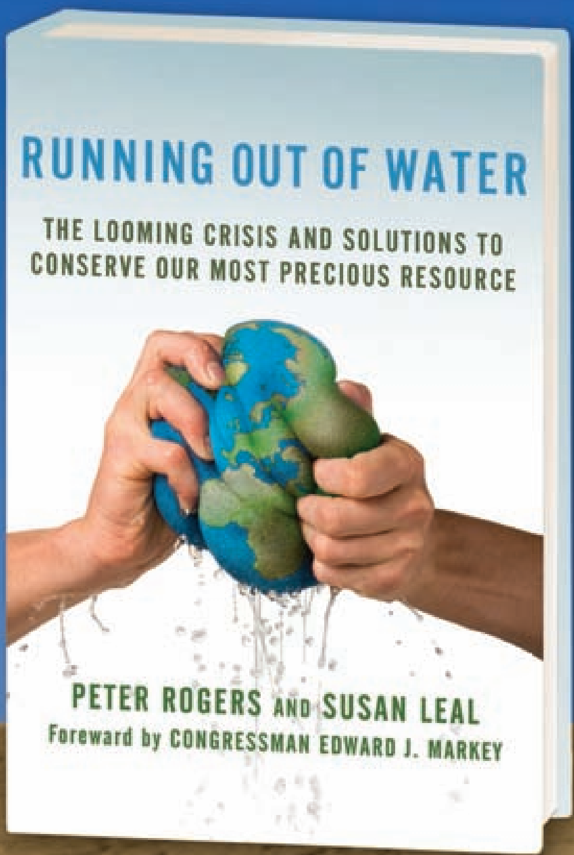
Although perfecting the process may take another decade, "we should start thinking carefully about this now," said Kazuto Kato, a bioethicist at Kyoto University in Japan. To make sure the gametes work normally, for instance, researchers will need to grow embryos and then destroy them, a morally contentious practice with prohibitions and policies differing around the world. Sperm and egg from skin cells eventually might be used for reproductive purposes, enabling parenthood at any age using tissue from either the living or dead. In fertility clinics, iPS cells could enable prospective parents to choose embryos for desired traits more easily than they can with conventional assisted-reproduction technologies. The possibilities raise a radical question about the moral status of human cells, noted Jan Helge Solbakk, head of research at the Center for Medical Ethics at the University of Oslo in Norway and chair of the society's ethics and public policy committee.

Although Kato called human reproductive cloning directly from iPS cell lines "very hypothetical," he pointed out progress for that possibility when he noted that three teams had produced mouse clones from iPS cells. Less expensive and more efficient than the process that produced Dolly the sheep, the iPS approach also would skirt the language of many current prohibitions against human reproductive cloning. Some bioethicists have called for a new international ban that would clearly prohibit the implantation of a human clone in part because of the tantalizing research uses for nascent embryos.

More immediate concerns have to do with control of the original donation and tissue grown from iPS cells. "Biobanks" all over the world already store biological material and related data for research, and many do not seek consent for future work as long as the material cannot be connected back to the donor. The far-reaching potential of iPS research, combined with a higher likelihood that cell lines will stay linked to a single donor (and that donor's health history), heightens the need for consensus, said Timothy Caulfield, research director of the Health Law Institute

FRESH SOLUTIONS

FOR OUR NATIONAL WATER SHORTAGE



"A call to action as well as a celebration of the progress already under way. *Running Out of Water* offers hope and guidance for getting that crucial job done."

—Congressman Edward J. Markey

"Rooted in real examples of water crises, Rogers and Leal point to clear, and well-tested, ways to solve these crises."

—John Briscoe, senior water adviser to the World Bank

"This book is more than just lamentations and excoriations . . . [including a] selection of eminently sensible, easily replicable, scalable solutions, and their sense that yes, the water world can be fixed."

—Marq de Villiers, author of *Water: The Fate of Our Most Precious Resource*

palgrave macmillan

macmillanscience

Now Available in Bookstores

$25.00 hc. / ISBN: 978-0-230-61564-9 • www.palgrave.com at the University of Alberta in Edmonton.

Yet such consensus may be hard to achieve. In research on attitudes, Caulfield has noticed a trend: clinical researchers, patient participants, privacy experts and the general public disagree about whether consent should be necessary for each new use of donated tissue or whether blanket consent will do. And how will a disillusioned cell donor withdraw when iPS cell lines have been distributed all over the world? Bedrock international research norms of consent and withdrawal may no longer be workable. "We have to recognize all the complicated issues that iPS research is engaging and get a sense of how existing laws and policies play out," Caulfield said.

Some ethicists suggest that tissue donors deserve a share of the tremendous commercial potential of iPS cell lines as disease models, drug-testing platforms or treatments. New partnerships could acknowledge the contributions of both the cell provider and the laboratories that grow and sustain iPS cell lines. Donors might share in some monetary rewards and be able to opt out of certain uses for iPS cells, such as for creating gametes or mixed species, or have a say in the overall direction of research, Solbakk suggested.

The stem cell society's ethics committee is working on a paper that would explore the rights of tissue donors and make recommendations by the end of the year. Solbakk also hopes to hold more public forums that could clarify research advances while also stimulating reflection on ethical challenges. He said the society would continue its efforts to reduce hype in the field. A new Web site aims to help patients evaluate claims by clinics that offer stem cell treatment and even submit a clinic for review by the society. "The most vulnerable resource," Solbakk said, "is trust."

Sally Lehrman is a fellow of the Markkula Center for Applied Ethics at Santa Clara University.

Fat Attack

Will three new antiobesity drugs beat a checkered safety history?

BY ERICA WESTLY

FINDING SAFE and effective weight-loss medications has long been a goal for drugmakers and physicians alike—roughly one third of American adults meet the clinical criteria for obesity, according to the Centers for Disease Control and Prevention. This year the U.S. Food and Drug Administration has been reviewing three new antiobesity drugs for government approval. Given the field's checkered past, however, major questions remain about the risks of pills that pare away the pounds.

Although drugs that seem promising early on sometimes prove ineffective or downright dangerous after they hit the market, the obesity field has seen more than its share of failures. In the 1960s amphetamines were touted as the answer to weight loss until they proved habit-forming. The mid-1990s witnessed the disaster with fen-phen (fenfluramine and phentermine), which caused heart valve disease. Then just a few years ago the FDA denied approval for a new weight-loss drug after it was linked to suicidal behavior.

To date, only two drugs are FDA-approved for long-term treatment of obesity, and they are not without concern. Earlier this year the European Union banned one of the compounds, sibutramine, or Meridia, after new reports of heart attack and stroke. The other drug, orlistat, now sold over the counter as Alli, causes gastrointestinal distress and has been associated with liver damage in some patients.

Nevertheless, researchers think drugs are the way to go and hope medications will one day replace costly and potentially dangerous surgeries such as gastric bypass. The situation is not unlike that for hypertension before the middle of the 20th century: until the advent of beta blockers in the 1960s, physicians removed sections of peripheral nerves to control high blood pressure. Today physicians treat hypertension almost exclusively with medication. Developing drugs for a chronic condition, whether it is obesity or hypertension, is challenging, though. "Most chronic diseases have lots of redundant mechanisms, so it is unusual to find a 'magic bullet,'" explains Frank Greenway, chief of the outpatient clinic at the Pennington Biomedical Research Center in Baton Rouge, La.

Obesity has a neuropsychiatric component, which makes it especially troublesome to treat. Each of the three new drugs facing FDA review targets the brain differently. One drug, called Contrave, takes aim at the brain's reward pathway, whereas the other two compounds affect brain areas that are involved with appetite. All three drugs appear to induce long-term weight loss. The concern is that like antiobesity drugs before them, which also targeted the brain, they could cause unwanted effects on the central and peripheral nervous systems.

OBESITY is best tackled with good eating and exercise habits beginning when one is young. Radical solutions such as gastric bypass surgery could be replaced by new antiobesity drugs, if deemed safe enough.

SANDY NICHOLSON *Redux Pictures*

Lorcaserin, one of the three new drugs, affects serotonin, which involves multiple brain processes besides appetite, including emotion and cardiovascular regulation. The company behind lorcaserin, San Diego–based Arena Pharmaceuticals, has gone to great lengths to show that the chemical does not cause the serotonin-related heart valve problems associated with fen-phen. Yet the drug could still lead to depression or increased cardiac risk factors, such as high blood pressure, especially if patients combine it with other drugs in an attempt to hasten weight loss.

The other two drugs, Contrave and Qnexa, could also cause unwanted neurological side effects. Bupropion, an ingredient in Contrave, has been linked to anxiety; topiramate, Qnexa's main ingredient, has been associated with memory problems. The companies behind Contrave and Qnexa—Orexigen in La Jolla, Calif., and Vivus in Mountain View, Calif., respectively—maintain that by combining the drugs with other agents, they have brought the doses below levels that would trigger adverse reactions. "Finding the right dosage is key," says Barbara Troupin, senior director of medical affairs at Vivus.

But problems could still occur, considering that patients with existing mental health issues are often excluded from obesity drug trials, so side effects not seen in trials could emerge when this population uses the medication. Such a situation may have occurred in 2007, when Sanofi-Aventis hailed Rimonabant, another neurotargeted drug, as a safe and effective weight-loss treatment. "The press releases looked great," Greenway remembers. Shortly after the drug was released in Europe, however, reports of Rimonabant-related suicides began trickling in. The drug was never approved in the U.S. and was later recalled in Europe.

As a result, the FDA will likely view the new antiobesity drugs with caution. In July an FDA advisory panel narrowly voted against Qnexa, citing concerns over side effects. The FDA is not required to act on the panel's recommendation, though.

Ed J. Hendricks, a physician who runs a weight-loss center in Sacramento, Calif., hopes at least one of the three drugs will be approved. "As the pathways behind obesity are better understood, the drugs are getting more specific," he says. The question is whether they will act specifically enough and prove safe for wide use.

Erica Westly is a freelance science writer based in New York City.

Social Analgesics

Feeling the pain of rejection? Try taking a Tylenol BY GARY STIX

WHAT IS A FATE as bad as death? Many contemporary and ancient societies considered banishment at least equal. After all, in the past, estrangement from family or friends, along with the corresponding exile away from the campfire or town gates, meant literally getting thrown to the wolves. Not surprisingly, our brains are wired with circuitry so that we can scrupulously avoid such fates, whether that means expulsion to the desert as in the Biblical tale of Hagar and Ishmael or the heartbreak of not getting that long-awaited invitation to the high school prom. The neurological wiring that makes us feel pain, new research suggests, also means that a common painkiller could ease the sting.

One brain area in question resides about an inch behind your forehead. Called the anterior cingulate cortex, it serves as one of the brain's control centers for that "why me?" feeling when you get picked last for the dodgeball game. It also happens to be the same circuitry that induces the emotional component of pain, that desperate feeling provoked by the throbbing of a toothache. Evolution may have piggybacked brain functions that regulate social interaction on top of a more primal pain system. The way we speak ("I'm crushed") even hints at just such a connection.

Research from the 1970s in rodents on the overlapping functions of this brain circuitry showed that opiates tended to quell not only painful stimuli but also the tiny squeaks that signal distress. C. Nathan DeWall, a social psychologist at the University of Kentucky who has researched the neurobiology of rejection for nearly 10 years, wondered whether an extraordinarily simple step to tone down these double-duty pain circuits might work in the human brain, which has evolved to master playground politics and other complex behaviors. Instead of dosing subjects with Vicodin, he and colleagues simply handed out acetaminophen (Tylenol) or a placebo to 62 volunteers. "We didn't have to use fancy drugs; we didn't have to get prescriptions," he says. "All we had to do was find a drug that was safe and effective in alleviating the type of pain that we're interested in."

PHYSICAL OR EMOTIONAL? **Circuits in the brain for both types of pain respond to acetaminophen, a recent study finds.**

GETTY IMAGES

In one part of the study, published in the July *Psychological Science,* participants reported feelings of rejection on questionnaires. In another part, they played a computer game in which they were progressively excluded from a virtual ball-passing group as time elapsed. Brain imaging revealed that the Tylenol-gobbling group appeared to experience fewer feelings of rejection than those who received a placebo did. "I believe this study reports some of the best evidence that the systems that mediate our reactions to rejection evolved out of systems that signal the potential for physical harm," says Kevin Ochsner, head of Columbia University's social cognitive neuroscience lab.

One study does not a combo headache and heartache drug make. "That's a question I get a lot: Should I take some acetaminophen before opening the letter from a potential employer?" DeWall comments. "It's a little too early to make a call for widespread use."

If validated, acetaminophen may become an invaluable research tool in seeking the neural underpinnings of not only exclusion but other mental processes related to social behavior. In one unpublished study, DeWall and his associates have found that subjects' moral judgments change after receiving acetaminophen. They become less wracked by indecision when facing the classic moral dilemma in which one person must be sacrificed to save many; they reject out of hand what they perceive to be a ludicrous choice. If acetaminophen really does assist in resolving internal emotional conflict, it might help socially awkward individuals who become distraught when confronted by more routine moral choices. An ability to induce subtle shifts in perspective may give entirely new meaning to the Tylenol slogan of "Feel better."

ENERGY & ENVIRONMENT

Sour Showers

Acid rain is back—this time triggered by nitrogen emissions

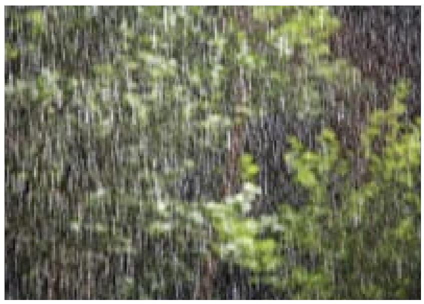
BY MICHAEL TENNESEN

THE ACID RAIN SCOURGE of the 1970s and 1980s that killed trees and fish and even dissolved statues on Washington, D.C.'s National Mall has returned with a twist. Rather than being sulfuric acid derived from industrial sulfur emissions, the corrosive liquid is nitric acid, which has resulted not just from smokestacks but also from farming.

Besides dissolving cement and limestone and lowering the pH of lakes and streams, acid rain leaches critical soil nutrients, injuring plants, and liberates toxic minerals that can enter aquatic habitats. To combat the problem the first time around, the U.S. Environmental Protection Agency passed the Clean Air Act Amendments of 1990, which cut sulfur emissions from power plants by 59 percent from 1990 to 2008. Emissions of nitrogen compounds, however, have not fallen as steeply.

Overall, coal-fired power plants and motor vehicles spew out most of the nation's nitrogen oxides, the feedstock for nitric acid rain. But a good deal of it also comes from the agricultural sector in the form of ammonia (NH_3), which bacteria can convert to nitric acid on the ground. A major culprit is fertilizer manufacture, which takes nonreactive nitrogen gas in the atmosphere and turns it into ammonia via the so-called Haber-Bosch process. Concentrated animal-feeding operations in the South also produce ammonia. "Agriculture is increasingly functioning as an intensively managed industrial operation, and that is creating serious water, soil and air problems," says Viney P. Aneja, a professor of air quality and environmental technology at North Carolina State University.

Scientists are beginning to document the damage. Researchers at Hubbard Brook Experimental Forest in New Hampshire's White Mountain National Forest found evidence of nitric acid rain, which appears to have originated from nitric oxides from the upper Midwest. They reported that it might reduce cold or stress tolerance in some tree species, including red spruce and sugar maple. Similarly, researchers have traced nitric oxide rising from Kentucky and Tennessee and drifting toward the Great Smoky Mountains, where researchers have observed some of the worst acid rain and forest decline, says William H. Schlesinger, president of the Cary Institute for Ecosystem Studies in Millbrook, N.Y.



RAINY DANGER: **Nitrogen emissions are triggering new bouts of acid rain, which in the 1980s did serious environmental harm.**

JOHN BURCHAM *Getty Images*

Although the U.S. could tighten existing clean air rules to combat atmospheric nitrogen emissions, the nation has neither comprehensive laws nor adequate monitoring devices for such emissions by livestock and farms. Schlesinger thinks that national arguments over climate change have allowed the U.S. to ignore the nitrogen problem, which he predicts will be the next big environmental issue. "It's another example of humans upsetting global biogeochemical cycles with unintended consequences," he says.

Government action could help significantly: the European Union, for instance, passed an acidification abatement pact called the Gothenburg Protocol in 1999, which has decreased Europe's nitrogen emissions by one third, during a time when U.S. emissions have remained constant. Adding insult to injury, the U.S. increased its ammonia emissions by 27 percent from 1970 to 2005, according to a 2009 paper in *Environmental Science & Technology*.

Without intervention, the problem will likely worsen. The growing world population, expected to increase from 6.5 billion today to nine billion by 2050, will put pressure on agricultural productivity and, subsequently, fertilizer use. The Integrated Nitrogen Committee of the EPA's science advisory board, which held a June public teleconference on the issue of reactive nitrogen in the environment, has generated a draft report that lays out the details, including management options for nitric acid rain. It also discusses ways to monitor atmospheric emissions, currently the weak link in the nitrogen-control picture. The final report is expected be released next year.

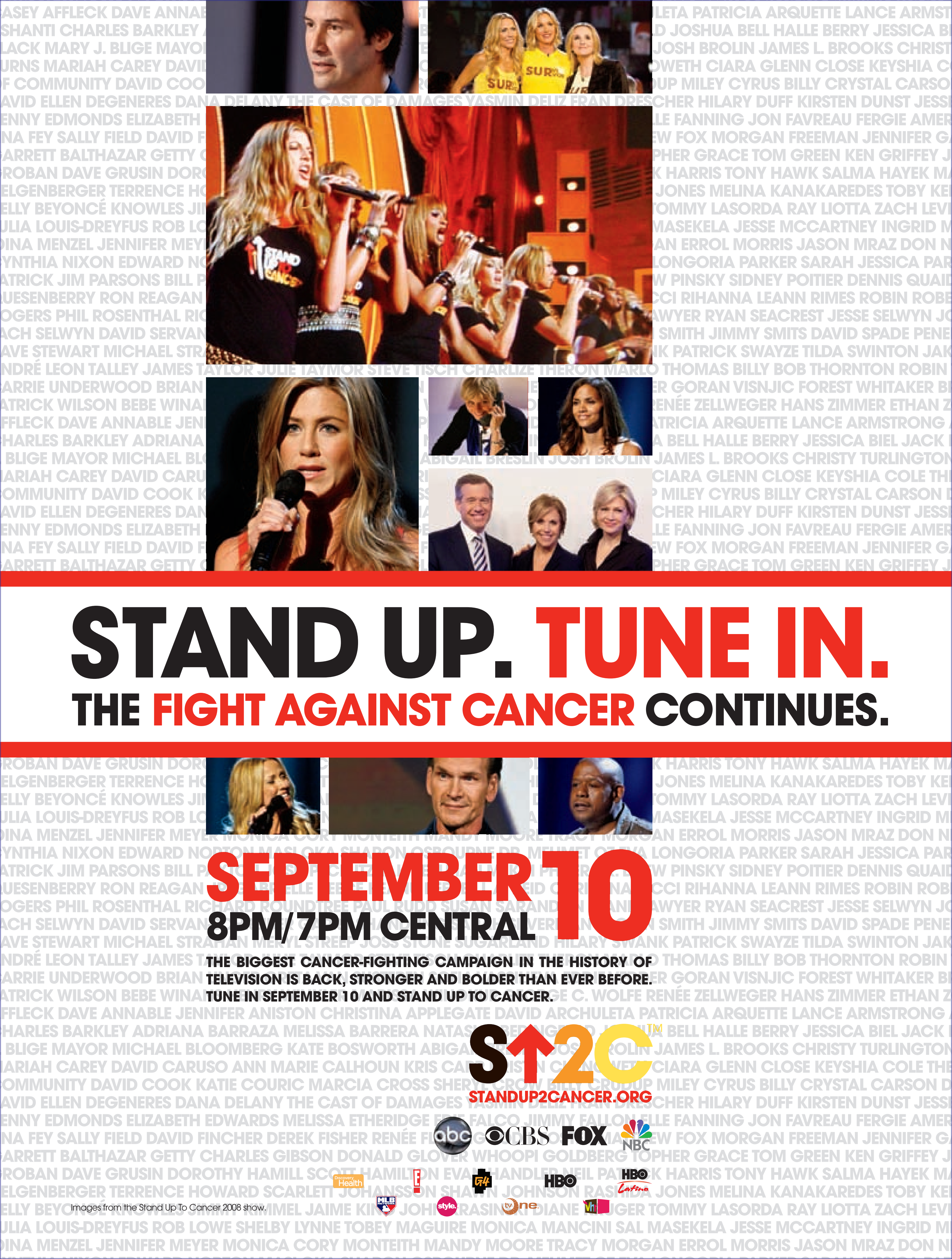
Michael Tennesen, based near Los Angeles, writes frequently about environmental issues.

Doubts on Dispersants

Attempt to resolve toxicity issue of oil dispersants muddies the water

BY DAVID BIELLO

TO BREAK UP THE OIL that leaked into the Gulf of Mexico, BP had applied by mid-July nearly two million gallons of dispersants, both at the sea's surface and below. Environmentalists worry that the chemicals could be as damaging as the oil. To address such concerns, the U.S. Environmental Protection Agency released early this summer preliminary data from its tests, but instead of quelling fears, the data have stirred up more questions.


STAND UP. TUNE IN.
THE FIGHT AGAINST CANCER CONTINUES.
SEPTEMBER 10
8PM/7PM CENTRAL
THE BIGGEST CANCER-FIGHTING CAMPAIGN IN THE HISTORY OF TELEVISION IS BACK, STRONGER AND BOLDER THAN EVER BEFORE. TUNE IN SEPTEMBER 10 AND STAND UP TO CANCER.
SU2C™
STANDUP2CANCER.ORG
abc CBS FOX NBC
Discovery Health E! G4 HBO HBO Latino
MLB style. tv one VH1
Images from the Stand Up To Cancer 2008 show.

In a bid to corroborate potentially suspect results that were provided by the dispersants industry, the EPA tested eight dispersants, including COREXIT 9500, the one most widely used by BP. The agency's results showed broad similarities with industry's analyses—some effects on silverside fish and mysid shrimp, but no significant disruption of hormonal systems of animals, at least at the cellular level. "All the dispersants are roughly equal in toxicity and generally less toxic than oil," said EPA assistant administrator and chemist Paul Anastas in a press briefing on June 30. "The dispersant constituents are expected to biodegrade in weeks to months, rather than remaining in the ecosystem for years as oil might."

But at least one outside toxicologist has found reason to criticize the EPA and the methods it has used. "There is not any information on what is the environmentally relevant level of dispersants," says toxicologist Carys L. Mitchelmore of the University of Maryland, who helped to write a 2005 National Research Council report on dispersants. Nor is there any evidence that the agency had any requirements for defining acceptable toxicity levels in the industry-provided data. From that information alone, "I could not compare and contrast which one was more toxic than the other," Mitchelmore recounts.

In fact, it remains unclear whether anyone at the EPA ever checked the industry-provided numbers as required by law. When SCIENTIFIC AMERICAN asked Anastas about that, he did not directly answer the question, and the EPA did not respond to follow-up questions. Such clarification would be useful because the industry data appear to be full of potential faults, including, in the analysis of one dispersant, the use of the wrong reference toxicant. Nor did the EPA show the best understanding of toxicology in urging BP in a directive to use dispersants with a "toxicity value less than" a certain cutoff: in toxicology, a chemical that produces harm at low concentrations, say, five parts per million, is *more* deadly than those that kill at 10 parts per million.

The problems are not entirely the fault of the EPA; policies for safety testing under current chemical regulations are flawed [see "Chemical Controls"; Perspectives, SCIENTIFIC AMERICAN, April]. "The magnitude of this event has raised important questions about how these previous, existing regulations [for dispersants] may need to be reexamined and revisited in ways that ask different questions and even better prepare us in the future," Anastas admitted.

Although Congress has suggested reforms, it is uncertain if the EPA will address these methodology issues as it explores the contamination in the Gulf of Mexico. In July the EPA began conducting toxicity tests for the specific light sweet crude from the Gulf, both alone and in conjunction with the various dispersants.

"Once it's mixed with oil, that's where you get the most impact, that's where you see most of the toxicity," says toxicologist Sergio Alex Villalobos of Nalco, the maker of COREXIT 9500. Anastas suggested that testing was expected to be completed before the end of August.

OIL CHECK: A Coast Guard ensign logs water samples from the Gulf of Mexico to help determine the effectiveness of oil dispersants used by BP.

COURTESY OF PETTY OFFICER 2ND CLASS LUKE PINNEO *U.S. Coast Guard*

TECHNOLOGY

Quantum Light Switch

A single atom acts as a transistor for photons BY DAVIDE CASTELVECCHI

POINT TWO LASER BEAMS so that they cross each other, and each goes through as if the other one did not exist. Light rays cannot interact with other light rays—or can they? With the help of a single atom, physicists have devised a system in which one light beam can turn another on or off. Such a light switch could serve as the basic component of futuristic optical quantum computers and may help open the way to a quantum version of the Internet, which would offer unbreakable data security.

The device makes use of a phenomenon called electromagnetically induced transparency, in which a laser beam can render opaque clouds of atoms temporarily transparent to a narrow wavelength of light. The cloud can then act as a switch for a second beam, either letting it through or blocking it. The result is similar to what happens with transistors in electronic circuits, where a voltage applied at one electrode controls whether current can flow between two other electrodes.

Applications such as quantum computing demand the control of beams down to single photons, the elementary particles of light. For that purpose, single atoms are better than clouds of them, says physicist Martin Mücke of the Max Planck Institute for Quantum Optics in Garching, Germany. He and his collaborators trapped a rubidium atom and aimed two different laser beams at it: one for probing, or transmitting, and the other one for switching. Ordinarily the atom acts as a barrier to photons from the probe beam because it would first absorb them—going from its "ground" state to an "excited" state—and then shoot them back, that is, reflect them. This condition would constitute the "off" state of the device.

But turning on the switching beam changed the atom's possible states, so that it now had two different ground states. The probe beam then had two different ways of exciting the electron, each starting from a different ground state, but in the mathematics describing the atom's quantum-mechanical nature, the two possibilities cancel out, so that no excitation was possible. Thus, the probe beam photons, rather than being absorbed, could get through, marking the "on" state.

Making single photons interact can be useful because a photon can carry the units of quantum information, called qubits. They can exist in two states simultaneously and thereby represent both the 0 and 1 of binary code at the same time. Thanks to this feature, quantum computers could perform certain operations in parallel. In principle, they could quickly perform calculations that a typical computer could not do, at least not before the sun swells up and bakes the earth five billion years from now.

Max Planck's Gerhard Rempe, the senior researcher on the team, points out that a single-atom device could do more than mere switching. For example, it could store photons and release them at will without damaging their delicate quantum states—an application known as quantum random-access memory, which could be crucial for data routers of a quantum Internet. In such a network, privacy is guaranteed by the law of quantum physics [see "Privacy and the Quantum Internet," by Seth Lloyd; Scientific American, October 2009].

The new device still needs improvement: in the off position, the atom still lets through 80 percent of photons from the second beam. But the researchers say that straightforward improvements, such as keeping the atom colder, could bring that number down to 10 percent, if not to 0. (A more substantial limitation is that handling single atoms requires a fairly sophisticated physics laboratory.) The team published its results in the June 10 *Nature*. (*Scientific American* is part of Nature Publishing Group.)

Right now the device's low efficiency limits its usefulness, comments Paul G. Kwiat, a quantum optics expert at the University of Illinois at Urbana-Champaign. But if the team can improve efficiency, he notes, it "could open a new, potentially efficient approach to quantum computing."

Origami Sheets That Fold Themselves

Researchers have invented a real-life Transformer, a device that can fold itself into two shapes on command. The system is hardly ready to do battle with the Decepticons—the tiny contraption forms only relatively crude boat and airplane shapes—but the concept could one day produce chameleonlike objects that shift between any number of practical shapes at will.

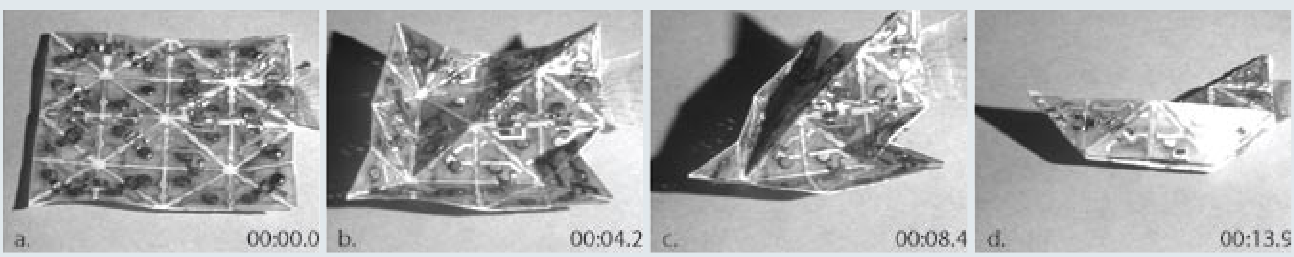
Self-folding sheets are just one facet of programmable matter. "Instead of programming bits and bytes, you program mechanical properties of the object," says Daniela Rus, a roboticist at the Massachusetts Institute of Technology.

The system, described online June 28 in the *Proceedings of the National Academy of Sciences USA,* consists of a thin sheet of resin–fiberglass composite, just a few centimeters across, segmented into 32 triangular panels separated by flexible silicone joints. Some of the joints have heat-sensitive actuators that bend 180 degrees when warmed by an electric current, folding the sheet over at that joint. Depending on the program used, the sheet will conduct a series of folds to yield the boat or airplane shape in about 15 seconds.

The researchers say that in principle the system could produce many more shapes than two. "We were looking for ways to embed a bunch of different functionalities into one low-profile sheet," says co-author Robert J. Wood, an electrical engineer at Harvard University.

In the near term, Rus envisions the computational origami technology forming the basis of three-dimensional displays—for instance, maps that can reproduce the topography of a given region on demand. In the more distant future, applications might move beyond shape mimicry to involve programmable optical, electric or acoustic properties.

—*John Matson*



AUTOBOTS, TRANSFORM! **Well, not really, but researchers have made "programmable matter" that folds itself into shapes, such as a boat.**

Watch a video of the shape-shifting matter at **ScientificAmerican.com/sep2010/shape**

COURTESY OF HARVARD MICROROBOTICS LAB

Snake Oil in the Supermarket

Food makers should have to prove the validity of their health claims

BY THE EDITORS

From cereals that boost immunity to yogurts that regulate digestion and juices that keep heart disease at bay, grocery stores in the U.S. are brimming with packaged foods and beverages that claim to improve health. Such declarations are good for business: sales of "functional foods"—those that manufacturers have modified to provide supposed health benefits—generated $31 billion in the U.S. in 2008, a 14 percent increase over 2006, according to Rockville, Md.–based market research firm Packaged Facts. But consumers are getting a rotten deal. Although health claims for foods may appear to be authoritative, in many cases science does not support them and the government does not endorse them. Not only do these products, many of which are nutritionally bereft, fail to deliver on their promises, but they may also give consumers a false sense of security that discourages them from taking more effective measures to attain wellness, such as exercise or medication.

In March the U.S. Food and Drug Administration issued warning letters to 17 food and beverage manufacturers concerning false or misleading health and nutrition claims on their products. It was an unusually expansive crackdown for the agency, whose regulatory power over food companies has declined over the past decades, thanks to Congress and the courts, which have tended to come down on the side of the food companies. The FDA's move, accompanied by an open letter from Commissioner Margaret Hamburg about the importance of accurate nutrition labeling, was a significant step toward halting the exploitation of science by food marketers, but it does not go far enough in protecting consumers from deceptive marketing.

The FDA currently issues guidelines for what claims companies can make about their foods. It allows statements about how products affect the normal structure and function of the body but prohibits unauthorized claims about disease. The agency, though, does not review compliance before food is packaged and shipped. Food products arrive at the stores emblazoned with questionable claims. Cheerios can lower cholesterol 4 percent in six weeks, asserted the box label, until the FDA sent General Mills a cease-and-desist letter in May 2009. Redco Foods's Salada Naturally Decaffeinated Green Tea promised to tackle Alzheimer's, rheumatism and cancer, until the March crackdown. The agency is then forced to play catch-up. Meanwhile the snake oil sits on supermarket shelves.

Holding health claims for food to the same scientific standards as those for drugs—and requiring manufacturers to convince the FDA of alleged benefits before releasing products for sale—would result in far fewer health claims on packaged foods, if recent developments in Europe are any indication. In 2006 Europe began holding food makers to rigorous scientific standards. Since then, the European Food Safety Authority has rejected, on the basis of insufficient evidence, a whopping 80 percent of the more than 900 claims they have assessed thus far. Among the rejects were claims about probiotic ingredients, which are commonly found in yogurt products and often touted for their alleged digestive benefits, and omega-3 fatty acids, which are frequently added to products ranging from orange juice to baby food and are often said to promote brain development. The simple act of asking for evidence is sometimes enough to reveal the shoddiness of a claim—some European firms drew supporting materials from Wikipedia, the American Heritage dictionary and the Bible.

Differences between the lenient U.S. system and the more restrictive European system are easily apparent. For instance, visitors to the Web site for Activia (www.activia.com)—a yogurt product from Dannon—will have a very different experience depending on which country they indicate they are from. The U.S. version prominently displays the product's putative health benefits, asserting that it can "help regulate your digestive system by helping reduce long intestinal transit time." (It does not say explicitly that the yogurt helps to alleviate constipation, which would be a clear violation of the FDA prohibition of unauthorized claims about specific medical conditions.) The U.K. version, on the other hand, says only that the yogurt contains an exclusive bacterial culture and, like other yogurts, is a source of calcium and vitamin B_{12}.

Industry representatives complain that having to prove claims about the health benefits of food would cost too much and take too long. It's a lame argument. The nation is currently engaged in a struggle against skyrocketing rates of obesity and other diet-related diseases that are among the leading causes of death in the U.S. In this context, unsubstantiated health claims on processed foods are a harmful abuse of science that we should not tolerate. ■

ILLUSTRATION BY MATT COLLINS

The Deepening Crisis

Failure to act on threats to global sustainability brings the world closer to disaster

BY JEFFREY D. SACHS

With this final column I will transition Sustainable Developments from *Scientific American* to the home page of the Earth Institute (www.earth.columbia.edu). Although I will continue to contribute occasional essays to the magazine, I will use this last regular column to say thank you and take stock of the deepening crisis of sustainable development.

During the four years of this column, the world's inability to face up to the reality of the growing environmental crisis has become even more palpable. Every major goal that international bodies have established for global environmental policy as of 2010 has been postponed, ignored or defeated. Sadly, this year will quite possibly become the warmest on record, yet another testimony to human-induced environmental catastrophes running out of control.

This was to be the year of biodiversity. In 2002 nations pledged, under the auspices of the United Nations Convention on Biological Diversity, to slow significantly the planetary loss of biodiversity by 2010. This goal was not even remotely achieved. Indeed, it was barely even noticed by Americans: the U.S. signed the convention in 1992 but never ratified it. Ratification fell victim to the uniquely American delusion that virtually all of nature should be subdivided into parcels of private property, within which owners should have their way.

This year was also to be the start of a new post-Kyoto treaty, but that effort was stillborn by the continuing paralysis of U.S. policy making. President Barack Obama came empty-handed to the Copenhagen climate change negotiations, and the U.S., China and other powers settled for a nonbinding declaration of sentiments and goals rather than an operational strategy and process of implementation.

According to Obama's 2008 election campaign, this was to be the first year of a new climate and energy policy for the U.S., too, and the second year of a "green recovery." We've had neither. The recovery has sputtered: Obama bet on "stimulating" exhausted consumers rather than on a long-term program of public investments in sustainable infrastructure. The Senate, true to form, sustained its 18th year of inaction on global warming since ratifying the U.N. Framework Convention on Climate Change in 1992.

This year was ushered in by the phony "Climategate" controversy, which involved leaked e-mails of a British climate research unit; the political right wing depicted some ill-considered language in the messages as proof of a vast global plot. Independent reviews have since rejected the charges of scientific conspiracy, but the damage is done: the U.S. public once again swings toward disbelief in the basic science of human-induced climate change.

We are losing not just time but the margin of planetary safety, as the world approaches or trespasses on various thresholds of environmental risk. With the human population continuing to rise by 75 million or more per year and with torrid economic growth in much of the developing world, the burdens of deforestation, pollution, greenhouse gas emissions, species extinction, ocean acidification and other massive threats intensify.

What deep features of our national and global socioeconomic processes cause these repeated failures? First, the risks to sustainability are truly unprecedented in their global scale and have come upon society rather suddenly in the past two generations. Second, the problems are scientifically complex and involve enormous uncertainties. Not only must public opinion catch up with reality, but key sciences must also scramble to measure, assess and address the new challenges.

Third, although the problems are global, politics is notoriously local, which impairs timely, coordinated international action. Fourth, the problems are unfolding over decades, whereas politicians' attention spans reach only to the next election and much of the public's to the next meal or paycheck. Fifth, vested corporate interests have mastered the dark arts of propaganda, and they can use their deep pockets to purchase a sea of deliberate misinformation to deceive the public.

Scientific American and the Earth Institute are committed partners in the same make-or-break effort: to bring objective science to the public sphere and to empower a democratic citizenry who must become responsible stewards of the planet before it is too late. ■

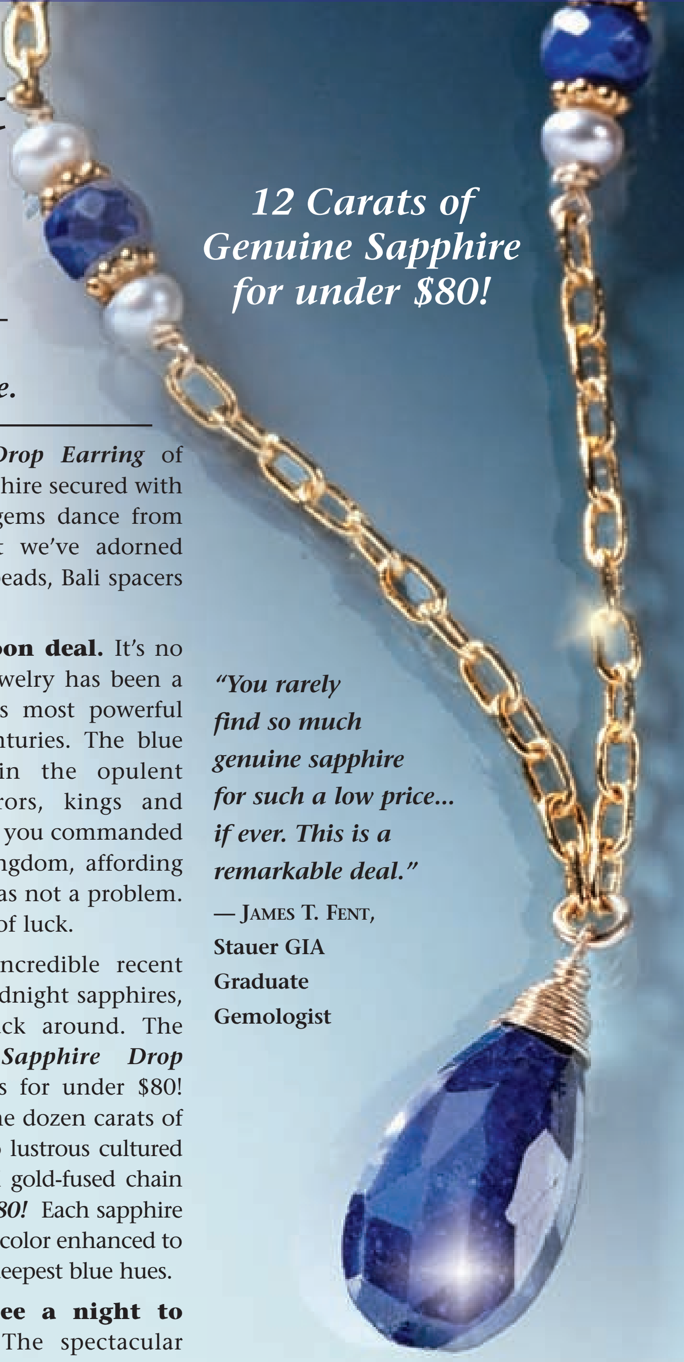
Jeffrey D. Sachs is director of the Earth Institute at Columbia University (www.earth.columbia.edu).

SCI AM An extended version of this essay is available at **www.ScientificAmerican.com/sep2010**

PHOTOGRAPH BY BRUCE GILBERT/EARTH INSTITUTE; ILLUSTRATION BY MATT COLLINS

Wife Discovers Secret Office Romance... And She's Thrilled

Make Your Life More Passionate After Dark with the 14K gold-fused Midnight Sapphire Drop Necklace.



12 Carats of Genuine Sapphire for under $80!

I should have seen it coming. The luxury business is full of temptation. After months of international travel and long, lonely nights in some of the world's most romantic cities... I was setting myself up for the fall. And I fell hard. When our designer showed me the ***12-Carat Midnight Sapphire Drop Necklace,*** it was love at first sight. After he told me we could offer it at ***only $79***, I knew this was more than just a fling.

The night she found out. I kept it from my wife for weeks, until our anniversary weekend in France. It was a clear summer evening and we stepped out onto the terrace for a look at the Paris skyline. I'm sure the Champs-Élysées glittered like a river of diamonds and the full moon blazed like a 1,000-watt bulb... but all I remember was her and her necklace. There was nothing brighter than that gorgeous drop of midnight sapphire. It sparkled like no other dark blue stone I'd ever seen.

Don't be afraid of the dark. The ***Midnight Sapphire Drop Necklace*** features a dangerously dark dollop of genuine sapphire, a faceted pear that weighs in at an amazing 10 carats! Secured with a twist of gold-fused wire, the blue gem dangles elegantly from an 18" cable chain that we've luxuriously layered in gold. Look closely and you can see that we've even added some opulent accents to the chain: a pair of fabulous one carat sapphire beads flanked by Bali-style spacers and lustrous, vanilla fresh-water pearls.

And we've created an equally fetching pair of companions to round out the night's ensemble. Each matching ***Midnight Sapphire Drop Earring*** of genuine dark blue sapphire secured with gold-fused wire. The gems dance from gold-fused hooks that we've adorned with 1-carat sapphire beads, Bali spacers and freshwater pearls.

A once-in-a-blue-moon deal. It's no secret that sapphire jewelry has been a favorite of the world's most powerful and privileged for centuries. The blue gem was a staple in the opulent collections of emperors, kings and maharajahs. As long as you commanded a vast and wealthy kingdom, affording large-carat sapphires was not a problem. Everyone else was out of luck.

But thanks to this incredible recent purchase of natural midnight sapphires, we've turned that luck around. The 12-carat ***Midnight Sapphire Drop Necklace*** can be yours for under $80! You read that right. One dozen carats of bold blue sapphire, two lustrous cultured pearls and a 14K gold-fused chain for ***less than $80!*** Each sapphire is scientifically color enhanced to bring out the deepest blue hues.

We guarantee a night to remember. The spectacular sparkle of the ***Midnight Sapphire Drop Necklace*** is something you really need to see for yourself. Whether you're headed for the social event of the year or a romantic dinner for two, we guarantee the necklace will light up the night. If you're not completely seduced by the ***Midnight Sapphire*** simply return it within 30 days for a complete refund of your purchase price. But we're confident that this midnight temptation will prove impossible to resist.

JEWELRY SPECS:

- 12 ctw of genuine, color enhanced sapphires
- Bali-style gold spacers with freshwater pearls
- 18" length cable chain

"You rarely find so much genuine sapphire for such a low price... if ever. This is a remarkable deal."

— James T. Fent, Stauer GIA Graduate Gemologist

Midnight Sapphire Drop Necklace
(12 ctw) ~~$495~~ *NOW* **$79** +s&p

Midnight Sapphire Drop Earrings
(6 ctw) ~~$195~~ *NOW* **$79** +s&p

Midnight Sapphire Drop Set
~~$690~~ *NOW* **$149** +s&p

Set includes earrings and necklace.

Call now to take advantage of this limited offer.

1-888 201-7148

Promotional Code MSN135-01
Please mention this code when you call.

Stauer

14101 Southcross Drive W., Dept. MSN135-01
Burnsville, Minnesota 55337

A+ Rating

www.stauer.com

Smart Luxuries—Surprising Prices

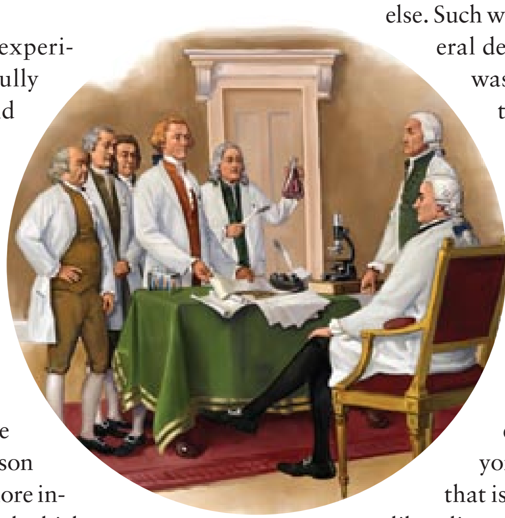
Democracy's Laboratory

Mixing science and politics is tricky but necessary for a functioning polity

BY MICHAEL SHERMER

Do you believe in evolution? I do. But when I say "I believe in evolution," I mean something rather different than when I say "I believe in liberal democracy." Evolutionary theory is a science. Liberal democracy is a political philosophy that most of us think has little to do with science.

That science and politics are nonoverlapping magisteria (vide Stephen Jay Gould's model separating science and religion) was long my position until I read Timothy Ferris's new book *The Science of Liberty* (HarperCollins, 2010). Ferris, the best-selling author of such science classics as *Coming of Age in the Milky Way* and *The Whole Shebang,* has bravely ventured across the magisterial divide to argue that the scientific values of reason, empiricism and antiauthoritarianism are not the *product* of liberal democracy but the *producers* of it.



Democratic elections are scientific experiments: every couple of years you carefully alter the variables with an election and observe the results. If you want different results, change the variables. "The founders often spoke of the new nation as an 'experiment,'" Ferris writes. "Procedurally, it involved deliberations about how to facilitate both liberty and order, matters about which the individual states experimented considerably during the eleven years between the Declaration of Independence and the Constitution." As Thomas Jefferson wrote in 1804: "No experiment can be more interesting than that we are now trying, and which we trust will end in establishing the fact, that man may be governed by reason and truth."

Many of the founding fathers were scientists who deliberately adapted the method of data gathering, hypothesis testing and theory formation to their nation building. Their understanding of the provisional nature of experimental findings led them naturally to form a social system wherein doubt and disputation were the centerpieces of a functional polity. "The new government, like a scientific laboratory, was designed to accommodate an ongoing series of experiments, extending indefinitely into the future," Ferris explains. "Nobody could anticipate what the results might be, so the government was structured, not to guide society toward a specified goal, but to sustain the experimental process itself."

For example, the political belief of John Locke that people should be treated equally under the law—which factored heavily in the construction of the U.S. Constitution—was an untested theory in the 17th century. In fact, Ferris told me in an interview, "few thinkers prior to the advent of the American liberal-democratic experiment thought democracy could work in any but the most limited forms" and that most political theorists believed that "the common people are too stupid and ignorant to be trusted electing their leaders." And yet, Ferris continued, "liberal democracy did succeed and is today the stated preference of the majority of the world's peoples, including both those who live in democratic nations and those who don't." What would constitute a failed experiment in the political laboratory? "If it ceased to exist in the nation under examination and was replaced by something else. Such was widely predicted to be the fate of the liberal democracies, but the verdict of experiment was otherwise: liberal democracy turned out to be the most stable and long-lasting form of government ever instituted."

But, I protest, aren't all political claims types of *beliefs?* No, Ferris responded: "Liberalism and science are methods, not ideologies. Both incorporate feedback loops through which actions (e.g., laws) can be evaluated to see whether they continue to meet with general approval. Neither science nor liberalism makes any doctrinaire claims beyond the efficacy of its respective methods—that is, that science obtains knowledge and that liberalism produces social orders generally acceptable to free peoples."

The myth of the scientific method as a series of neat and tidy steps from hypothesis and prediction to experiment and conclusion is busted once you go into a lab and observe the more haphazard and messy realities of how researchers feel their way toward discovery. So it is with liberal democracies, which almost never work out as planned but somehow progress ever closer to finding the right balance between individual liberty and social order. The constitutions of nations are grounded in the constitution of humanity, which science is best equipped to understand. ■

Michael Shermer is publisher of Skeptic *magazine (www.skeptic.com) and author of* The Mind of the Market.

PHOTOGRAPH BY BRAD SWONETZ; ILLUSTRATION BY MATT COLLINS

A Year of Living Dangerously

Writing about science and society invites reactions, good and bad, from the middle to the fringe

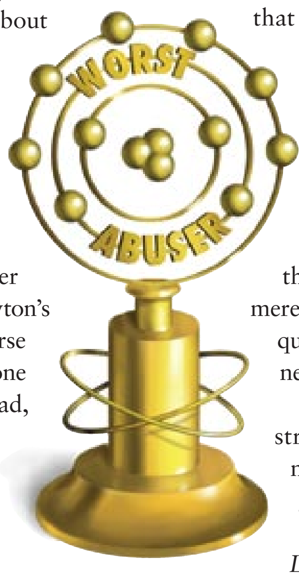
BY LAWRENCE M. KRAUSS

Last September I wrote my first column for *Scientific* *American,* and this September marks my last one. In writing on science issues relevant to our culture and society, there is an inevitable tension between sticking just to science issues and commenting on potentially hot-button social issues. I have tried during the past 12 months to strike some balance, but without fail those issues that stir the greatest outrage also stir the greatest interest.

Nothing seems to stir more discussion than pieces about science and religion, an observation that reminds me of the comment that Henry Kissinger reputedly made about academic disputes: they are so vicious because the stakes are so small. After all, science will continue irrespective of religious opinions, and I expect organized religion will continue to be a part of the cultural landscape, too, largely unaffected by the ongoing march of human knowledge, as it has been for centuries.

Probably my greatest surprise came from the column on my favorite elementary particles, neutrinos. Several notes of thanks came from scientists who have devoted their lives to studying neutrinos' properties; perhaps they feel underappreciated, even by their colleagues, for studying such ephemeral objects.

Among topics I didn't get a chance to write about, one stands out, so I will take advantage of this last opportunity to elicit hate mail (and to shamelessly plug my new book about the late physicist Richard Feynman, which is relevant because of its title, *Quantum Man*).



No area of physics stimulates more nonsense in the public arena than quantum mechanics—and with good reason. No one intuitively understands quantum mechanics because all of our experience involves a world of classical phenomena where, for example, a baseball thrown from pitcher to catcher seems to take just one path, the one described by Newton's laws of motion. Yet at a microscopic level, the universe behaves quite differently. Electrons traveling from one place to another do not take any single path but instead, as Feynman first demonstrated, take *every* possible path at the same time.

Moreover, although the underlying laws of quantum mechanics are completely deterministic—I need to repeat this, they are completely deterministic—the results of measurements can only be described probabilistically. This inherent uncertainty, enshrined most in the famous Heisenberg uncertainty principle, implies that various combinations of physical quantities can never be measured with absolute accuracy at the same time. Associated with that fact, but in no way equivalent to it, is the dilemma that when we measure a quantum system, we often change it in the process, so that the observer may not always be separated from that which is observed.

When science becomes this strange, it inevitably generates possibilities for confusion, and with confusion comes the opportunity for profit. I hereby wish to bestow my Worst Abusers of Quantum Mechanics for Fun and Profit (but Mostly Profit) award on the following:

DEEPAK CHOPRA: I have read numerous pieces by him on why quantum mechanics provides rationales for everything from the existence of God to the possibility of changing the past. Nothing I have ever read, however, suggests he has enough understanding of quantum mechanics to pass an undergraduate course I might teach on the subject.

THE SECRET: This best-selling book, which spawned a self-help industry, seems to be built in part on the claim that quantum physics implies a "law of attraction" that suggests good thoughts will make good things happen. It doesn't.

TRANSCENDENTAL MEDITATION: TMers argue that they can fly by achieving a "lower quantum-mechanical ground state" and that the more people who practice TM, the less violent the world will become. This last idea at least is in accord with quantum mechanics, to the extent that if everyone on the planet did nothing but meditate there wouldn't be time for violence (or acts of kindness, either).

For the record: Quantum mechanics does not deny the existence of objective reality. Nor does it imply that mere thoughts can change external events. Effects still require causes, so if you want to change the universe, you need to act on it.

Feynman once said, "Science is imagination in a straitjacket." It is ironic that in the case of quantum mechanics, the people without the straitjackets are generally the nuts. ■

Lawrence M. Krauss, a theoretical physicist and science commentator, is Foundation Professor and director of the Origins Initiative at Arizona State University (www.krauss.faculty.asu.edu).

PHOTOGRAPH BY NANCY DAHL-TACCONI; ILLUSTRATION BY MATT COLLINS


SODEMO-NSK
ICC - EMC - JEHIER
AOT-RABOURDIN-MAHLE
LYCEE LA JOLIVERIE
microjoule
FMC
MICHELIN
BOSCH
SKF
AVIVA
LET'S GO FURTHER ON ONE GALLON OF FUEL.
We must learn to use energy more efficiently. For 25 years, the Shell Eco-marathon® has supported teams worldwide who explore ways to maximize fuel economy. Last year's winner was capable of traveling 8,870 miles on the equivalent of one gallon of fuel. This spirit epitomizes our relationship with car manufacturers, finding ways to make cars more efficient. And it's typical of our ambition to help build a better energy future. Let's go. www.shell.com/letsgo

[INTRODUCTION]

eternal fascinations with the end

Why we're suckers for stories of our own demise

<< BY MICHAEL MOYER >>

PHOTOGRAPHS BY ZACHARY ZAVISLAK


50
DEATH
77
BIODIVERSITY
42
AGING
60
INDIGENOUS CULTURES
56
THE CORPUS
68
TECHNOLOGY
76
WATER
95
OIL
82
CIVILIZATION

ONCE AGAIN, THE WORLD IS ABOUT TO END. The latest source of doomsday dread comes courtesy of the ancient Mayans, whose calendar runs out in 2012, as interpreted by a cadre of opportunistic authors and blockbuster movie directors. Not long before, three separate lawsuits charged that the Large Hadron Collider would seed a metastasizing black hole under Lake Geneva. Before that, captains of industry shelled out billions preparing for the appearance of two zeros in the date field of computer programs too numerous to count; left alone, this tick of the clock would surely have shaken modern civilization to its foundations.

You might think that the enterprise of science, with its method and its facts, would inoculate us against the most extravagant doomsday obsessions. But it doesn't. If anything, it just gives us more to worry about.

Some of the most fervent and convincing doomsayers, after all, are scientists. Bill Joy, co-founder and former chief scientist of Sun Microsystems, has warned that of out-of-control nanobots could consume everything on earth. Astronomer Royal Martin Rees has publicly offered a bet that a biological catastrophe—accidental or intentional—will kill at least one million people by 2020 (so far, no takers). Numerous climatologists sound the alarm about the possibility of runaway global warming. They all stand on the shoulders of giants: British economist Thomas Malthus predicted in the 19th century that the rise in population would lead to widespread famine and catastrophe. It never happened, but that didn't stop Stanford biologist Paul R. Ehrlich from renewing the warning in his 1968 book *The Population Bomb* when he predicted that global famine was less than two decades away. Catastrophe didn't arrive then, either, but does that mean it never will? Not necessarily. Still, people often worry disproportionately about disasters that are unlikely to occur.

Science may be a culprit, but it also offers some explanation for why we can be so fearful. Some researchers think that apocalyptic dread feeds off our collective anxiety about events that lie outside our individual control. The fear of nuclear war and environmental decay that gripped the nation in the 1960s was a big factor in the rise of the counterculture, says John R. Hall, a sociologist at the University of California, Davis, and author of *Apocalypse: From Antiquity to the Empire of Modernity*. In this decade, civilization has suffered through even more fundamental threats. "After events like 9/11 and the Great Recession, as well as technological disasters like the BP oil spill, people begin to wonder—not just people who are fringe zealots or crazies—whether modern society is any longer capable of solving its problems," Hall says. If the world appears to be going to hell, goes the thinking, perhaps that's just what is happening.

The impulse is partially a consequence of our pattern-seeking nature—we are, after all, creatures of the savanna, programmed to uncover trends in the natural world. It is in our nature to weave a simple story from a complex set of data points. (In recent years this tendency has been amplified by news media that are very good at turning complex events into cartoon crises.) The desire to treat terrible events as the harbinger of the end of civilization itself also has roots in another human trait: vanity.

We all believe we live in an exceptional time, perhaps even a critical moment in the history of the species. Technology appears to have given us power over the atom, our genomes, the planet—with potentially dire consequences. This attitude may stem from nothing more than our desire to place ourselves at the center of the universe. "It's part of the fundamental limited perspective of our species to believe that this moment is the critical one and critical in every way—for good, for bad, for the final end of humanity," says Nicholas Christenfeld, a psychologist at the University of California, San Diego. Imagining the end of the world is nigh makes us feel special.

Our fears of the apocalypse may in the end mirror the most fundamental fear of all: fear of our own mortality. It is all of a piece—death, the dissolution of our people, the extinction of our species. Regardless of how we feel about it, flux is the nature of the world, and endings are an inescapable—and often overlooked—part of life. That is why we chose to devote the lion's share of this issue of *Scientific American* to the theme of endings. We look at the chance that civilization will fall to pandemic or asteroid, to the loss of indigenous knowledge spread among the cultures of the world, to the declining resources that our planet will struggle to provide.

Some of these endings are more probable than others. Some, such as the end of time, are downright paradoxical. We start our journey, though, with a look at the inevitable—the private end that we will all have to face and our efforts to forestall it. ■

Michael Moyer is a staff editor at Scientific American.

For more essays, video and multimedia on "The End," including audio from *Scientific American*'s partnership with WNYC radio's "The Takeaway," go to **www.ScientificAmerican.com/TheEnd**

Inside this special issue

PEOPLE

PLANET

UNIVERSE

RESTART

[MEDICINE]

why can't we live forever?

As we grow old, our own cells begin to betray us. By unraveling the mysteries of aging, scientists may be able to make our lives longer and healthier

« BY THOMAS KIRKWOOD »

[KEY CONCEPTS]

- The average life span of humans continues to lengthen, and some scientists have begun to ponder whether this trend will continue indefinitely.
- Not every species ages, and some research suggests that drugs or changes in diet may slow metabolism or alter basic aging processes so that we can live longer. All proposed longevity strategies remain unproved, however.

—The Editors

IF YOU WERE GIVEN a free hand to plan how your life will end—your last weeks, days, hours and minutes—what would you choose? Would you, for example, want to remain in great shape right up until the last minute and then go quickly? Many people say they would choose that option, but I see an important catch. If you are feeling fine one moment, the very last thing you would want is to drop dead the next. And for your loving family and friends, who would suffer instant bereavement, your sudden death would be a cruel loss. On the other hand, coping with a long, drawn-out terminal illness is not great either, nor is the nightmare of losing a loved one into the dark wastes of dementia.

We all prefer to avoid thinking about the end of life. Yet it is healthy to ask such questions, at least sometimes, for ourselves and to correctly define the goals of medical policy and research. It is

JON KRAUSE

also important to ask just how far science can help in efforts to cheat death.

WE'RE LIVING LONGER

IT IS OFTEN SAID that our ancestors had an easier relationship with death, if only because they saw it so much more often. Just 100 years ago life expectancy was shorter by around 25 years in the West. This literal fact of life resulted because so many children and young adults perished prematurely from a whole variety of causes. A quarter of children died of infection before their fifth birthday; young women frequently succumbed to complications of childbirth; and even a young gardener, scratching his hand on a thorn, might be lost to fatal blood poisoning.

Over the course of the past century sanitation and medical care so dramatically reduced death rates in the early and middle years of life that most people now pass away much later, and the population as a whole is older than ever before. Life expectancy is still increasing worldwide. In the richer countries around the world it lengthens five hours or more every day, and in many developing countries that are catching up the rate quickens still faster. Today the dominant cause of death is the aging process itself and the various diseases to which it gives rise—whether cancer, which drives cells to proliferate out of control, or Alzheimer's, at the opposite pole, which causes premature death of brain cells.

Until as recently as 1990, demographers predicted confidently that the historical trend of increasing life expectancy would soon cease. Aging, many researchers believed, was fixed—a process programmed into our biology that resulted in a built-in time of death.

No one foresaw the continued increase in life expectancy. It has taken our politicians and planners by surprise. Scientists are still coming to terms with the notion that aging is not fixed, that average life spans have not reached a limit. They change and continue to change, stretched for reasons that we do not fully understand. The declining death rates of the very old are now driving human life expectancy into uncharted territory. If the prevailing certainties about human aging have crumbled, what is left? What does science actually know about the aging process?

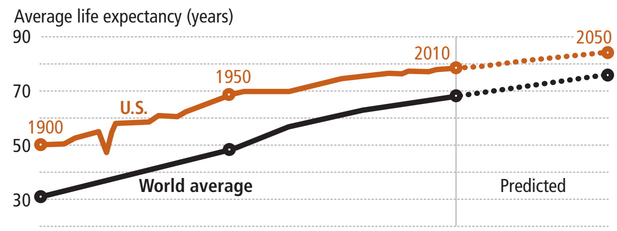
Accepting new ideas is not always easy, because scientists are humans, too, and we have all grown up with fairly rigid precon-

[LONGEVITY METER]

HOW MUCH MORE CAN LIFE SPAN INCREASE?

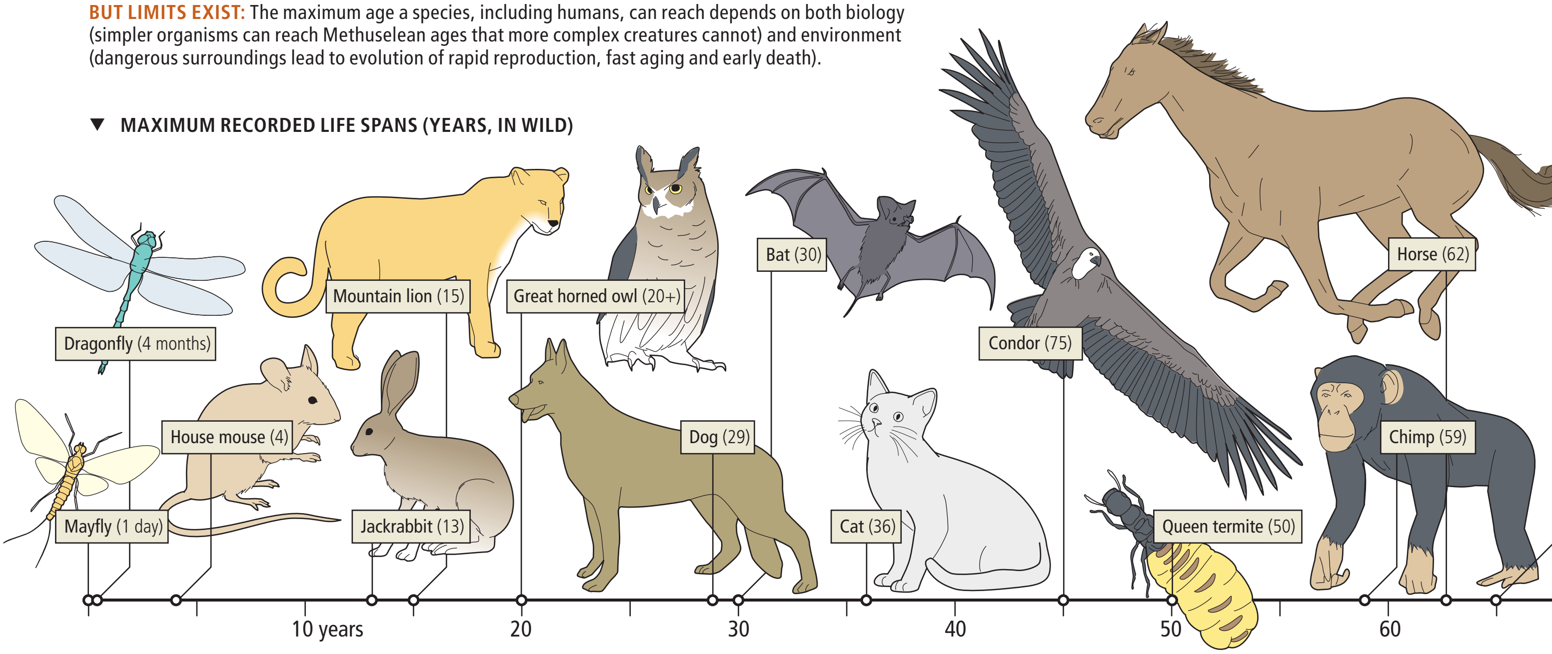
Human life expectancy, or average life span, has been rising for more than 100 years in the U.S. and globally (*graph*). Evidence suggests, however, that biological constraints keep most species from surpassing age limits specific to that species (*below*). Investigators hope interventions aimed at relaxing such constraints will extend today's maximum achievable life span or will at least help people stay healthy longer than they do now.

LIVES GET LONGER: Advances in medicine and sanitation have extended life spans in the U.S. and around the world.



BUT LIMITS EXIST: The maximum age a species, including humans, can reach depends on both biology (simpler organisms can reach Methuselean ages that more complex creatures cannot) and environment (dangerous surroundings lead to evolution of rapid reproduction, fast aging and early death).

▼ MAXIMUM RECORDED LIFE SPANS (YEARS, IN WILD)



ceptions about how the body ages. Some years ago, while driving with my family in Africa, a goat ran under the wheels of our vehicle and was killed instantly. When I explained to my six-year-old daughter what just happened, she asked, "Was it a young goat or an old goat?" I was curious why she wanted to know. "If it was old, it's not as sad, because it wouldn't have had so long to live anyway," came her answer. I was impressed. If such sophisticated attitudes to death form this early, small wonder that modern science struggles to come to terms with the reality that most of what we thought we knew about aging is wrong.

To explore current thinking about what controls aging, let us begin by imagining a body at the very end of life. The last breath is taken, death takes hold and life is over. At this moment, most of the body's cells are still alive. Unaware of what just happened, they carry out, to the best of their abilities, the metabolic functions that support life—procuring oxygen and nutrients from the surrounding environment and using them to generate the energy needed to make and power the activities of proteins (the main working parts of cells) and other cellular components.

In a short while, starved of oxygen, the cells will die. With their death, something of immense antiquity will come to its own quiet end. Each and every one of the cells in the body that just died could, if the records were available, trace its ancestry through an unbroken chain of cell divisions backward in time through an almost unimaginable four billion years to the emergence of the earliest forms of cellular life on this planet.

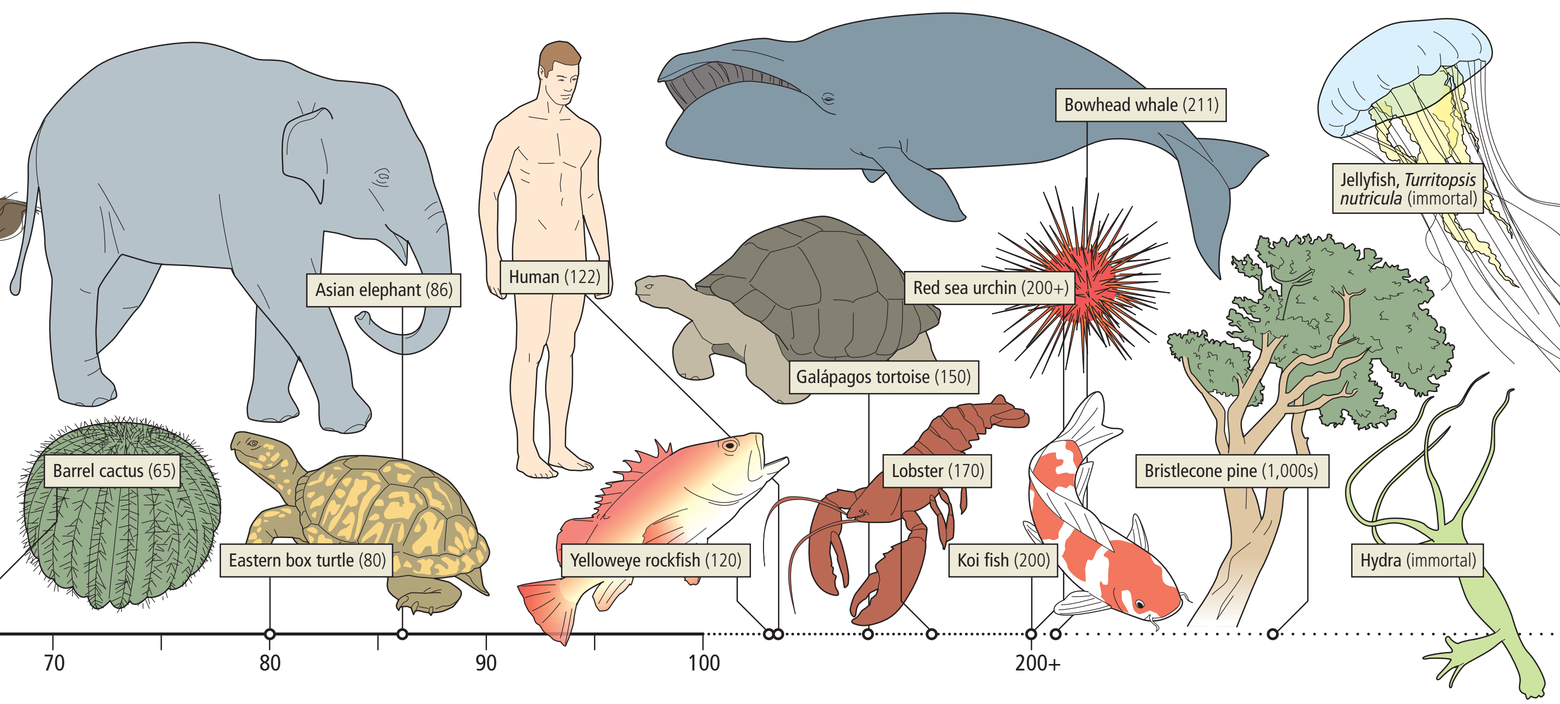
Death is assured. But some of your cells, at least, have this astonishing property: they are endowed with something as near to immortality as can be attained on earth. When your death occurs, only a tiny number of your cells will continue this immortal lineage into the future—and then only if you have children. Only one cell of your body escapes extinction—a sperm or an egg—for each surviving child. Babies are born, grow, mature and reproduce, and so it continues.

The scenario we have just imagined reveals not only the fate of our mortal body, or "soma," made up of all the nonreproductive cells, but also the almost miraculous immortality of the cellular lineage to which we belong. The central puzzle in aging science, from which all else follows, is, Why do most creatures have a mortal soma? Why is it that evolution has not led all our cells to enjoy the apparent immortality of the reproductive lineage, or germ line, as represented by the sperm and the egg? This puzzle was first recognized by 19th-century German naturalist August Weismann, and a solution occurred to me in the bath one winter night in early 1977. I believe that the answer, now called the disposable soma theory, goes a long way toward explaining why different species age as they do.

WHY WE AGE AS WE DO

THE THEORY is best understood by considering the challenges cells and complex organisms face as they try to survive. Cells are damaged all the time—DNA gets mutated, proteins get damaged, highly reactive molecules called free radicals disrupt membranes, and the list goes on. Life depends on the continual copying and translation of genetic data, and we know that the molecular machinery handling all these things, excellent as it may be, is not perfect. Considering all these challenges, the immortality of the germ line is actually remarkable.

Living cells operate constantly under threat of disruption, and the germ line is not immune. The reason that the germ line does not die out in a catastrophe of errors has to do, on the one hand, with its highly sophisticated mechanisms for cellular self-maintenance and repair and, on the other hand, with its ability to get rid of its more serious mistakes through continual rounds of compe-



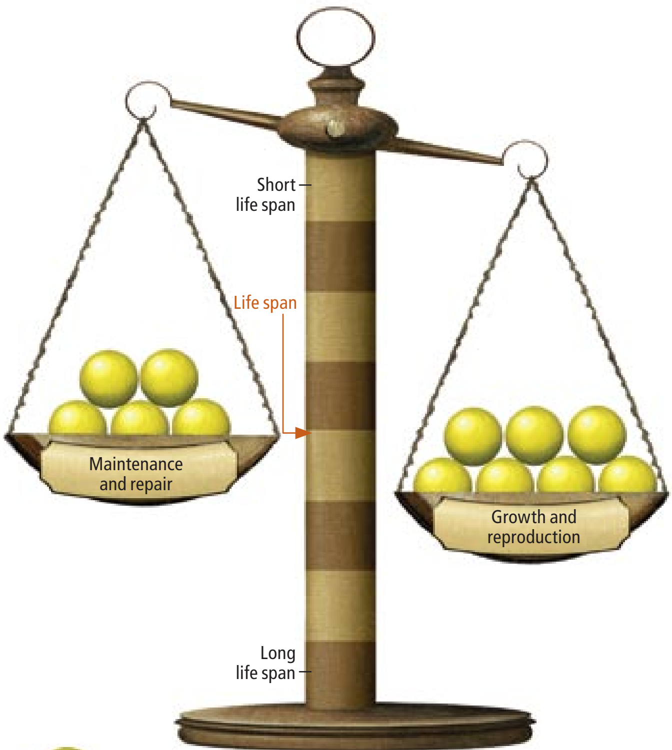
JASON LEE (*animals*); LUCY READING-IKKANDA, SOURCE: "THE WORLD ECONOMY IN MILLENNIAL PERSPECTIVE," BY ANGUS MADDISON, OECD, 2001 (*world, 1900–1950*); "WORLD POPULATION AGEING, 2009," BY THE UNITED NATIONS, DECEMBER 2009 (*world, 1950–2050*); WWW.GAPMINDER.ORG (*U.S., 1800–2010*); U.S. CENSUS BUREAU, INTERNATIONAL DATA BASE AND CENTERS FOR DISEASE CONTROL AND PREVENTION (*U.S., 1950–2050*) (*graph*)

[A THEORY OF AGING]

HOW AGING STEMS FROM TRADE-OFFS

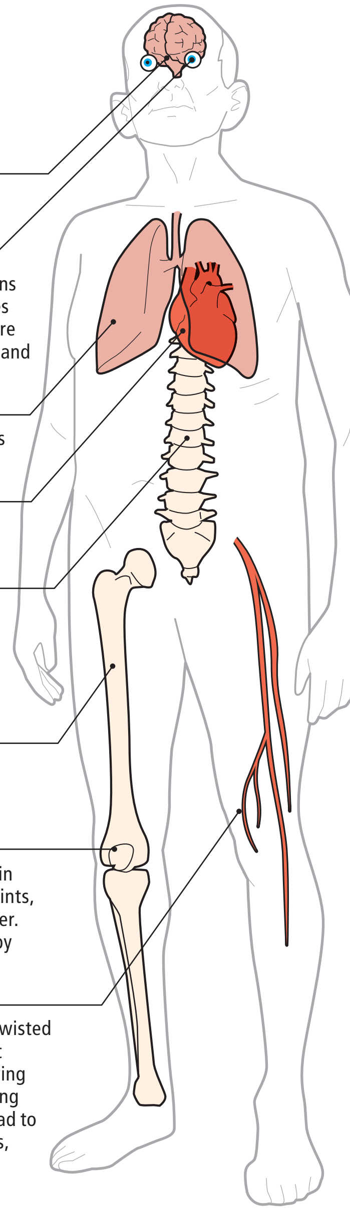
Aging occurs because our body must make a trade-off between reproducing and staying in good repair, according to the author's "disposable soma" theory. Given a limited supply of energy, the amount that goes to making and protecting sperm and eggs tips the scale away from ensuring that "somatic" cells—skin, bone, muscle, and so on—remain in good condition. As a result, cells accumulate damage over time, which ultimately causes some organ or another to become diseased. If bodily functioning is sufficiently compromised, death ensues.

▼ HOW ENERGY IS ALLOCATED IN THE BODY



Cellular energy generated from nutrients

FLAGGING CELL REPAIR LEADS TO A GRADUAL DECLINE ▶



BRAIN
Memory and reaction time may begin to decline around age 70.

EYES
Difficulty focusing on close objects begins in 40s; ability to see fine detail decreases in 70s; from age 50, susceptibility to glare increases, and ability to see in dim light and to detect moving targets decreases.

LUNGS
Maximum breathing capacity diminishes by 40 percent between ages 20 and 80.

HEART
Heart rate during maximal exercise falls by 25 percent between ages 20 and 75.

SPINAL DISKS
Years of pressure on the spongy disks that separate the vertebrae can cause them to slip, rupture or bulge; then they, or the vertebrae themselves, can press painfully on nerves.

BONES
Bone mineral loss begins to outstrip replacement around age 35; loss speeds up in women at menopause.

JOINTS
Repetitive motions through the years thin the slippery protective coverings over joints, causing bones to grind against each other. The resulting pain may be exacerbated by osteoarthritis and other disorders.

VEINS
Veins in the legs become enlarged and twisted when small valves that should snap shut between heartbeats (to keep blood moving up toward the heart) malfunction, causing blood to pool. Severe varicosities can lead to swelling and pain and, on rare occasions, to life-threatening blood clots.

JON KRAUSE (*scales*); JASON LEE, SOURCE: BALTIMORE LONGITUDINAL STUDY OF AGING (*human body*)

tition. Sperm are produced in vast excess; usually only a good one can fertilize the egg. Egg-forming cells are produced in much greater numbers than can ovulate; stringent quality control eliminates the ones that fail to make the grade. And finally, if errors slip past all these checks, natural selection provides the final arbiter of which individuals are the fittest to transmit their germ line to future generations.

After the seemingly miraculous feat of growing a complex body from a single cell—the fertilized egg—it should be relatively straightforward merely to keep a body going indefinitely—as American evolutionist George Williams has pointed out. Indeed, for some multicelled organisms, an absence of aging appears to be the rule. The freshwater hydra, for example, shows an extraordinary power of survival. Not only does the hydra apparently not age, in the sense that as it gets older it shows no increase in death rate or decline in fertility, it also appears capable of regrowing a whole new body from even a tiny fragment, if by chance it is cut into pieces. The secret of the hydra's eternal youth: quite simply, germ cells permeate its body. If the immortal germ line is everywhere, it actually comes as no surprise that an individual hydra can survive without any foreseeable end, presuming it does not succumb to injury or predators.

In most multicelled animals, however, the germ line is found only in the tissue of the gonads, where the sperm and eggs form. This arrangement provides great advantages. During the long history of evolution, it freed other cell types to become specialists—nerve, muscle and liver cells, among others, that are required for the development of any complex organism, whether a *Triceratops* or a human.

This division of labor had far-reaching consequences for how organisms age and how long they can live. As soon as the specialist cells surrendered the role of continuing the species, they also abandoned any need for immortality; they could die after the body had passed on its genetic legacy through the germ line to the next generation.

ULTIMATE TRADE-OFFS

SO HOW LONG can those specialist cells survive? In other words, how long can we and other complex organisms live? The answer for any given species has a lot to do with the environmental threats its ancestors faced as they evolved and with the energy costs of maintaining the body in good operating order.

By far the majority of natural organisms die at relatively young ages because of accidents, predation, infection or starvation. Wild mice, for example, are at the mercy of a very dangerous environment. They are killed rather quickly—it is rare for a wild mouse to see its first birthday. Bats on the other hand are safer because they can fly.

Meanwhile maintenance of the body is expensive, and resources are usually limited. Out of the daily intake of energy, some might go to growth, some to physical work and movement, some to reproduction. Some energy, instead, might be stored as fat to protect against famine, but much gets burned just to fix the innumerable faults that arise every second the organism is alive. Another increment of these scarce resources goes to proofread the genetic code involved in the continual synthesis of new proteins and other essential molecules. And still another allocation powers the energy-hungry garbage disposal mechanisms that clear molecular debris out of the way.

Here is where the disposable soma theory comes in. The theory posits that, like the human manufacturer of an everyday product—a car or a coat, for example—evolving species have to make trade-offs. It does not pay to invest in allowing indefinite survival if the environment is likely to bring death within a fairly predictable time frame. For the species to survive, a genome basically needs to keep an organism in good shape and enable it to reproduce successfully within that time span.

At all stages of life, even to its very end, the body does its utmost to stay alive—in other words, it is programmed not for aging and death but for survival. But under the intense pressure of natural selection, species end up placing higher priority on investing in growth and reproduction—in the perpetuation of the species—than on building a body that might last forever. So aging is driven by the gradual lifelong accumulation of diverse forms of unrepaired molecular and cellular damage.

No biological software program, then, dictates precisely when it is time to die, but growing evidence suggests that certain genes can nonetheless influence how long we live. Tom Johnson and Michael Klass, working with tiny nematode worms, discovered a gene with such an effect on longevity in the 1980s. Mutation of a gene that the researchers aptly named *age-1* produced a 40 percent increase in average life span. Since then, investigators in many laboratories have found numerous other genes capable of increasing nematode life span, and similar mutations have turned up in other animals, from fruit flies to mice.

The genes that extend life span mostly alter an organism's metabolism, the way it uses energy for bodily functions. Often investigators find these genes play a role in the insulin-signaling pathway, pivotal in metabolic regulation. The cascades of molecular interactions constituting this pathway shift the overall level of activity of literally hundreds of other genes responsible for controlling all the intricate processes that carry out cellular maintenance and repair. In effect, it seems that lengthening life span requires changing exactly those processes we know protect the body against buildup of damage.

The amount of food available also ratchets metabolism up or down. As long ago as the 1930s, researchers discovered, rather surprisingly, that underfeeding laboratory rodents extends their lives. Once again, modulating metabolism seems to have an effect on the rate of damage accumulation, because mice subjected to dietary restriction increase the activity of a range of maintenance and repair systems. At first glance, it might seem strange that an animal short of food should spend more, not less, energy on bodily maintenance. A period of famine is, however, a bad time to reproduce, and some evidence suggests that during famines certain animals will do better to switch off their fertility, thereby diverting a large fraction of their remaining energy budget to cell maintenance.

[THE AUTHOR]

Thomas Kirkwood is professor of medicine and director of the Institute for Ageing and Health at Newcastle University in England. His books include the award-winning *Time of Our Lives: The Science of Human Aging,* written for a general readership, and *Chance, Development and Aging* (with Caleb E. Finch) mapping out how intrinsic chance, as well as genes and environment, shapes the way the body grows, develops and ages.

COURTESY OF DAVID GLEN WALKER

OF MICE AND MEN

THIS NOTION of caloric restriction—and its purported ability to extend longevity—has captured the attention of people who wish to live longer. Humans who go hungry in the hope of a longer life should take note, though, that such a mechanism is much less likely to work for us because our slow-paced metabolism differs greatly from that of organisms in which this strategy has already been tested.

Dramatic extension of life span has indeed been achieved in worms, flies and mice. These animals, with their short-lived, fast-burn biology, have an urgent need to manage their metabolism in a way that adapts rapidly to changing circumstances. In nematode worms, for example, most of the more spectacular effects on life span result from mutations that evolved to allow the worms to switch their development to a stress-resistant form whenever they find themselves in a bad environment and potentially required to make a long trek to find better living conditions. We humans, in any case, may not have the same flexibility in altering our own metabolic control. Immediate metabolic effects, of course, occur in humans who undergo voluntary dietary restriction, but only time—and many hungry years—will tell if these have any beneficial impact on the aging process and, in particular, on longevity.

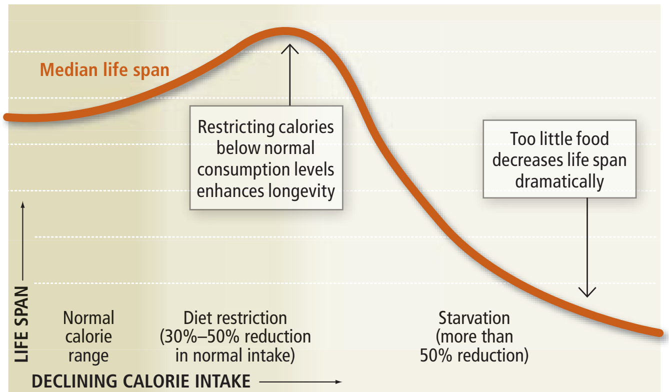
[HINTS FOR NEW DRUGS]

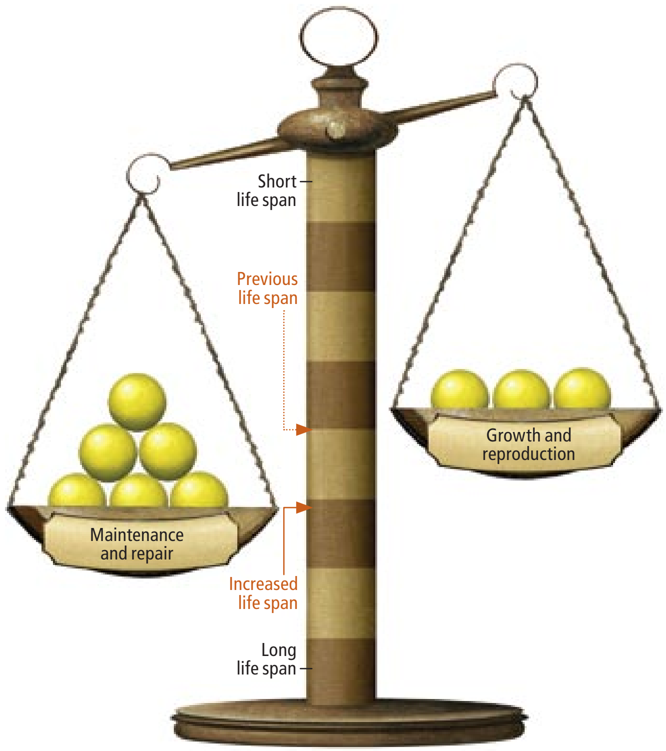
CAN WE SLOW AGING?

No one yet knows how to slow human aging. But basic research into the process might eventually yield longevity drugs. Some compounds might tinker with cell metabolism (energy use) to mimic benefits seen in animals (*below*); others might change the way damaged cells behave (*opposite page*).

LEAN AND LONG-LIVED: Certain therapies might redirect cell metabolism, tilting the scale toward maintenance and repair functions and away from reproduction, thereby keeping bodily organs healthy longer. Calorie restriction lengthens the median life span of flies, worms and mice over that of animals eating a normal diet (*graph*). It is unclear yet whether caloric restriction can work in humans.

▼ RESTRICTING CALORIES ENHANCES LIFE SPAN IN ANIMALS





▲ RESTRICTING CALORIES AFFECTS ENERGY ALLOCATION

The goal of gerontology research in humans, however, is always improving health at the end of life, rather than achieving Methuselean life spans.

One other thing is also very clear: the longer-lived worms, flies and mice still undergo the aging process. Aging happens because damage still accumulates and in time leads to the breakdown of healthy functions of the body. Therefore, if we want our end to be actually better, we need to look elsewhere. In particular, we need to focus on figuring out how to safely limit or reverse the buildup of damage that leads eventually to age-related frailty, disability and disease. This goal represents a huge challenge and calls for some of the most demanding of today's interdisciplinary research.

NO SIMPLE ANSWERS

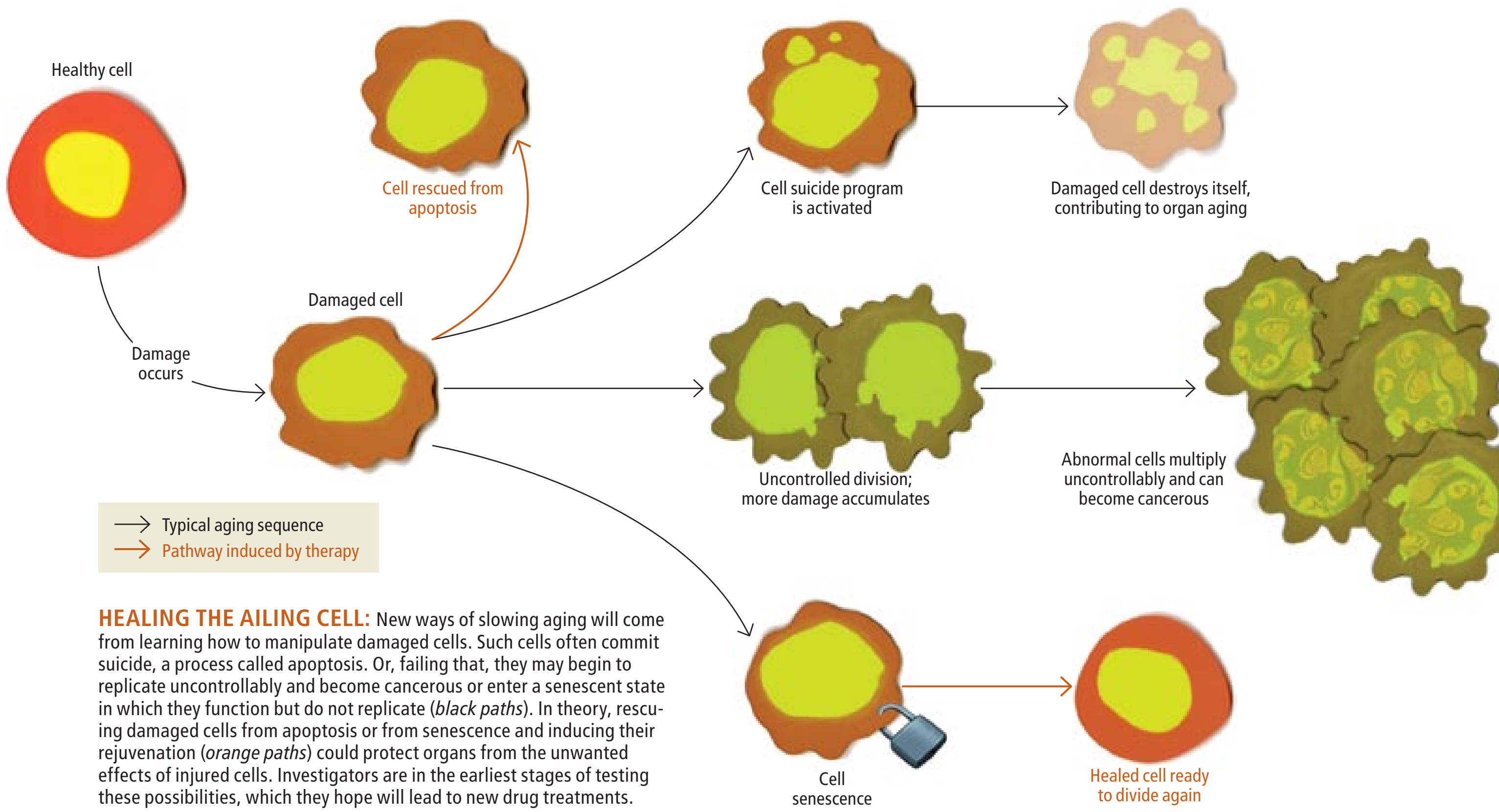
AGING IS COMPLICATED. It affects the body at all levels, from molecules to cells to organs. It also involves multiple kinds of molecular and cellular damage. And although it is true that, in general, this damage accumulates with age and occurs slower in some cell types than in others (depending on the efficiency of the repair systems), injury to any given cell occurs randomly, and the extent can differ even in two cells of the same type in an individual. Thus, all individuals age and die, but the process varies considerably—more confirmation that aging does not stem from a genetic program that specifies how quickly we become frail and die. To understand aging in enough detail to intervene in a suitably targeted fashion that stops or slows the death of selected kinds of cells, we need to know the nature of the molecular defects that drive the aging process at the cellular level. How many of these flaws must accrue before the cell can no longer function? How many defective cells need to accumulate in a given organ before it shows signs of disease? And if we agree that some organs are more important to target than others, how do we deliver the necessary precision?

It may be possible to combat aging by altering important mechanisms that cells use to counteract the buildup of damage. One way that a cell responds to too much wear and tear is simply to kill itself. At one time, scientists viewed this cellular suicide process, technically called apoptosis, as evidence that aging adheres to a genetic program. In aged tissues the frequency of cells killing themselves increases, and this process does indeed contribute to aging. But we now know that apoptosis acts chiefly as a survival mechanism that protects the larger body from injured cells that could potentially cause trouble, notably, ones that have become malignant.

Apoptosis happens more in old organs because their cells have suffered more insults. Remember, though, that in nature animals rarely live long enough to grow old. Apoptosis evolved to deal with damaged cells in younger organs, when many fewer would need to be eliminated. If too many cells die, an organ fails or becomes debilitated. So apoptosis is good and bad—good when it deletes potentially dangerous cells, bad when it deletes too many. Nature cares more about survival of the young than managing decline in old age, so not all apoptosis might be strictly necessary in our later years. In some diseases, such as stroke, researchers hope that by suppressing apoptosis in the less damaged tissue, the resulting loss of cells may be reduced, thereby aiding recovery.

Instead of dying, hurt cells that are normally able to reproduce

JON KRAUSE (*scales and cells*); LUCY READING-IKKANDA; SOURCE: "EXTENDING HEALTHY LIFE SPAN—FROM YEAST TO HUMANS," BY LUIGI FONTANA ET AL. IN *SCIENCE*, VOL. 328; APRIL 16, 2010 (*graph*)



HEALING THE AILING CELL: New ways of slowing aging will come from learning how to manipulate damaged cells. Such cells often commit suicide, a process called apoptosis. Or, failing that, they may begin to replicate uncontrollably and become cancerous or enter a senescent state in which they function but do not replicate (*black paths*). In theory, rescuing damaged cells from apoptosis or from senescence and inducing their rejuvenation (*orange paths*) could protect organs from the unwanted effects of injured cells. Investigators are in the earliest stages of testing these possibilities, which they hope will lead to new drug treatments.

may take a less extreme course and simply stop dividing, a fate known as replicative senescence. Fifty years ago Leonard Hayflick, now at the University of California, San Francisco, discovered that cells tend to divide a set number of times—now called the Hayflick limit—and then stop. Later work showed that they often stop dividing when the caps, or telomeres, that protect the ends of chromosomes erode too much. But other details of how cell senescence sets in remained obscure.

Recently, though, my colleagues and I have made an exciting discovery. We found that each cell has highly sophisticated molecular circuitry that monitors the level of damage both in its DNA and in its energy-forming units known as mitochondria. When the amount of damage passes some threshold, the cell locks itself into a state where it can still perform useful functions in the body but can never divide again. As with apoptosis, nature's bias toward the survival of the young probably means that not all these lockdowns are strictly necessary. But if we are to unpick the locks and so restore some division capacity to aged cells, without unleashing the threat of cancer, we need to understand very thoroughly just how cell senescence works.

The demanding science needed to make this discovery required a multidisciplinary team, including molecular biologists, biochemists, mathematicians and computer scientists, as well as state-of-the-art instruments for imaging the damage in living cells. Where such discoveries might lead we do not yet know, but it is through studies of this kind that we can hope to identify novel drugs able to combat age-related diseases in completely new ways and thereby shorten the period of chronic illness experienced at the end of life.

The difficulty of this type of basic research means that many years, perhaps decades, may pass before these drugs come to market.

Using the science of aging to improve the end of life represents a challenge, perhaps the greatest yet to face medical science. Solutions will not come easily, despite the claims made by the merchants of immortality who assert that caloric restriction or dietary supplements, such as resveratrol, may allow us to live longer. The greatest human ingenuity will be needed to meet this challenge. I believe we can and will develop treatments targeted at easing our final years. But when the end arrives, each of us—alone—will need to come to terms with our own mortality. All the more reason then to focus on living—on making the most of the time of our lives, because no magic elixir will save us. ■

MORE TO EXPLORE

How and Why We Age. Leonard Hayflick. Ballantine Books, 1994.

Understanding Ageing. Robin Holliday. Cambridge University Press, 1995.

Why We Age: What Science Is Discovering about the Body's Journey through Life. Steven N. Austad. John Wiley and Sons, 1999.

Understanding Ageing from an Evolutionary Perspective. T. B. Kirkwood in *Journal of Internal Medicine,* Vol. 263, No. 2, pages 117–127; February 2008.

The End of Age. Thomas Kirkwood. BBC Reith Lectures. **www.bbc.co.uk/radio4/reith2001**

Comment on this article at **www.ScientificAmerican.com/TheEnd**

when does life belong to the living?

With thousands of people on the waiting lists for organs, doctors are bending the rules about when to declare that a donor is dead. Is it ethical to take one life and give it to another?

« BY ROBIN MARANTZ HENIG »

[KEY CONCEPTS]

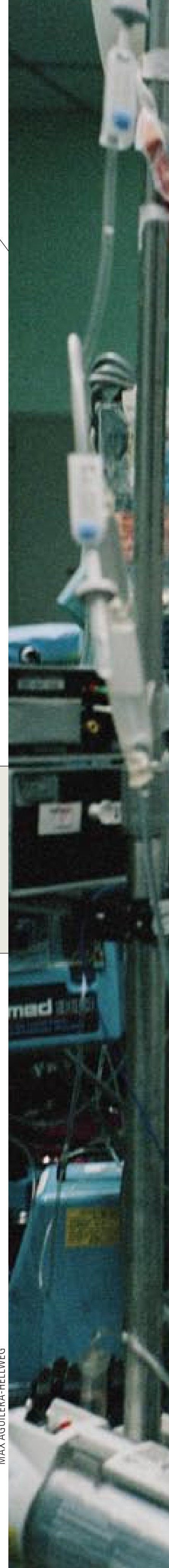
- Transplant surgeons must wait for a specified period after death to extract a potential donor's organs.
- In these oxygen-starved moments, the organs decay, making a precise determination of the moment of death paramount. Still, the process of death may render organs unusable.
- Ethicists have begun to question whether it is necessary for a patient to be fully dead before beginning transplant surgery.

—The Editors

DEATH USED TO BE A SIMPLE AFFAIR: either a person's heart was beating, or it was not. That clarity faded years ago when heroic medical technology started to keep hearts beating indefinitely. Although we have had decades to ponder the distinctions between various states of grave physiological failure, if anything our confusion has grown. When is it ethical to turn off a ventilator or remove a feeding tube? When does "life support" lose its meaning? And most critically, at what point is it acceptable to cut into a body and remove the heart that could save another life?

These issues are not academic. They raise questions about health care costs—is it worth using expensive machinery on a body that is for all intents and purposes dead?—as well as about dignity in end-of-life care. This year's "death panel" subplot of the health care debate fed off the real fears people have about being taken advantage of when at their weakest.

But more than anything else, what drives bioethicists' efforts to arrive at precise definitions of death is organ donation. Currently more than 100,000 people in the U.S. are waiting for organs that could save their lives. Every year some 7,000 will die waiting. The question of when death comes is urgent. The sooner an organ can



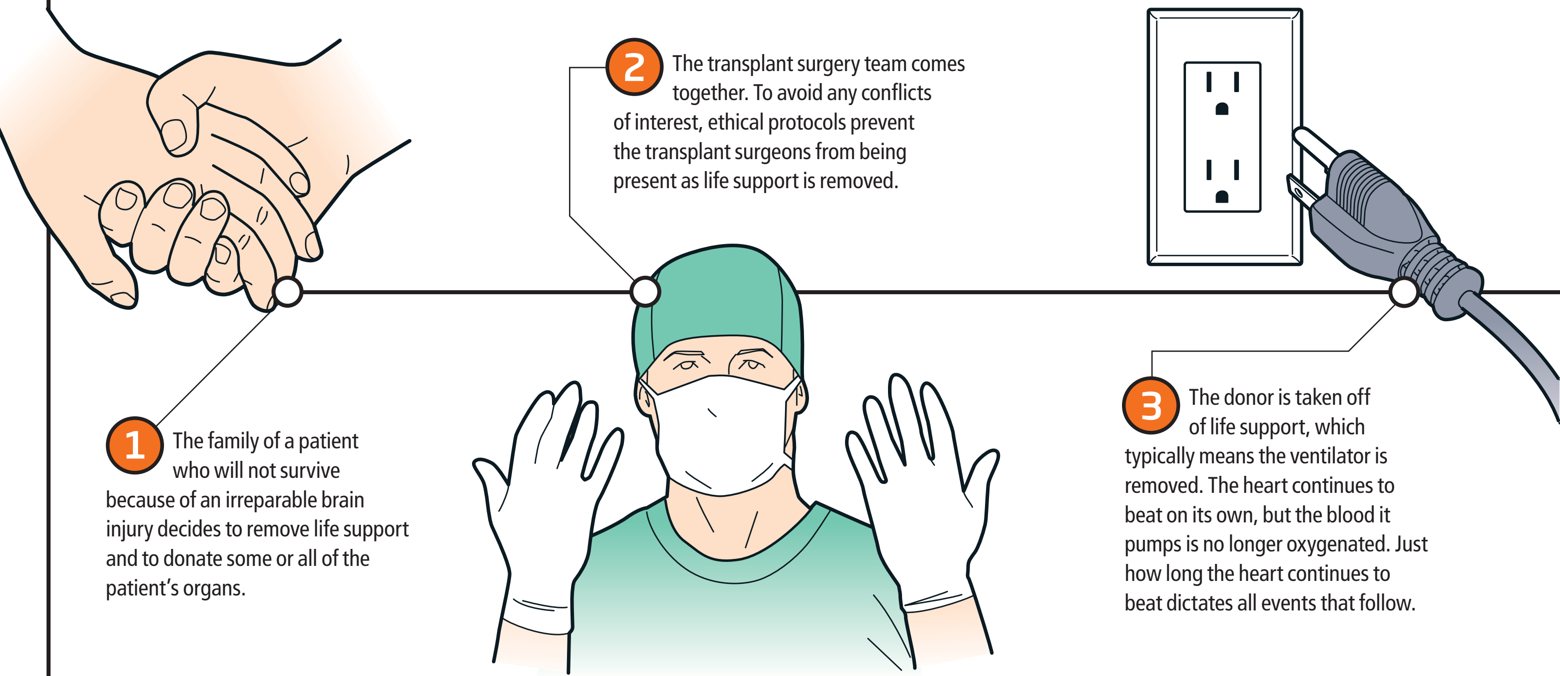
MAX AGUILERA-HELLWEG

LAST GIFT: More than 8,000 individuals donated their organs upon their death in the U.S. last year. Here surgeons remove the heart, kidneys, pancreas, liver, lungs, eyes and some bones from a woman who has been declared brain-dead.

[TRANSPLANT SURGERY]

THE STOPWATCH IN THE OPERATING ROOM

Most organ donations happen when a donor is declared brain-dead, which indicates that both the higher brain and the brain stem are irreparably injured. If just the higher brain suffers from irrecoverable injury, doctors must first remove life support and allow the donor to die before beginning surgery. Timing is everything—the surgeons must allow for enough time to ensure the donor's heart doesn't spontaneously start beating again, but not so long that oxygen-starved organs decay past the point of usability.



JASON LEE

be removed, the less time it spends without oxygen and the greater the chance of a successful transplantation. This has led medical practitioners to push for extracting organs as soon as ethically possible, a push that has forced some surgeons into morally treacherous waters.

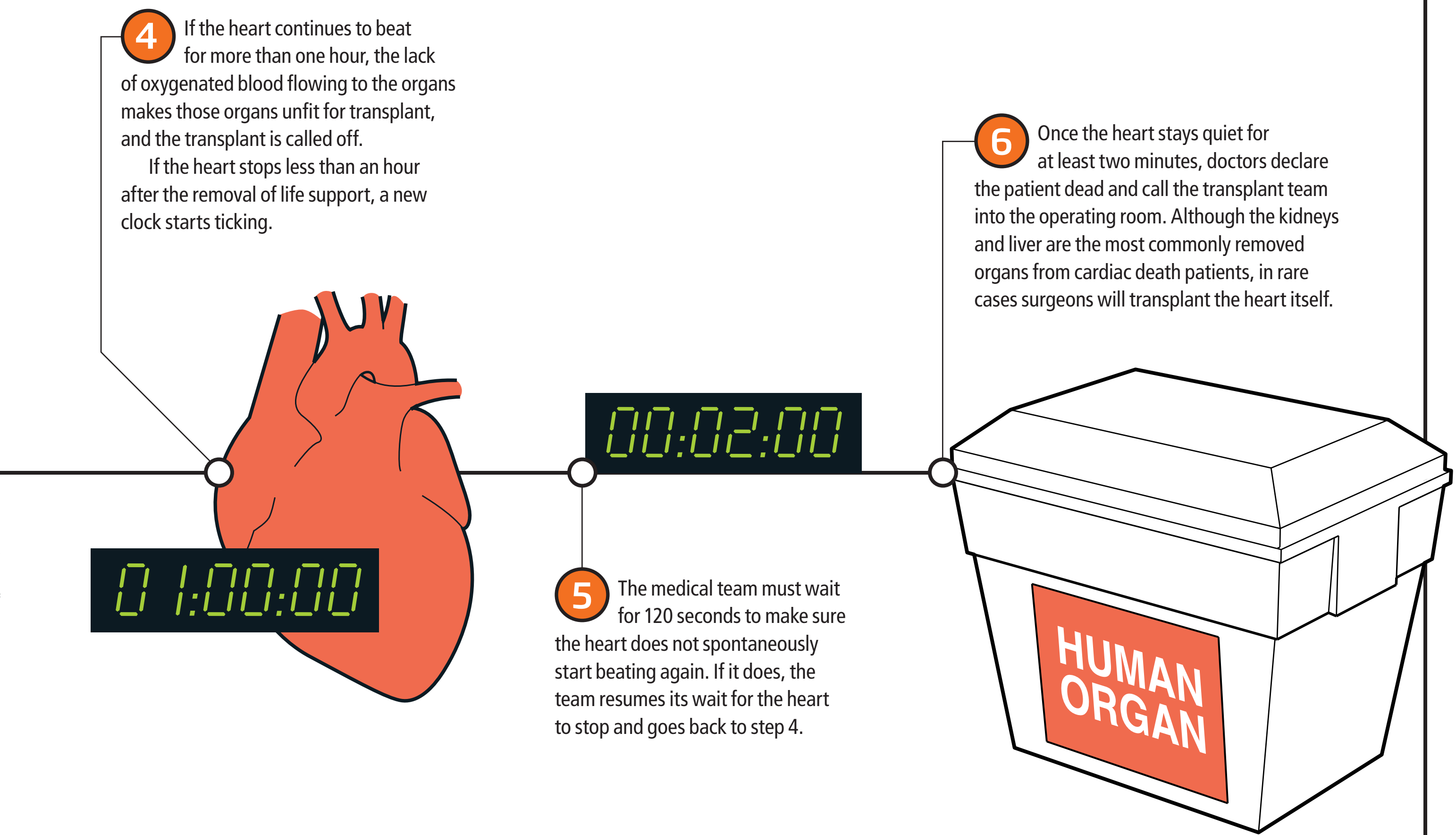
In 2008 San Francisco transplant surgeon Hootan Roozrokh faced felony criminal charges (not including murder) for hastening the death of a potential liver donor. (He was acquitted.) Only months later a team of pediatric surgeons in Denver came under fire for transplanting the hearts of three brain-damaged newborns less than two minutes after their hearts stopped beating—an interval their critics said might have been too short to ensure the hearts would not spontaneously start beating once again. The act violated decades-old medical protocols designed to ensure that organs would never be harvested from the living. In their dispatch, the surgeons cut to the essence of the debate over death and organ transplantion: At what point is it acceptable to declare one life over to save another?

To help resolve this moral dilemma, doctors and ethicists have had to do a little dance for the past 40 years, defining death in a way that makes organ donation possible yet morally defensible. In doing so, they have invented such confusing and slightly ghoulish terminology as "brain-dead" and "heart-beating cadaver." They have also set up a system that may lead to a new socially acceptable cause of death, one that would allow doctors to cut into grievously injured patients while they are still alive to retrieve their organs. Some would call it death by organ donation.

THE STANDARD

IN THE 1960S, when organ transplantation became feasible and was poised to transform medicine, bioethicists wanted to make sure that transplant surgeons did not go too far in their zeal to save lives. They insisted on the "dead-donor rule," which says that organs can be taken only from donors who have been declared dead. But in the contemporary hospital, when is a donor dead, exactly? Just breathing and having a pulse aren't necessarily the same thing as being "alive"; advanced medical technology can make breath and heartbeat happen in almost anyone. If death is defined the way it has been for eons, as the cessation of circulatory and respiratory function, what do you call a patient who is, for instance, attached to a ventilator?

To address this issue, a blue-ribbon Harvard Medical School panel met in 1968 and arrived at the concept of "irreversible coma," more commonly known as brain death. By this term, they meant that the cerebral cortex—the seat of consciousness, language, empathy, fear and everything else that makes us human—is irreversibly destroyed. Destroyed, too, is the brain stem, which orchestrates such basic physiological functions as breathing, heartbeat and homeostasis. Modern medical machinery may keep the body oxygenated, but the person inside is gone.



The definition of death has been reviewed periodically since then by groups of bioethicists, and although the terminology sometimes changes, the substance remains basically the same. The concept of brain death (often known by the more modern and clinical term "the neurological standard of death") has since become encoded into law in nearly every state in the U.S. Ethicists and the law agree: a person whose cortex and brain stem are destroyed has ceased to be alive, even if the body is warm and pink. That body is no longer considered a person. Instead it is a heart-beating cadaver.

This set of circumstances is perfect for a transplant surgeon. Organs begin to deteriorate from lack of oxygen within minutes of the cessation of heartbeat and respiration, so transplant surgeons want to begin the process of retrieval as close to the moment of death as possible. With the neurological standard, this moment can be choreographed. Removal from the ventilator can be timed to coincide with the arrival of a surgical team that will take organs from the body. Indeed, the people who meet the neurological definition of death make up at least 85 percent of the donor pool for vital organ transplants.

As for that last 15 percent? Herein lies the gray area. These people's brains might be permanently injured, but they still have activity in the brain stem, which means they are not brain-dead. They must be declared dead the old-fashioned way—when they stop breathing and their hearts stop beating. With the advent of modern medical technology, pinpointing this moment is often much less straightforward than it sounds.

DEAD ENOUGH

THE MACHINERY for one of these transplants starts whirring when, say, a potential organ donor suffers a massive stroke that destroys all higher brain functioning, as happened in the case involving Hootan Roozrokh. Or it begins when a baby is born with profound brain damage caused by anencephaly or when, as in the Denver hospital, birth complications deprive the brain of oxygen for too many crucial minutes. People in such situations will surely die, once life support is taken away, but if they die in a way that preserves their hearts, lungs or livers, many other lives would be saved. There's the rub: the organs cannot be removed until the patients die on their own. Yet death, if it happens too slowly, could destroy those very organs.

In preparation for transplant, the doctor removes the patient from life support, cutting off the circulatory and respiratory machinery that keeps organs oxygenated. Eventually the heart stops beating altogether, but this does not occur instantly. If it takes more than an hour for the heart to stop, the transplant procedure is abandoned; by that time, oxygen-depleted organs have become too damaged to use. If it takes less than an hour, the second step begins: the surgeon waits a few more minutes after the heart stops—long enough to give the heart a chance to restart spontaneously if it is going to—before retrieving the organs. No heart has ever "autoresuscitated" after more than two minutes, so by a consensus known as the Pittsburgh Protocol, transplant surgeons wait at least 120 seconds after the last beat before removing organs.

What must go through the mind of a transplant surgeon during these two minutes? With each tick of the second hand, the organs are decaying, making a successful transplant that much less likely and endangering the chances of saving another life. The deadline is somewhat arbitrary—a compromise reached by committee.

Pediatric transplant surgeons David Campbell and Biagio Pietra of Denver's Children's Hospital found themselves in situations such as this during three cases between 2004 and 2007. In each case, an infant at the hospital suffered from a severe congenital heart defect. Surgeons had previously attempted to fix the tiny hearts but were not successful. It was clear that without a transplant, each of the children would not live long.

The surgeons found potential donors for the children—newborns with severe brain damage resulting from birth apnea and healthy, beating hearts. These newborns were going to die. The only question was whether they would be able to save another life. The surgeons pulled the plug and waited, but they did not wait the full 120 seconds—in two cases, they acted only 75 seconds after the heart's final beat.

As the surgeons later wrote in the *New England Journal of Medicine,* they were acting on the advice of the hospital's ethical review board, who thought that the surgeons were ethically bound to violate the Pittsburgh Protocol for the sake of the three babies who needed the heart transplants.

The *NEJM* editors, recognizing how controversial this article would be, convened a roundtable discussion about whether the Denver doctors had behaved ethically. They had, said Robert D. Truog, a Harvard physician and bioethicist, but he insisted that the trouble was not with the surgeons' behavior but with the dead-donor rule itself. He argued that it should be abandoned, because it serves only as a smoke screen, one that allows us to argue about superficial minutiae such as the number of seconds that must pass before surgeons can begin transplantation. Only two questions matter: Is the person so gravely injured that recovery is impossible, and has the family consented to organ donation? If the answer is yes on both counts, then there is no ethical difference between death by removal of life support and death by removal of organs.

Another roundtable participant, bioethicist Arthur L. Caplan of the University of Pennsylvania [see "Life Designed to Order," on page 93], recoiled at Truog's suggestion, mostly because of how it would be interpreted by an already skittish lay public. "We ought not underestimate public unease," he said. "Making people wonder if you're going to cut corners on their care in order to salvage organs from them is a very dangerous area to be in."

Doing away with the dead-donor rule would be fraught with political and ethical hazards. Truog insists that safeguards would still make it ethical to retrieve organs—specifically, doctors must be absolutely certain that death is both inevitable and imminent, and there must be iron-clad assurance that the patient or legal surrogate has been fully informed before consenting. But it is hard to say whether these protections would be adequate. Such a move would lead to "moral and legal chaos," wrote Edmund D. Pellegrino of Georgetown University, chair of the President's Council on Bioethics, in the council's 2008 report *Controversies in the Determination of Death.* Following Truog's suggestion, he wrote, would conflate the ethics of organ donation with such end-of-life controversies as assisted suicide and the removal of life support from patients in long-term comas.

If the medical establishment ever does scrap the dead-donor rule, and death by organ retrieval became an acceptable standard, there would be a shift in the delicate balance of declaring death versus harvesting organs—but just how it would shift is anyone's guess. It is safe to say that as long as safeguards were rigorously applied, no one would be turned into an organ donor who might otherwise have had a chance of recovery. Beyond that, anything is possible. In one scenario, a big proportion of the 7,000 people who die every year waiting for a transplant would be saved because more organs, in better condition, would be available. In another, significantly more would die, with organs becoming scarce as people hesitate to sign donor cards for fear of having their bodies ripped open before they are completely dead.

It is this uncertainty about trade-offs, about exchanging one person's life for another's, that makes defining death in the 21st century so complicated. If all that the definition of death told us was when to stop heroic measures and when to start grieving, that would be one thing. With organ donation hovering in the wings, the question is more charged. The definition of death becomes a matter of giving one diminishing life the possibility of a second chance—by defining another diminishing life as already and irreparably over. ■

[THE AUTHOR]

Robin Marantz Henig is a contributing writer at the *New York Times Magazine* and author of eight books, including most recently *Pandora's Baby: How the First Test Tube Babies Sparked the Reproductive Revolution.* She has received two Science in Society awards from the National Association of Science Writers and a career achievement award from the American Society of Journalists and Authors.

MORE TO EXPLORE

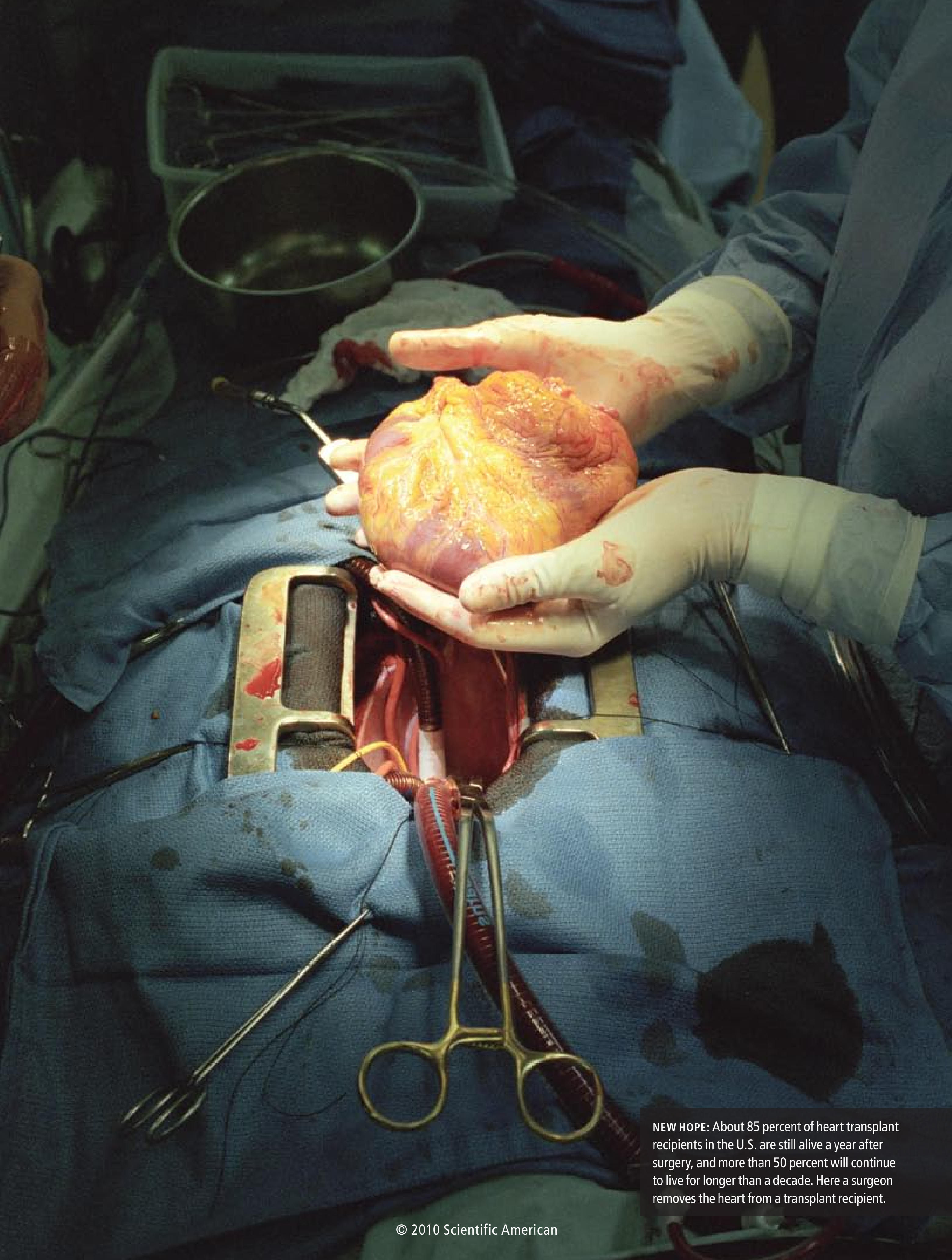
Rethinking the Ethics of Vital Organ Donations. Franklin G. Miller and Robert D. Truog. The Hastings Center Report, November/December 2008. **www.thehastingscenter.org/Publications/HCR/Detail.aspx?id=2822**

Controversies in the Determination of Death. Report by the President's Council on Bioethics, December 2008. **http://bioethics.georgetown.edu/pcbe/reports/death**

Organ Donation after Cardiac Death. Video roundtable convened by the *New England Journal of Medicine*. **http://content.nejm.org/cgi/content/full/359/7/669/DC1**

Comment on this article at **www.ScientificAmerican.com/TheEnd**

COURTESY OF JEFFREY R. HENIG (*Henig*); MARK PETERSON *Corbis* (*surgery*)



NEW HOPE: About 85 percent of heart transplant recipients in the U.S. are still alive a year after surgery, and more than 50 percent will continue to live for longer than a decade. Here a surgeon removes the heart from a transplant recipient.

[FORENSICS]

dust to dust

The brief, eventful afterlife of a human corpse

<< BY ARPAD A. VASS >>

[KEY CONCEPTS]

- After death, the human body decomposes through four stages.
- The final, skeleton stage may be reached as quickly as two weeks or as slowly as two years, depending on temperature, humidity and other environmental conditions where the body lies.
- Dead bodies emit a surprising array of chemicals, from benzene to freon, which can help forensic scientists find clandestine graves.

—The Editors

WELCOME OR NOT, dying is a natural part of the circle of life. Death initiates a complex process by which the human body gradually reverts back to dust, as it were. In the language of forensics, decomposition transforms our biological structures into simple organic and inorganic building blocks that plants and animals can use.

Four main factors affect the pace and completeness of decay. The most important is temperature: the rate of chemical reactions in a cadaver doubles with each 10 degree Celsius rise. Humidity or water from the environment buffers those reactions, slowing their effects. Extreme acidity or alkalinity hastens how quickly enzymes degrade biological molecules—although again, the presence of ample water can mediate the effects. Finally, anything that blocks exposure to oxygen, such as burial, submersion or high altitude, will slow decomposition. Depending on the interplay of these four factors, the body can turn into a skeleton as rapidly as two weeks or take more than two years.

Forensic scientists use their knowledge of the biology and chemistry of decomposition, together with the variables that affect the speed of decay, to estimate a person's time of death and to help investigators discover clandestine graves [*see box on page 59*]. Medical experts and ethicists may not agree on how to define the moment of death [see "When Does Life Belong to the Living?" by

PHOTOGRAPHS BY GRANT DELIN

FRESH CORPSE

DONATED BODIES are left exposed to the elements at the University of Tennessee's "Body Farm," so researchers can study decomposition's four stages, starting with the "fresh" state (*shown*).

Robin Marantz Henig, on page 50], but they know in great detail the stages through which a body gradually decomposes. The stages are described below. The timescales noted are approximate and refer to a body that is lying open to the air. Being buried unshrouded in soil or in a casket could extend the intervals significantly.

STAGE 1: FRESH DAYS 1 TO 6

IN THE FIRST STAGE, soft tissue begins to decompose in a chain of events that starts with autolysis, or self-digestion. When breathing and circulation cease, cells are left without a supply of oxygen. The cells survive for a few minutes to a few days, but they can no longer pass wastes into the bloodstream. Carbon dioxide, one of the by-products of metabolism, is acidic, and as it accumulates, the acidity inside a cell increases, causing cell membranes to rupture. Single membranes surrounding organelles called lysosomes tend to dissolve first. The sacs contain digestive enzymes normally used by cells to break down organic molecules such as proteins. As these enzymes spill out, they begin digesting the cell from the inside out, eventually creating small blisters in and on internal tissues and organs and on the skin. The blister fluid, consisting of digested cell innards, is rich in nutrients.

As blisters rupture, the fluids give the surface of the corpse a moisture-laden sheen. Deep skin cells begin to slough off, resulting in skin slippage, one of the first visually revolting signs of decomposition.

Within a few hours after death, several other phenomena also begin. Muscles stiffen (rigor mortis), starting in the eyelids, jaw and neck, when cells no longer pump out calcium ions; such pumping keeps muscles supple. For a time, muscle cells continue to convert nutrients into energy, but without oxygen the process produces lactic acid, which also causes muscles to contract. Gelling of the cell's innards, resulting from increased acidity, contributes to the stiffening. Rigor mortis peaks in 24 hours but then relaxes as cells succumb to autolysis.

The body also starts to cool (algor mortis) to ambient temperature, generally at approximately 0.8 degree C per hour. Algor mortis can of course be influenced by the body's location and size, clothing and weather conditions.

Within an hour or two of death, the pull of gravity makes red and white blood cells settle (livor mortis), gradually giving a purplish-red hue to the epidermis, except in areas that are being compressed, such as skin in contact with the ground. Maximum congealing takes place at six to 12 hours. Marbling occurs after several days as blood and proteins begin to decompose and liberate sulfur-rich compounds, giving the corpse one of its offensive odors.

STAGE 2: BLOAT DAYS 7 TO 23

AFTER ABOUT A WEEK, the release of those nutrient-rich fluids begins to fuel an army of microbes that further liquefy the body's soft tissue. Bacteria, fungi and protozoa (from the corpse and from the environment) attack the tissue, producing numerous gases, including carbon dioxide, methane, hydrogen sulfide, ammonia, and a variety of so-called volatile organic compounds such as benzene. Because the greatest concentration of microbes in the body is in the intestinal tract, the most obvious bloating, or distension, occurs there. Trapped gases can eventually erupt from the rectum or even rip apart the abdominal wall.

STAGE 3: ACTIVE DECAY DAYS 24 TO 50

DURING THIS STAGE, insects (primarily maggots and beetles) and sometimes carnivores join microorganisms in removing the remaining traces of tissue. Much of the body's muscle and fat has been reduced to a foul-smelling, liquidy pastelike substance. If the tissue has been open to air (aerobic conditions), it will have a pH greater than 9.0, highly basic (7.0 is neutral). If the corpse has been buried so that anaerobic (oxygen-free) conditions prevail, the body will be acidic (less than 7.0). The more extreme the pH, the quicker the decomposition.

If conditions are basic and also warm and moist, lipids (primarily triglycerides) will go through a chemical reaction called saponification that creates adipocere, also known as grave wax. (The reaction is the basis for how commercial soap is made from animal fat.) Adipocere can range in color from whitish to dark yellow, with the occasional brown chunk here and there. It can also have a variety of consistencies, from hard and crumbly if decomposition has progressed rapidly to soft and pasty for slower decay. If grave wax covers decomposing tissue, it will create an anaerobic environment and shield the tissue from its surroundings, retarding the process and potentially delaying complete liquefaction at that site for years.

[THE AUTHOR]

Arpad A. Vass is a research scientist at Oak Ridge National Laboratory and an associate research professor of forensic anthropology at the University of Tennessee. He developed the decompositional odor analysis database at Oak Ridge.

STAGE 4: DRY DAYS 51 TO 64

IN THE DRY STAGE, the last traces of tissue are removed, leaving the human skeleton. Odors and disfigurement are largely gone. Bones then go through their own decomposition process, called diagenesis, which can last years to decades. Bone has two components: protein (collagen) and a mineral, hydroxyapatite. Protein degrades first, which leaves the remaining skeletal material susceptible to cracking and flaking. Once the protein is gone, freezing and thawing, moisture, carnivores and erosion will break it down into dust. But if the bones lie in soil that is very dry and contains certain minerals, the minerals can fill in the cracks and voids, bonding the hydroxyapatite and allowing the combination to fossilize and survive the ravages of time. ■

MORE TO EXPLORE

Beyond the Grave: Understanding Human Decomposition. Arpad A. Vass et al. in *Microbiology Today,* Vol. 28, pages 190–192; November 2001.

Odor Analysis of Decomposing Buried Human Remains. Arpad A. Vass et al. in *Journal of Forensic Sciences,* Vol. 53, No. 2, pages 384–391; March 2008.

Comment on this article at **www.ScientificAmerican.com/TheEnd**

DRY BONES
HUMAN SKELETONS in the final "dry" state can last for years and can fossilize if the soil is arid and contains certain minerals.

[DETECTION TECHNOLOGY]

TIME OF DEATH?

Forensic scientists like myself study decomposing bodies to improve our methods for accurately determining how long someone has been dead and for finding clandestine graves. We have identified more than 400 chemicals released during decomposition that give us clues for both tasks. My laboratory has also created an electronic handheld instrument (called Labrador) that can detect many of these compounds. About 30 of the chemicals, when identified together, provide very good evidence that hidden human remains have been found. Among them:

FREONS. These molecules are similar to the coolant in your refrigerator or air conditioner and accumulate (in inert form) in tissue and bone matrixes during a lifetime of ingesting fluoridated water or products such as toothpaste.

AROMATIC HYDROCARBONS. Human decomposition has a unique, sickly sweet odor, largely created by aromatics such as benzene, an important component of gasoline.

SULFUR COMPOUNDS. The same dimethyl disulfides and hydrogen sulfides released by decaying vegetation in swamps and bogs contribute a rotten-egg smell.

CARBON TETRACHLORIDE. Created by bacteria during decomposition, this nasty compound was once used in fire extinguishers, as a dry-cleaning solvent and in making chlorofluorocarbons (which partially destroyed the ozone layer). It is now banned from most applications because it is highly toxic and can even cause cancer. How ironic that after a lifetime of health-conscious living, we revert to this and other known carcinogens. —*A.A.V.*

BARASANA PEOPLE of the Northwest Amazon of Colombia believe that man and nature are one. Their philosophy of interconnectedness has given rise to land management practices that minimize the impact of the Barasana on the environment. In 1991 the Colombian government granted the Indian peoples of the Northwest Amazon legal land rights to an area the size of the U.K. Thanks to that decision, the once endangered Barasana are experiencing a powerful rebirth. They are among the rare lucky ones.

last of their kind

The world's cultures have been disappearing, taking valuable knowledge with them, but there is reason to hope

<< TEXT AND PHOTOGRAPHS BY WADE DAVIS >>

OVER THE PAST DECADE geneticists have proved that all people alive today are descendants of a relatively small number of individuals who walked out of Africa some 60,000 years ago and carried the human spirit and imagination to every corner of the habitable world. Our shared heritage implies that all cultures share essentially the same potential, drawing on similar reserves of raw genius. Whether they exercise this intellectual capacity to produce stunning works of technological innovation (as has been the great achievement of the West) or to maintain an incredibly elaborate network of kin relationships (a primary concern, for example, of the Aborigines of Australia) is simply a matter of choice and orientation, adaptive benefits and cultural priorities. Each of the planet's cultures is a unique answer to the question of what it means to be human. And together they make up our repertoire for dealing with the challenges that will confront us as a species in the millennia to come.

But these global voices are being silenced at a frightening rate. The key indicator of this decline in cultural diversity is language loss. A language, of course, is not merely a set of grammatical rules or a vocabulary. It is the vehicle by which the soul of each particular culture comes into the material world. Each one is an old-growth forest of the mind. Linguists agree, however, that 50 percent of the world's 7,000 languages are endangered. Every fortnight an elder dies and carries with him or her into the grave the last syllables of an ancient tongue. Within a generation or two, then, we may be witnessing the loss of fully half of humanity's social, cultural and intellectual legacy. This is the hidden backdrop of our age.

People often ask why it matters if these exotic cultures and their belief systems and rituals disappear. What does a family in New York care if some distant tribe in Africa is extinguished? In truth it probably matters little, no more than the loss of New York would directly affect a tribe in Africa. I would argue that the loss of either way of life does matter to humanity as a whole.

Consider the achievements of the Polynesians. Ten centuries before Christ—at a time when European sailors, incapable of measuring longitude and fearful of the open ocean, hugged the shores of continents—the Polynesians set sail across the Pacific, a diaspora that would eventually bring them to every island from Hawaii to Rapa Nui, the Marquesas to New Zealand. They had no written word. They only knew where they were by remembering how they had got there. Over the length of a long voyage the navigator had to remember every shift of wind, every change of current and speed, every impression from sea, sky and cloud. Even today Polynesian sailors, with whom I have voyaged, readily name 250 stars in the night sky. Their navigators can sense the presence of distant atolls of islands beyond the visible horizon by watching the reverberation of waves across the hull of their vessels, knowing that every island group had its own reflective pattern that can be read with the ease with which a forensic scientist reads a fingerprint. In the darkness they can discern five distinct ocean swells, distinguishing those caused by local weather disturbances from the deep currents that pulsate across the Pacific and can be followed as readily as a terrestrial explorer would follow a river to the sea.

There are many such examples of ancient wisdom. Among the Barasana people of the northwest Amazon in Colombia, for whom all the elements of the natural world are inextricably linked, complex mythologies about the land and its plants and animals have given rise to highly effective land-management practices that serve as a model for how humans can live in the Amazon basin without destroying its forests. The Buddhists of Tibet spend their lives preparing for a moment that we spend most of our lives pretending does not exist: death. Surely their science of the mind—informed by 2,500 years of empirical observation—has something meaningful to contribute to the human patrimony.

This is not to say that cultures should be forced to remain static, that they cannot maintain their identity while changing some of their ways. The Haida did not stop being Native American when they gave up the dugout canoe for the motorboat any more than ranchers in Montana ceased being Americans when they put aside the horse and buggy in favor of the automobile. It is not change or technology that threatens culture; it is domination.

[THE AUTHOR]

WADE DAVIS is an anthropologist, ethnobotanist, filmmaker and photographer. His most recent book, *The Wayfinders: Why Ancient Wisdom Matters in the Modern World*, was published in 2009 by Anansi and provided the inspiration for this photo essay.

The ultimate tragedy is not that archaic societies are disappearing but rather that avertible forces are driving vibrant peoples and languages out of existence. These external threats take many forms. They may be industrial, as in the case of the egregious forestry practices that have destroyed the subsistence base of the nomadic Penan in the rain forests of Borneo, or the toxic effluents of the petrochemical industry that have compromised the once fertile soils that the Ogoni people of the Niger Delta farmed. Epidemic disease is another menace to culture—to wit, the Yanomamï of the Amazon have suffered dreadful mortality as a result of exotic pathogens brought into their lives by the gold miners who have invaded their lands. Or the threat may be ideology, as in the domination of Tibetan Buddhists by the Communist Chinese.

That cultures do not always fade away but rather may be casualties of other societies' priorities is actually an optimistic observation, because it suggests that if humans are the agents of cultural decline, we can foster cultural survival. Following the Colombian government's 1991 decision to grant land rights to the Indians of the northwest Amazon, for example, the Barasana are now flourishing. Our goal should not be to freeze people in time. Instead we must find ways to ensure that in a pluralistic, interconnected world all peoples may benefit from modernity without that engagement demanding the sacrifice of their ethnicity. ■

HOKULE'A, the sacred canoe of the Polynesian Voyaging Society, sails off the shores of Hawaii. Traditional Polynesian wayfinders navigate the seas without the aid of instruments. Rather they employ dead reckoning, keeping track of where they are by mentally mapping the distance and direction they have traveled since departing the last known point.

ARIAAL WOMAN on Mount Marsabit in northern Kenya returns home with firewood. The Ariaal are among the tribal people who for generations survived the Kaisut Desert's droughts by living as pastoral nomads. Under pressure from international aid organizations starting in the 1970s, they settled down, which led to depletion of their resources and permanent dependence on the aid groups.

ABOVE: ABORIGINAL MEN in Australia's Arnhem Land hunt for food. In the Aboriginal worldview there is no past, present or future—there is not even a word for time. The goal of humanity is not to transform nature but to maintain the world as it was when it came into being. **BELOW:** The Penan, who dwell in the rain forests of Borneo, long flourished as nomads. But logging has destroyed their culture and driven them to settle.

INUK CHILD peers into a pool of meltwater in Nunavut, Canada. Melting of the sea ice from global warming threatens the polar bear and other animals that the indigenous peoples of the Arctic hunt for food.

MORE TO EXPLORE

Nomads of the Dawn: The Penan of the Borneo Rain Forest. Wade Davis, Ian MacKenzie and Shane Kennedy. Pomegranate Press, 1995.

Seafaring in the Contemporary Pacific Islands: Studies in Continuity and Change. Edited by Richard Feinberg. Northern Illinois University Press, 1995.

The Search for Shangri-La: A Journey into Tibetan History. Charles Allen. Abacus, 2000.

As Pastoralists Settle: Social, Health, and Economic Consequences of the Pastoral Sedentarization in Marsabit District, Kenya. Edited by Elliot Fratkin and Eric Abella Roth. Springer, 2005.

When Languages Die: The Extinction of the World's Languages and the Erosion of Human Knowledge. K. David Harrison. Oxford University Press, 2007.

Shadows in the Sun: Travels to Landscapes of Spirit and Desire. Wade Davis. Island Press, 2010.

Comment on this article at **www.ScientificAmerican.com/TheEnd**

good riddance

A highly selective list of human creations the world would be better off without

More inventions we wish would go away at **www.ScientificAmerican.com/TheEnd**

DAYLIGHT SAVINGS TIME

The extra hour of sunshine comes at a steep price

DAYLIGHT SAVINGS time has marginally scientific origins: its inventor, New Zealand naturalist George Vernon Hudson, published two papers in the late 19th century arguing for a seasonal two-hour clock shift to "more fully utilize the long days of summer." The primary appeal, though, has always been to save on energy costs, because extra daylight in the evening reduces the need for lighting. Germany instituted *Sommerzeit* ("summertime") as a means to save coal during wartime, and by 1918 Europe, Russia and the U.S. had all followed suit. Clocks went back to normal in peacetime, until daylight savings was temporarily mandated again during World War II. In 1966 the U.S. Congress passed the Uniform Time Act, the first nonwartime implementation of the practice (although, technically, each state could decide whether to go along); daylight savings has since been extended as a response to energy shocks such as the oil embargo of the 1970s.

Unfortunately, the strategy may not confer any energy savings to the climate-controlled world. An upcoming study in the *Journal of Economics and Statistics* examined electricity consumption patterns from a "natural experiment" in Indiana, where some regions observed daylight savings time and others didn't, until the state mandated universal adoption in 2006. The regions that observed daylight savings consumed more electricity than those that did not. The authors attributed the findings to greater use of fans and air conditioners during extended summer days.

Other studies have demonstrated that the switch to daylight savings may lead to more traffic accidents (it disrupts circadian rhythms, leading to sleep deprivation), depression (a 2008 study showed that men are more likely to commit suicide in the early weeks of daylight savings), and may even contribute to increased risk of heart attacks (incidence spikes from 5 to 10 percent the first week after the clocks shift forward, according to a Swedish study). Quite a price to pay—when all George Vernon Hudson really wanted was a few extra hours of sunshine to collect bugs. —*John Pavlus*

COURTESY OF NASA (*shuttle*); EVA HEDLING *Aurora Photos* (*clock*)

SPACE SHUTTLE

This pickup truck to low Earth orbit was neither cheap nor safe

TO MANY AMERICANS, the Space Transport System—or space shuttle, as it is commonly known—embodies not just NASA's efforts in low Earth orbit, but the entire endeavor of human spaceflight. That is exactly the problem—and why the shuttle's retirement in 2011 is a good thing.

"Many people think that the shuttle is capable of going to the moon or beyond, and they see its cancellation as some kind of devastating hit to our spacefaring capability, when in reality that's never been on the table," says Jim Bell, professor of astronomy at Cornell University and president of the nonprofit Planetary Society. "The farthest it's ever gone is still just a whisker above Earth's surface."

The public has always had the mistaken impression that the shuttle was a proven technology, when in reality it has always been a fundamentally experimental vehicle. "The question the shuttle was designed to answer is, 'Is it possible to make spaceflight routine?' The answer is no, not at that level of technology," says Scott Pace, director of George Washington University's Space Policy Institute. "It was a brilliant engineering feat, but now we have different questions for manned spaceflight to address."

Of course, the most compelling reason for retiring the shuttle is the sheer danger of flying it, as the *Challenger* and *Columbia* disasters demonstrated. "Spaceflight is always dangerous—there's no getting around that," Pace says. "But there are those who say that if we're going to risk human lives, it should be for higher stakes than routine service missions."

Bell argues that the end of the shuttle era should provide an opportunity for NASA to refocus on more ambitious objectives such as human travel to Mars and the solar system beyond. The shuttle is "a beautiful, sexy space machine, and we shouldn't dis it," he says. "But the shuttle today is as far removed from the beginning of the Apollo program as Apollo was from the *Spirit of St. Louis*. If you think about these turning points, we're probably due for one." —*John Pavlus*

TEFLON

Handy in the kitchen, deadly in lakes and rivers

FOOD MIGHT NOT STICK to Teflon, but Teflon sticks to us. The factories that produce the nonstick pans pollute lakes, rivers, wildlife and plants with perfluorooctanoic acid, a chemical by-product. The chemical, which does not break down in the environment, has found its way into the bodies of more than 95 percent of Americans and is "likely to be carcinogenic for humans," according to the Environmental Protection Agency. Other studies have linked it to infertility, immune problems and impaired prenatal growth. Although Teflon is safe in the kitchen when used correctly, if an empty pan were left for several minutes on a burner, reaching 500 degrees Fahrenheit, the coating would break down, releasing toxic fumes.

Teflon has given DuPont, the company that manufactures the coating, its own share of headaches. In 2005 the company was slammed with a $16.5-million fine—the biggest civil administrative penalty in the EPA's history—for hiding test results showing that perfluorooctanoic acid was contaminating drinking water near a DuPont facility in West Virginia and that the chemical crosses the placenta from mother to child. DuPont says the chemical is safe; nonetheless, the company has vowed to eliminate it from the Teflon manufacturing process by 2015 and to replace it with alternatives that break down more quickly. Renee Sharp of the Environmental Working Group, a nonprofit watchdog, says too few data are available: "We don't have a lot of assurance that the stuff coming onto the market now is considerably safer." *—Melinda Wenner Moyer*

LANDFILLS

Garbage doesn't just disappear after we throw it out

AMERICANS GENERATE 250 million tons of trash every year, of which only 83 million tons—about a third—gets recycled or composted. The rest goes into landfills, which are essentially giant factories that convert garbage into toxic materials and greenhouse gases. Water leaching through the detritus picks up industrial chemicals and heavy metals, all too often depositing those poisons in nearby groundwater supplies. Meanwhile anaerobic bacteria convert organic matter into methane, a greenhouse gas more potent than carbon dioxide.

When confronted with this reality, a number of organizations, both private and municipal, have attempted to live by a zero-waste philosophy, pushing to reduce the amount of trash they send to a landfill to nearly zero by reusing what they can and recycling the remainder. Ideally landfills would eventually become a thing of the past.

Unilever's Lipton Tea plant in Suffolk, Va., for example, now sends 92 percent less waste to landfills than it did in 2007. The plant now recycles 70 percent of its waste and composts 22 percent more. Many other companies, including Apple, Epson, Hewlett-Packard, Xerox and Walmart plan to sharply curtail their waste streams or eliminate them entirely.

These companies are acting in their own self-interest: achieving zero waste by using fewer resources in the first place is a way to cut costs. The Lipton plant eliminated plastic straps from shipping pallets, replaced disposable wipes with reusable rags and gave every employee a lunch tin with metal utensils. Every year the plan saves more than eight million gallons of water, five gigawatt-hours of electricity and, not least, tens of thousands of dollars.

Dozens of cities have also signed on to the zero-waste goal, using incentives instead of technology to get there. San Francisco instituted a "pay as you throw" program that charges residents based on volume of household trash they throw out. It is also one of the first cities in the U.S. to implement a curbside composting program in addition to recycling. The measures have already allowed San Francisco to divert 72 percent of its waste, rolling back the clock on the amount of trash it sends to landfills to rates not seen since 1980. *—Christopher Mims*

DORLING KINDERSLEY *Getty Images (egg in pan)*; FRITZ HOFFMANN *Corbis (landfill)*

WALLED GARDENS

How much longer can Apple's safe, cultivated world hold out against history?

COMPUTERS ARE CHAOS. That's the appeal behind the so-called walled garden, a carefully curated electronic ecosystem that allows you to interact only with vetted software or Web sites. The philosophy underpins Apple's wildly popular iOS—the operating system that powers iPads and iPhones—which may be the most wide-reaching walled garden of all. The success of these devices is challenging the long-held belief that, when it comes to computers and the Internet, openness will always win out.

The superiority of open systems has been axiomatic since the fall of AOL. In the 1990s, when the World Wide Web was new, customers flocked to AOL's comfortable menu of prepackaged content. After a few years, however, users began to realize that the world outside this wall was infinitely more interesting, and entrepreneurs wanted to build new businesses free of interference from overseeing "gardeners." "This is about more than just saying, 'Oh, how nice and open we are!'" says Jeff Jarvis, director of interactive journalism at City University of New York and author of *What Would Google Do?* "Openness brings real, positive business changes to how you operate—whether it's media, software, anything."

Yet when it comes to innovation, the Achilles' heel of AOL's walled garden approach, Apple seems to be beating the odds. Many developers—the entrepreneurs who ultimately determine whether a platform will feature the most interesting applications—prefer Apple's closed technology to competitors, such as Google's Android, that use open-source software. The single platform means they don't have to create 10 different versions of their program for a jumble of different devices and wireless carriers. The iOS "allows us to focus on our craft and not the expensive and time-consuming administrative, technical and compatibility-related issues that plague most platforms," says Calvin Carter, founder of Bottle Rocket, a prominent iPhone app developer.

To some degree, a new generation of tech-savvy consumers may also have a higher tolerance for closed systems than previous consumers. Social-networking juggernaut Facebook, which began as a walled garden for Ivy League college students, suffered a major backlash from users when it started relaxing its privacy policies, opening personal data up to outside view.

The most important issue to today's users may not be openness so much as trust. Openness is still important, Jarvis says, but it's just one among many variables; trust, on the other hand, is essential. For example, Google's pervasive products and bottomless databases could easily seem sinister (and do, to many), but the company goes to great lengths to give its customers reason to trust it, including its support of the Data Liberation Front, which helps users maintain control over their personal information, and other initiatives.

How well will Apple be able to hold on to its customers' trust? Its handling of iPhone apps doesn't bode well. Some prominent app developers have publicly renounced the iOS platform because Apple's App Store approval rules—which the company has never deigned to publish or explain in detail—seemed to them capricious. Critics have charged that Apple censors political speech. And the firm's restrictive developer agreements prohibit programmers from using certain popular tools, such as Flash, to build their apps.

Apple CEO Steve Jobs insists that these measures are essential if Apple is to maintain the high quality that made the iPhone such a hit in the first place. But if the history of AOL is any guide, Apple's quality advantage won't last forever. Sooner or later, it might have to learn a thing or two about trust from the likes of Google. *—John Pavlus*

THOMAS ERNSTING *laif/Redux Pictures (mobile network operator)*

DROPPED CALLS

Data-hungry smart phones still have to work as phones

AS BANDWIDTH-HUNGRY smart phones proliferate, cellular networks have been crushed by downloads and video streams in densely populated urban areas, leading to dropped calls and slow data transfer rates. The exemplar of the unfortunate trend is AT&T, whose networks in New York City and San Francisco have been vigorously mocked by the iPhone-toting technorati.

Unfortunately, the fundamental problem is not technology, but geometry. The strength of a signal coming from a cell tower drops off rapidly with distance, and three quarters of the area covered by any given tower is in the distant half of its range. Worse yet, the wider the coverage area of any one tower, the more cell phone users it must handle.

The obvious solution is to build more towers. Wireless companies have begun to divide coverage area into smaller units served by low-cost "microcells." Dividing a coverage area in two increases the available bandwidth by 85 percent. The smallest of the microcells, called femtocells, can be placed in a user's home or apartment, albeit for a price. In March, AT&T began to sell $150 femtocell base stations that route calls through a customer's home Internet connection; Sprint is rumored to be working on base stations of its own.

—Christopher Mims

BUNKER FUEL

Exhaust from ships kills 90,000 people every year

CARGO SHIPS burn some of the nastiest stuff on earth: bunker fuel. Cheap and untaxed, it's a low-grade oil that is as thick as hot tar. The dirtiest variety—the kind ships burn when on the open ocean—is 4.5 percent sulfur by weight; sulfur, of course, is the foul element that forms sulfur dioxide, contributing to acid rain and respiratory ailments. (In contrast, diesel sold in the U.S. is just 0.0015 percent sulfur.) Bunker fuel leads to the premature deaths of an estimated 90,000 people a year.

This July the International Maritime Organization began to tighten controls on what was previously the world's least-regulated liquid fuel. In the first phase, a 1.5 percent cap on the sulfur content of bunker fuel burned close to shore (in so-called sulfur emission control areas such as the coast of California) will drop to 1 percent. By 2020 the organization will require that all bunker fuel have a sulfur content of less than 0.5 percent—a change that would halve its death toll.

These sulfur regulations are an important start, but they do not address a larger and potentially more important problem with bunker fuel: its carbon dioxide emissions contribute to global warming. If the international shipping fleet were a country, it would be the world's sixth-highest greenhouse gas emitter, right behind Japan and just ahead of Germany.

—Christopher Mims

GENE PATENTS

Naturally occurring genes are not a human invention

MORE THAN THREE DECADES ago Ananda Chakrabarty, a microbiologist at General Electric's laboratories in Schenectady, N.Y., genetically engineered a bacterium that was capable of dissolving crude oil. When he applied for a patent, the examiner initially refused his request, arguing that living organisms were not patentable. An appeals court later overturned the judgment, and in 1980 the U.S. Supreme Court ruled in Chakrabarty's favor.

For years this verdict seemed innocuous enough. Chakrabarty's bacterium was by most reasonable measures a novel invention, something profoundly different from the naturally occurring DNA that courts had previously ruled unpatentable. In time, however, the U.S. Patent and Trademark Office began to award patents to researchers not just for the invention of novel organisms but also for the act of isolating or purifying existing genetic material.

In the mid-1990s the Utah-based company Myriad Genetics secured patents for the *BRCA1* and *BRCA2* genes (pronounced "brick-ah"); mutations in these genes confer a fivefold increased risk of breast cancer in women who inherit them. Myriad's patents meant that a company effectively owned naturally occurring genes found in thousands, if not millions, of women. They also enabled the company to charge two groups of people large sums of money: women who wanted genetic tests to see if they were at high risk for breast cancer and researchers who wanted to work with the genes in the lab. Patients such as Lisbeth Ceriani, a single mother from Massachusetts who had already been treated once for breast cancer, could not get tested for the gene, because she could not afford Myriad's $3,000 price tag.

In 2009 Ceriani (along with several other patients, the American Civil Liberties Union and the American College of Medical Genetics) filed suit against Myriad, challenging the validity of its *BRCA* patents. Even though other courts had previously honored the Chakrabarty precedent, in March of this year U.S. District Court judge Robert W. Sweet struck down seven of the *BRCA* patents. In his verdict, Sweet called the common practice of isolating a gene to render it patentable "a 'lawyer's trick' that circumvents the prohibition on the direct patenting of the DNA in our bodies but which, in practice, reaches the same result."

Many scientists celebrated the verdict, arguing that gene patents can suppress independent research and innovation. Kenneth Berns, a microbiologist at the University of Florida, thinks eliminating patent protection for genes will make it easier to develop treatments for genetic diseases and provide patients with affordable genetic testing. ACLU spokesperson and staff attorney Sandra Park agrees that ending gene patenting would help clarify research opportunities. "A lot of researchers know genes are patented and don't want to bother pursuing work in a particular area," she says. "There's a fear that further on, if a scientist does find something clinical-

SAM SLOAN *Alamy (oil blob)*; BRUCE BENEDICT *Corbis (driving)*

HUMAN DRIVERS

The people behind the wheel are the most dangerous part of driving

IN THE WAKE of Toyota's much publicized recall for unintended acceleration, the idea of conceding control of our cars to software seems about as sane as letting a Roomba vacuum cleaner do brain surgery. And yet the data are unequivocal: according to multiple studies conducted over the past 25 years, so-called human factors—such as distraction, intoxication or just plain misjudgment—are the primary cause of traffic accidents and fatalities. Reason suggests that the sooner we can get fallible, inconsistent, idiotic humans out of the driver's seat, the safer our roads will be.

But are sci-fi-style, fully automated highways a realistic goal? David Shinar, head of Ben-Gurion University of the Negev's Human Factors Safety Laboratory in Israel, says that while human drivers will probably never be completely replaced, our role may simply change. "We're moving from a situation in which the driver is the controller of the system, to one in which the driver will be monitoring the system—sort of like a plane on autopilot," Shinar says. "Even when that system is engaged, the pilot doesn't go back into the first class cabin and take a nap. What we can expect are cars that need less direct controls from the driver; instead, the driver will intervene in the event of something unexpected."

Established systems such as electronic stability control (which detects and prevents skidding) can combine with newer technologies such as devices that keep vehicles in their lanes to create a virtual "safety bubble" around the car that counteracts human error, allowing cars to maintain a steady, slot-car-like course on the road with minimal input from the driver. In 2007 a driverless Chevy Tahoe nicknamed "Boss" successfully navigated a challenge course that included realistic traffic flow—even traffic jams—raising the possibility that autonomous vehicles might arrive sooner than previously thought. *—John Pavlus*

ly useful, the patent holder will step in."

Myriad plans to challenge the verdict. "Judge Sweet's decision sets a bad precedent for the biotech industry," says Richard Marsh, the company's executive vice president and general counsel. "Without the promise of patents, companies will not make the capital commitment to advance the medical science behind these molecular diagnostic products." The argument for gene patenting boils down to the need to attract investment. Without the limited monopoly that patent protection creates, says Bill Warren, a life sciences specialist at the Sutherland law firm in Atlanta, investors will not provide the capital necessary to develop new genetic innovations and treatments. "Generally gene patents are a very good thing, and I would not want to see them broadly excluded," he says.

Who will ultimately triumph—Mother Nature or the biotech industry? The answer is still up in the air. If Myriad's planned appeal fails, Park says the patent office has indicated it will award no further gene patents, a sweeping move that would most likely resign gene patenting to the dustbin of American history: "Removing DNA from a cell does not turn it into an invention."

—Elizabeth Svoboda

BISPHENOL A

This widely used yet unnecessary chemical could be making kids sick

ELIZABETH WATT *Getty Images (water bottle)*

AN ESTIMATED 95 percent of Americans harbor traces in their bodies of bisphenol A (BPA), a chemical widely used to make plastic containers, canned-food linings and dental sealants. Animal studies suggest that BPA, which resembles the sex hormone estrogen, can impair brain, ovary and sperm development in children exposed to it directly or in utero and that it may increase their risk for cancer and obesity. And although results from animal studies do not always apply to humans, "it is foolhardy to ignore these signals," warns Philip Landrigan, director of the Mount Sinai Children's Environmental Health Center in New York City.

But ignored they have been. When the National Institutes of Health asked the National Toxicology Program to evaluate BPA's safety in 2003, the program hired an industry contractor, Sciences International, which deemed the chemical safe. As the nonprofit Environmental Working Group later revealed, the contractor's other clients included BPA manufacturers, a finding that raised questions about impartiality. Then, in 2008, the Food and Drug Administration sent a letter to the U.S. House of Representatives Committee on Energy and Commerce stating, again, that BPA was safe; the agency later admitted that it had largely based this conclusion on two studies sponsored by the American Plastics Council. One has not been published in a peer-reviewed journal, and the other has been critiqued by academic experts as having "flawed experimental design." In March 2009 an international panel of experts concluded that the FDA's safety assessment of BPA had been "incomplete and unreliable."

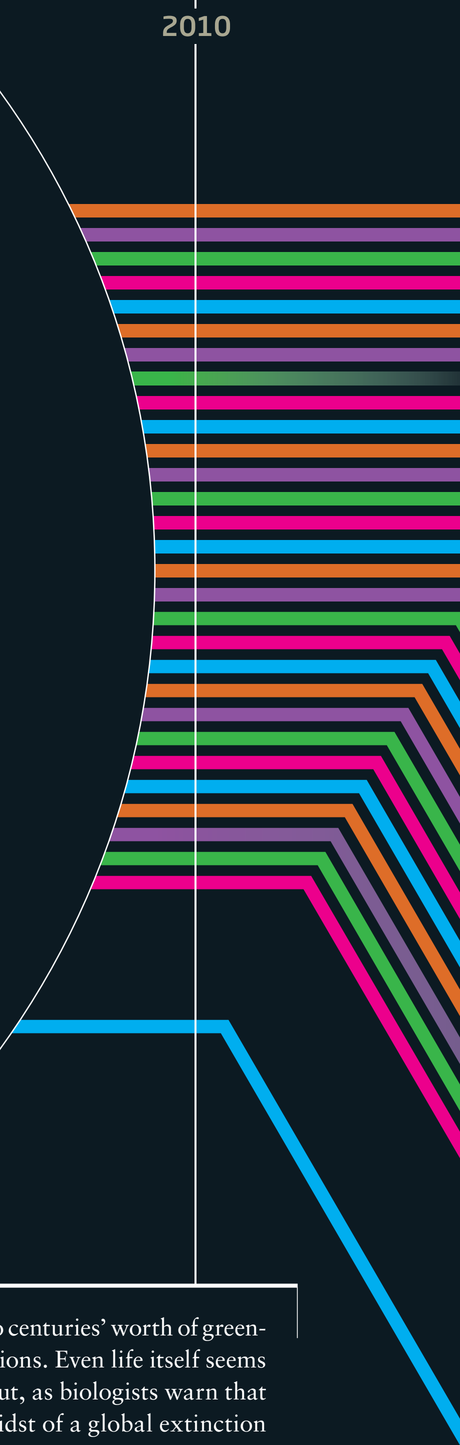
This past January the FDA finally admitted that it had "some concern" about the potential effects of BPA on fetal and child health; the NIH also promised to spend $30 million on related research in the coming years. Politicians have made a bigger push by introducing bills in many cities and states limiting its use, including the promise by Senator Dianne Feinstein of California that when the FDA Food Safety Modernization Act is brought to the Senate floor later this year—the House passed it last year—she will propose an amendment that will ban use of the chemical in food containers.

Industry groups such as the Grocery Manufacturers Association and the U.S. Chamber of Commerce oppose banning BPA, claiming that the chemical is safe and that switching to alternatives might prove costly. Yet the public backlash to BPA is growing, and major companies such as Gerber and Nalgene have already begun to phase out its use. *—Melinda Wenner Moyer*

[ENVIRONMENT]

how much is left?

A graphical accounting of the limits to what one planet can provide



BY MICHAEL MOYER
WITH REPORTING BY CARINA STORRS

IF THE 20TH CENTURY was an expansive era seemingly without boundaries—a time of jet planes, space travel and the Internet—the early years of the 21st have showed us the limits of our small world. Regional blackouts remind us that the flow of energy we used to take for granted may be in tight supply. The once mighty Colorado River, tapped by thirsty metropolises of the desert West, no longer reaches the ocean. Oil is so hard to find that new wells extend many kilometers underneath the seafloor. The boundless atmosphere is now reeling from two centuries' worth of greenhouse gas emissions. Even life itself seems to be running out, as biologists warn that we are in the midst of a global extinction event comparable to the last throes of the dinosaurs.

The constraints on our resources and environment—compounded by the rise of the middle class in nations such as China and India—will shape the rest of this century and beyond. Here is a visual accounting of what we have left to work with, a map of our resources plotted against time.

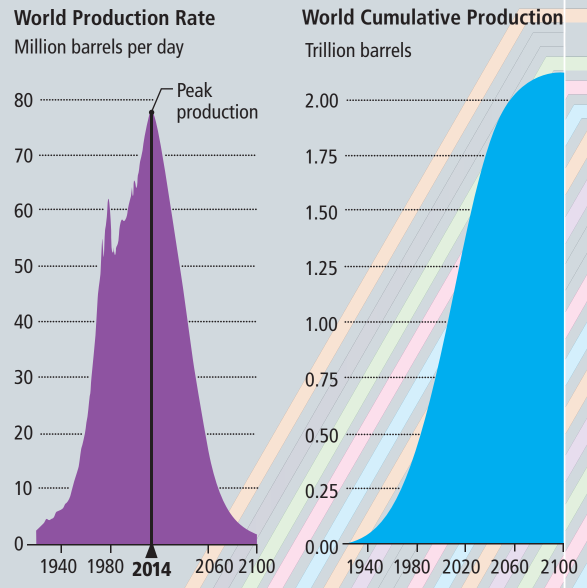
Experience an interactive version of this article at **www.ScientificAmerican.com/interactive**

JEN CHRISTIANSEN

[FOSSIL FUELS]

2014 >> THE PEAK OF OIL

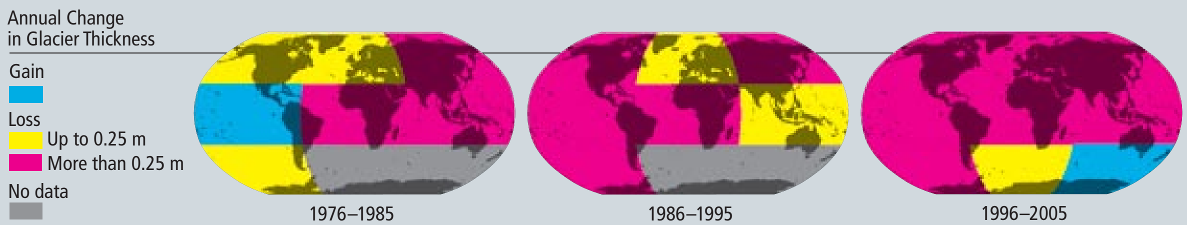
The most common answer to "how much oil is left" is "depends on how hard you want to look." As easy-to-reach fields run dry, new technologies allow oil companies to tap harder-to-reach places (such as 5,500 meters under the Gulf of Mexico). Traditional statistical models of oil supply do not account for these advances, but a new approach to production forecasting explicitly incorporates multiple waves of technological improvement. Though still controversial, this multi-cyclic approach predicts that global oil production is set to peak in four years and that by the 2050s we will have pulled all but 10 percent of the world's oil from the ground.



[WATER]

1976-2005 >> GLACIER MELT ACCELERATES

Glaciers have been losing their mass at an accelerating rate in recent decades. In some regions such as Europe and the Americas, glaciers now lose more than half a meter each year.



[MINERALS]

2028 >> INDIUM

Indium is a silvery metal that sits next to platinum on the periodic table and shares many of its properties such as its color and density. Indium tin oxide is a thin-film conductor used in flat-panel televisions. At current production levels, known indium reserves contain an 18-year world supply.

[WATER]

2025 >> BATTLE OVER WATER

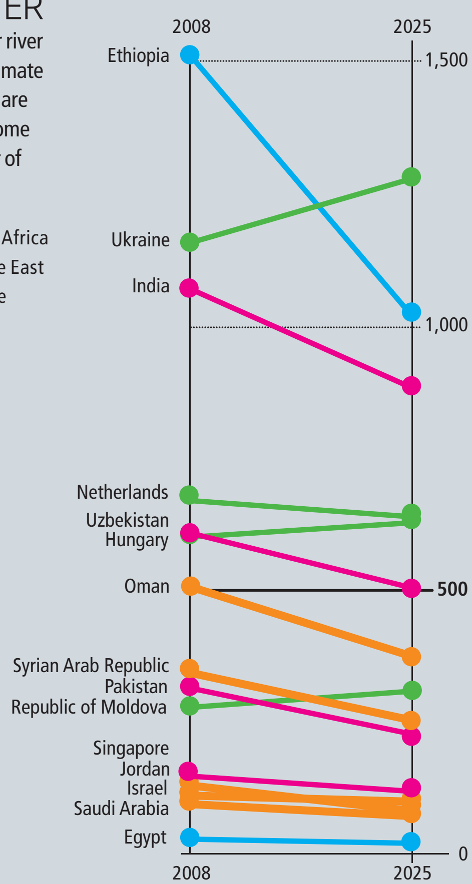
In many parts of the world, one major river supplies water to multiple countries. Climate change, pollution and population growth are putting a significant strain on supplies. In some areas renewable water reserves are in danger of dropping below the 500 cubic meters per person per year considered a minimum for a functioning society.

DRYING OUT

Total Renewable Water per Capita

Cubic meters per person per year

- Asia
- North Africa
- Middle East
- Europe



POTENTIAL HOT SPOTS

EGYPT: A coalition of countries led by Ethiopia is challenging old agreements that allow Egypt to use more than 50 percent of the Nile's flow. Without the river, all of Egypt would be desert.

EASTERN EUROPE: Decades of pollution have fouled the Danube, leaving downstream countries, such as Hungary and the Republic of Moldova, scrambling to find new sources of water.

MIDDLE EAST: The Jordan River, racked by drought and diverted by Israeli, Syrian and Jordanian dams, has lost 95 percent of its former flow.

FORMER SOVIET UNION: The Aral Sea, at one time the world's fourth-largest inland sea, has lost 75 percent of its water because of agricultural diversion programs begun in the 1960s.

[MINERALS]

2029 >> SILVER

Because silver naturally kills microbes, it is increasingly used in bandages and as coatings for consumer products. At current production levels, about 19 years' worth of silver remains in the ground, but recycling should extend that supply by decades.

[FOOD]

>> FEWER FISH

Fish are our last truly wild food, but the rise in demand for seafood has pushed many species to the brink of extinction. Here are five of the most vulnerable.

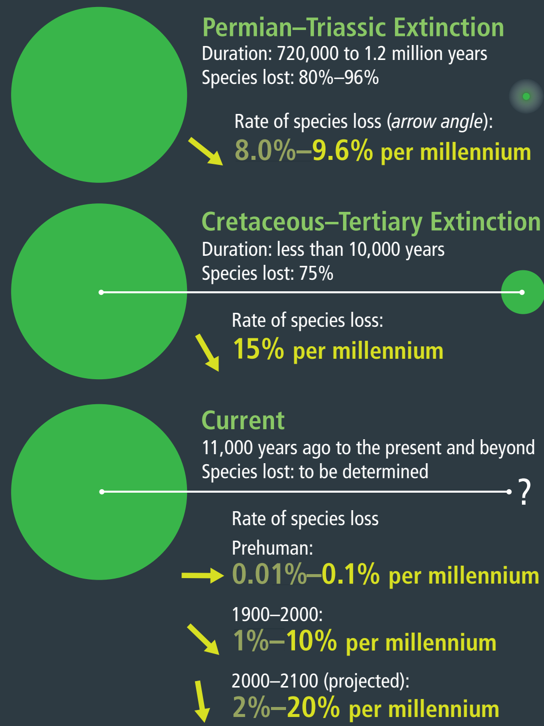
HAMMERHEAD SHARKS have declined by 89 percent since 1986. The animals are sought for their fins, which are a delicacy in soup.

JASON LEE (*fish*)

[BIODIVERSITY]

>> OUR MASS EXTINCTION

Biologists warn that we are living in the midst of a mass extinction on par with the other five great events in Earth's history, including the Permian-Triassic extinction (also known as the Great Dying; it knocked out up to 96 percent of all life on Earth) and the Cretaceous-Tertiary extinction that killed the dinosaurs. The cause of our troubles? Us. Human mastery over the planet has pushed many species out of their native habitats; others have succumbed to hunting or environmental pollutants. Here we compare our current extinction with its predecessors using the latest estimates of species loss per year. If trends continue—and unfortunately, species loss is accelerating—the world will soon be a far less diverse place.

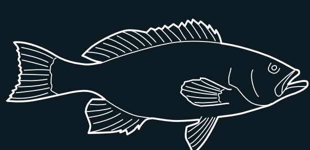


[MINERALS]

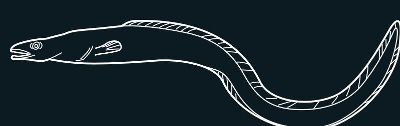
2030 >> GOLD

The global financial crisis has boosted demand for gold, which is seen by many as a tangible (and therefore lower-risk) investment. According to Julian Phillips, editor of the *Gold Forecaster* newsletter, probably about 20 years are left of gold that can be easily mined.

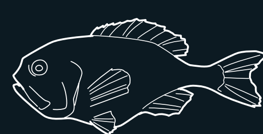
RUSSIAN STURGEON have lost spawning grounds because of exploitation for caviar. Numbers are down 90 percent since 1965.



YELLOWMOUTH GROUPER may exist only in pockets of its former range, from Florida to Brazil.



EUROPEAN EEL populations have declined by 80 percent since 1968; because the fish reproduces late in life, recovery could take 200 years.



ORANGE ROUGHY off the coast of New Zealand have declined by 80 percent since the 1970s because of overfishing by huge bottom trawlers.

[FOOD]

2050 >> FEEDING A WARMING WORLD

Researchers have recently started to untangle the complex ways rising temperatures will affect global agriculture. They expect climate change to lead to longer growing seasons in some countries; in others the heat will increase the frequency of extreme weather events or the prevalence of pests. In the U.S., productivity is expected to rise in the Plains states but fall further in the already struggling Southwest. Russia and China will gain; India and Mexico will lose. In general, developing nations will take the biggest hits. By 2050 counteracting the ill effects of climate change on nutrition will cost more than $7 billion a year.

The Effects of Global Warming on Agriculture

Percent change in production for the world's eight largest growers (by the 2080s)

Argentina	2.2%
Australia	–15.6%
Brazil	–4.4%
China	6.8%
India	–28.8%
Mexico	–25.7%
Russia	6.2%
U.S.	8%
Pacific Northwest	26%
Rockies and Plains	47%
Southeast	–18%
Southwest Plains	–25%

[MINERALS]

2044 >> COPPER

Copper is in just about everything in infrastructure, from pipes to electrical equipment. Known reserves currently stand at 540 million metric tons, but recent geologic work in South America indicates there may be an additional 1.3 billion metric tons of copper hidden in the Andes Mountains.

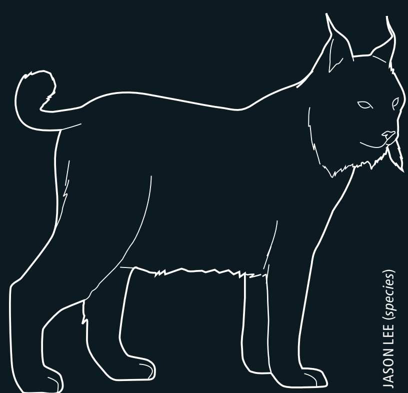
[BIODIVERSITY]

>> MORTAL THREATS

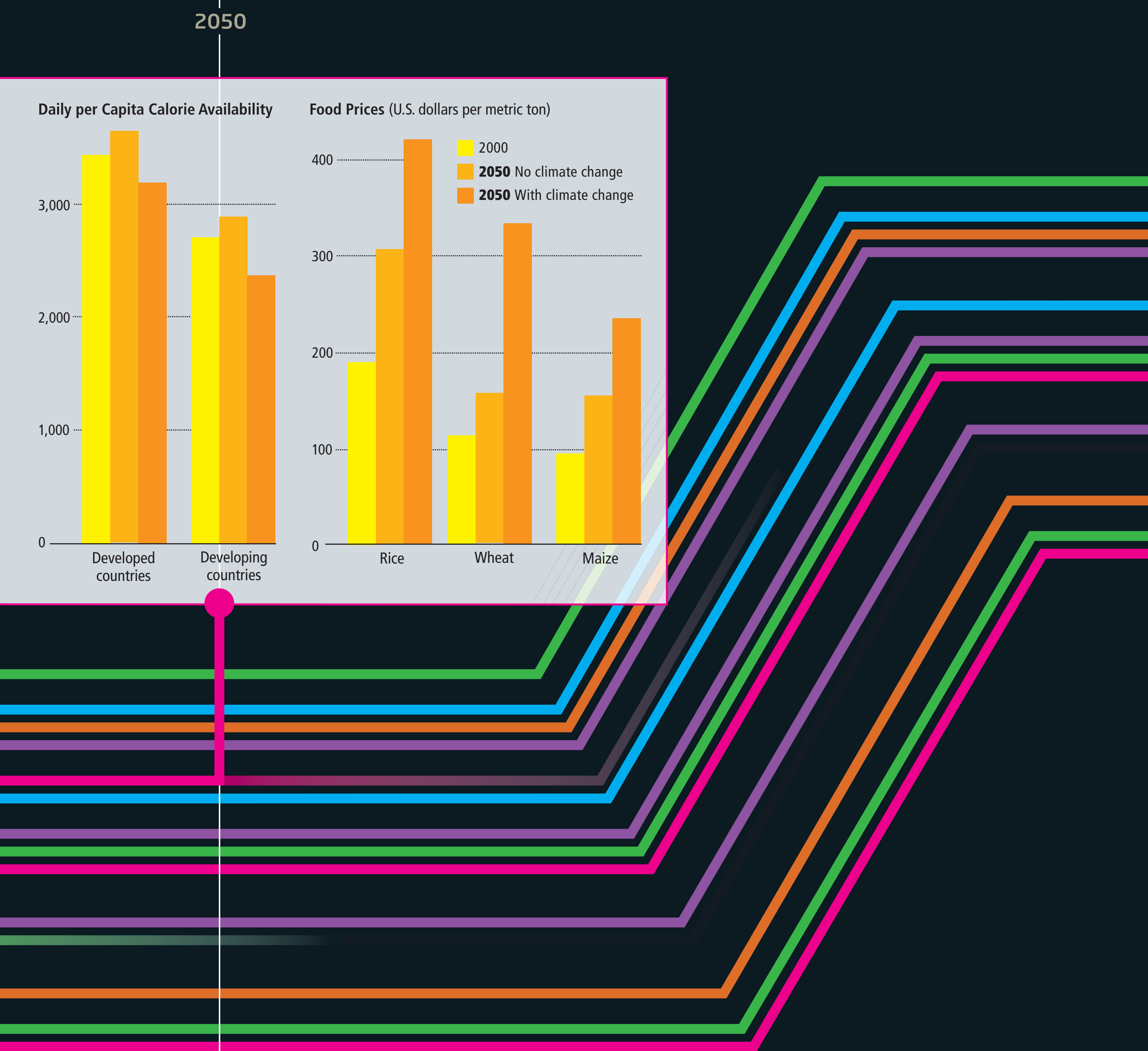
As the total number of species declines, some have fared worse than others [see "Our Mass Extinction," on preceding page]. Here, at the right, are five life-forms, the estimated percentage of species thought to be endangered, and an example of the threats they face.

MAMMALS
18 percent endangered

The Iberian lynx feeds on rabbits, a prey in short supply in the lynx's habitat ever since a pediatrician introduced the disease myxomatosis from Australia to France in 1952 to kill the rabbits in his garden.



JASON LEE (*species*)

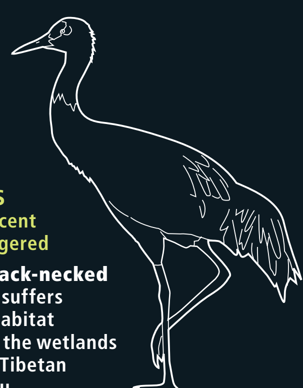


PLANTS
8 percent endangered

The **St. Helena redwood** is native to the island in the South Atlantic where Napoleon lived his last years. Its excellent timber led to exploitation; by the 20th century only one remained in the wild.

LIZARDS
20 percent endangered

The **blue spiny lizard** must retreat from the sun before it overheats; higher temperatures have cut down on the time it can forage for food.



BIRDS
10 percent endangered

The **black-necked crane** suffers from habitat loss in the wetlands of the Tibetan plateau.

AMPHIBIANS
30 percent endangered

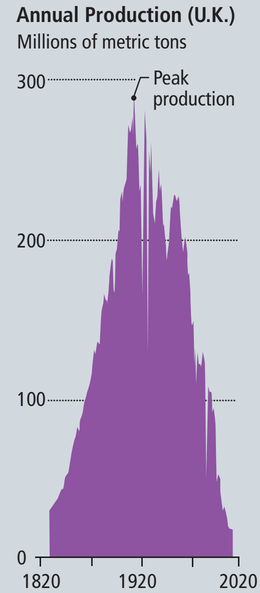
Archey's frog has been devastated by a fungal disease in its native New Zealand.

2060

[FOSSIL FUELS]

2072 >> LIMITS OF COAL

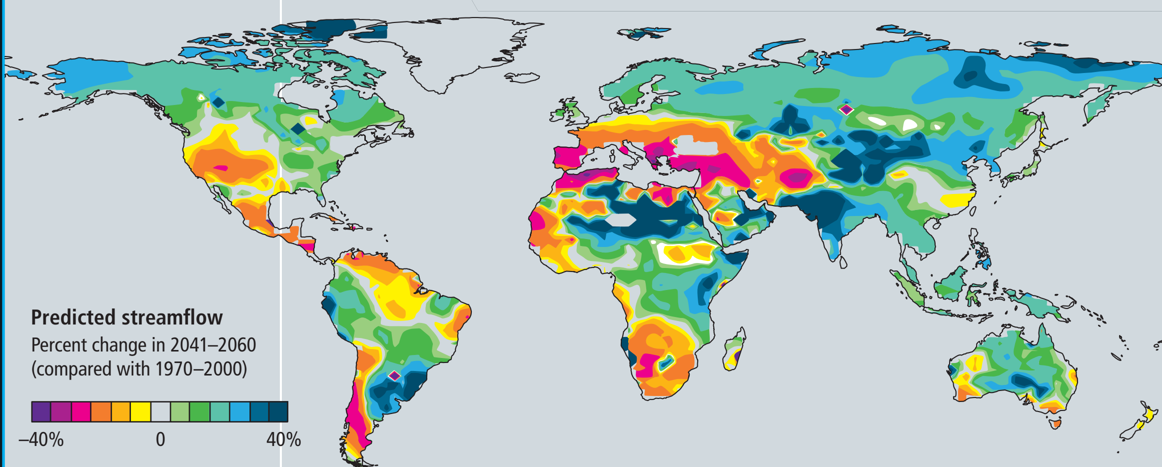
Unlike oil, coal is widely thought to be virtually inexhaustible. Not so, says David Rutledge of the California Institute of Technology. Governments routinely overestimate their reserves by a factor of four or more on the assumption that hard-to-reach seams will one day open up to new technology. Mature coal mines show that this has not been the case. The U.K.—the birthplace of coal mining—offers an example. Production grew through the 19th and early 20th centuries, then fell as supplies were depleted. Cumulative production curves in the U.K. and other mature regions have followed a predictable S shape. By extrapolating to the rest of the world's coal fields, Rutledge concludes that the world will extract 90 percent of available coal by 2072.



[WATER]

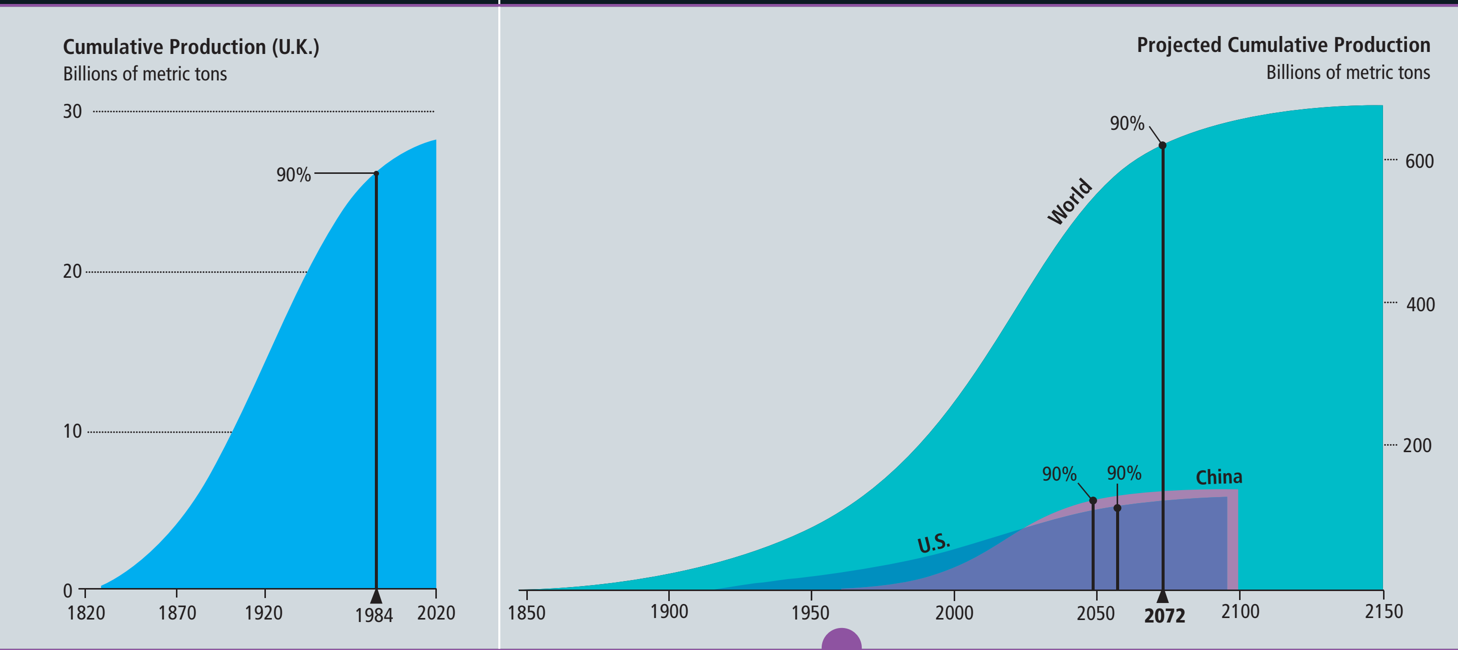
2060 >> CHANGING THE COURSE OF A RIVER

Climate change will shift weather patterns, leading to big changes in the amount of rain that falls in any given region, as well as the amount of water flowing through streams and rivers. Scientists at the U.S. Geological Survey averaged the results of 12 climate models to predict how streamflow will alter over the next 50 years. While East Africa, Argentina and other regions benefit from more water, southern Europe and the western U.S. will suffer.



JESSICA HUPPI (*map*)

2070



[WATER]

2070 >> HIMALAYAN ICE

Snow melt from the Himalayas is a prime source of water for Asia's major river valleys, including the Yellow, Yangtze, Mekong and Ganges. By 2070 ice-covered landmass in the Himalayas could decrease by 43 percent.

[WATER]

2100 >> THE ALPS

Parts of the Alps are warming so quickly that the Rhone Glacier is expected to have disappeared by the end of the century.

[MINERALS]

2560 >> LITHIUM

Because lithium is an essential component of the batteries in electric cars, many industry analysts have worried publicly that supplies won't keep up with growing demand for the metal. Still, known lithium reserves are big enough to keep us supplied for more than five centuries, even ignoring the vast supply of lithium in seawater.

[SOURCES]

WATER *Global Glacier Changes: Facts and Figures*. U.N. Environment Program/World Glacier Monitoring Service, 2008; AQUASTAT Database, U.N. Food and Agriculture Organization; "Global Pattern of Trends in Streamflow and Water Availability in a Changing Climate," by P.C.D. Milly et al., in *Nature,* Vol. 438; Nov. 17, 2005. **FOOD** *Climate Change: Impact on Agriculture and Costs of Adaptation,* by Gerald C. Nelson et al. International Food Policy Research Institute, Washington, D.C., 2009; *Global Warming and Agriculture: Impact Estimates by Country,* by William R. Cline. Center for Global Development, Washington, D.C., 2007. **OIL** "Forecasting World Crude Oil Production Using Multicyclic Hubbert Model," by Ibrahim Sami Nashawi et al., in *Energy Fuels,* Vol. 24, No. 3; March 18, 2010. **COAL** David Rutledge, submission to *International Journal of Coal Geology*, 2010. **MINERALS** *Mineral Commodity Summaries 2010*. U.S. Geological Survey. **BIODIVERSITY** "Consequences of Changing Biodiversity," by F. Stuart Chapin III et al., in *Nature.* Vol. 405; May 11, 2000; "Quantifying the Extent of North American Mammal Extinction Relative to the Pre-Anthropogenic Baseline," by Marc A. Carrasco et al., in *PLoS ONE.* Vol. 4, No. 12; Dec. 16, 2009; "Re-assessing Current Extinction Rates," by Nigel E. Stork, in *Biodiversity Conservation,* Vol. 19, No. 2; Feb. 2010; "The Future of Biodiversity," by Stuart L. Pimm et al., in *Science,* Vol. 269; July 21, 1995; "Are We in the Midst of the Sixth Mass Extinction? A View from the World of Amphibians," by David B. Wake and Vance T. Vredenburg, in *Proceedings of the National Academy of Sciences USA,* Vol. 105, Supplement 1; Aug. 12, 2008.

laying odds on the apocalypse

PROBABLE

EXCEEDINGLY RARE

ODDS

KILLER PANDEMIC

One in 2 in the next 30 years

DESTRUCTION RANKING: 4

Humankind is more vulnerable than ever to a devastating, Black Death–style pandemic, says Joseph Fair, director of global field operations for the Global Viral Forecasting Initiative. He declined to predict when one might strike, instead rating civilization as a lowly two on a 10-point preparedness scale. The next pandemic, Fair says, will likely be a pox or a virus that is either new to humans or a more deadly adaptation of a common virus.

SOLAR SUPERSTORM

One in 20 in the next 15 years

DESTRUCTION RANKING: 2

"We don't want to be alarmist," says Daniel N. Baker, a space scientist at the University of Colorado at Boulder, but a solar eruption could grow large enough to knock out the power grids and communication systems over much of the world. "If that were to occur today with our modern, highly electronically connected society," Baker says, "it would undoubtedly be devastating to the most advanced countries."

RUNAWAY GLOBAL WARMING

One in 2 in the next 200 years

DESTRUCTION RANKING: 3

The ice sheets in Greenland and West Antarctica together contain enough water to raise global sea levels by about 12 meters, erasing coastal cities and making refugees of hundreds of millions of people. Without a change of behavior, humankind could set into motion the irreversible melting of both ice sheets by the end of this century, says Henry Pollack, an emeritus professor of geophysics at the University of Michigan at Ann Arbor and author of *A World without Ice* (Avery, 2009). "My particular feeling is that it'll be touch and go as to whether we can actually achieve the avoidance of Greenland and West Antarctic ice loss," Pollack says. "The consequences of displacing so many people—the world has never dealt with something like that."

SUPERVOLCANO

One in 100 in the next 1,000 years

DESTRUCTION RANKING: 5

A supervolcano would spew at least 1,000 cubic kilometers of ash and lava, or about 1,000 times the ejecta from the 1980 eruption of Mount St. Helens. Such an explosion would significantly alter global weather patterns for decades, which would in turn lead to drought and famine.

Find our list of the best books and movies about the apocalypse at **www.ScientificAmerican.com/TheEnd**

MODERATE DEVASTATION

DESTRUCTION

ILLUSTRATIONS BY LOU BROOKS

Could modern civilization really come to an end? Experts take stock of eight doomsday scenarios

<< BY JOHN MATSON, WITH REPORTING BY JOHN PAVLUS >>

WITH ALL DUE RESPECT to T. S. Eliot, maybe the world really does end with a bang, not a whimper. Whether of our own creation (nuclear holocaust) or of nature's (asteroid impact), plenty of cataclysms could doom civilization—perhaps even putting the survival of the species in jeopardy. We assessed the likelihood of several doomsday scenarios, from oft-discussed threats such as climate change to more fanciful ideas such as quantum fluctuations that would destroy our universe. The probabilities listed here are not scientific fact—an impossible goal when estimating the possibility of unprecedented events—but informed conjecture based on researchers' expert opinions. We also relied on those opinions to approximate how catastrophic each event would be, ranging from 1 (localized chaos) to 10 (good-bye, universe).

NUCLEAR WAR

One in 30 in the next 10 years

DESTRUCTION RANKING: 6

An accident or cyberattack could spur a nuclear exchange between the U.S. and Russia, killing hundreds of millions of people, says Kennette Benedict, executive director and publisher of the *Bulletin of the Atomic Scientists.* A more likely scenario is a terrorist attack on an urban area using smaller nukes; Benedict pegs those odds at better than 50–50 over the next 15 years.

GIANT ASTEROID IMPACT

One in 1 million in the next 100 years

DESTRUCTION RANKING: 9

Although a 10-kilometer-wide species ender might be a long shot, a smaller, more common asteroid strike could still wreak serious havoc. A three-kilometer object (rough odds: one in 200,000 this century) could kill a quarter of the world's population and temporarily destroy civilization.

NEARBY GAMMA-RAY BURST

One in 15 over 100 million years

DESTRUCTION RANKING: 7

Most of these cosmic blasts are thought to form when a massive star collapses into a black hole. None has ever been observed in our galaxy, which is fortunate: a nearby flash could pummel Earth with radiation and ravage the atmosphere's protective ozone layer. Some researchers think that one could have caused a mass extinction 440 million years ago.

BUBBLE NUCLEATION

One in 1 billion in the next 1 trillion years

DESTRUCTION RANKING: 10

What if another universe popped up spontaneously within our own? This is the bubble scenario, whereby our universe flips into a new state with different fundamental forces. The transition would happen when a tiny bubble pops up imprinted with the new laws of nature, then "expands at nearly the speed of light and engulfs the surrounding space, including what remains of our solar system," says Alexander Vilenkin, a cosmologist at Tufts University. But we can probably push it way down the worry list. Vilenkin is willing to bet "a large amount of money" that bubble nucleation is not going to happen in the next trillion years. He was not clear on how his opponent would collect were he to lose.

TOTAL EXTERMINATION

[COSMOLOGY]

could time end?

Yes. And no. For time to end seems both impossible and inevitable. Recent work in physics suggests a resolution to the paradox

<< BY GEORGE MUSSER >>

[KEY CONCEPTS]

- Einstein's general theory of relativity predicts that time ends at moments called singularities, such as when matter reaches the center of a black hole or the universe collapses in a "big crunch." Yet the theory also predicts that singularities are physically impossible.
- A way to resolve this paradox is to consider time's death as gradual rather than abrupt. Time might lose its many attributes one by one: its directionality, its notion of duration and its role in ordering events causally. Finally, time might give way to deeper, timeless physics.

—The Editors

IN OUR EXPERIENCE, nothing ever really ends. When we die, our bodies decay and the material in them returns to the earth and the air, allowing for the creation of new life. We live on in what comes after. But will that always be the case? Might there come a point sometime in the future when there is no "after"? Depressingly, modern physics suggests the answer is yes. Time itself could end. All activity would cease, and there would be no renewal or recovery. The end of time would be the end of endings.

This grisly prospect was an unanticipated prediction of Einstein's general theory of relativity, which provides our modern understanding of gravity. Before that theory, most physicists and philosophers thought time was a universal drumbeat, a steady rhythm that the cosmos marches to, never varying, wavering or stopping. Einstein showed that the universe is more like a big polyrhythmic jam session. Time can slow down, or stretch out, or let it rip. When we feel the force of gravity, we are feeling time's rhythmic improvisation; falling objects are drawn to places where time passes more slowly. Time not only affects what matter does but also responds to what matter is doing, like drummers and dancers firing one another up into a rhythmic frenzy. When things get out of hand, though, time can go up in smoke like an overexcited drummer who spontaneously combusts.

The moments when that happens are known as singularities. The term actually refers to any boundary of time, be it beginning or end. The best known is the big bang, the instant 13.7 billion years ago when our universe—and, with it, time—burst into existence and began expanding. If the universe ever stops expanding and starts contracting again, it will go into something like the big bang in reverse—the big crunch—and bring time crashing to a halt.

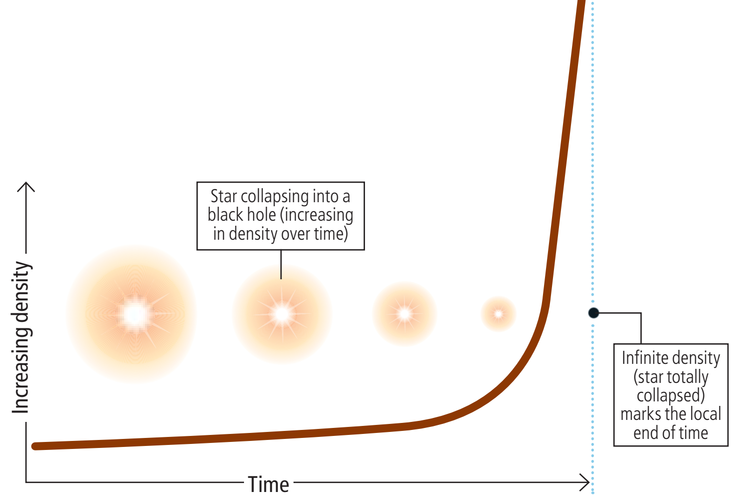
Time needn't perish everywhere. Relativity says it expires inside black holes while carrying on in the universe at large. Black holes have a well-deserved reputation for destructiveness, but they are even worse than you might think.

PHOTOGRAPHS BY HOLLY LINDEM

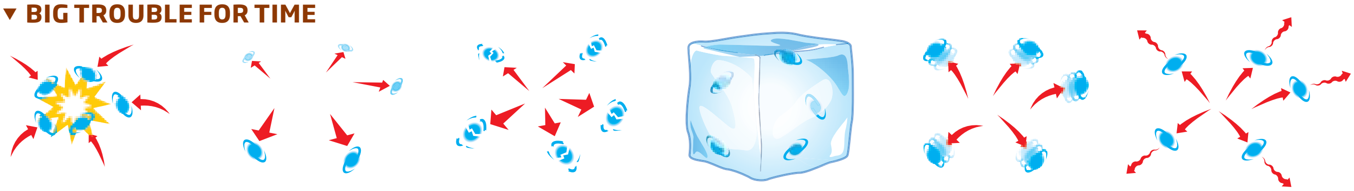
[HOW TIME MIGHT END]

ULTIMATE DOOMSDAY

Time can end in a disquieting variety of ways, according to Einstein's general theory of relativity. For instance, when a black hole forms, the density of matter increases, which intensifies the force of gravity, which further increases the density, which further intensifies gravity, and so it goes until density and gravity both become infinite—a condition known as a singularity (*right*). Matter ceases to be, and time runs out for that region of space. A similar fate could befall the entire universe (*below*).



▼ BIG TROUBLE FOR TIME



Big Crunch
Cosmic expansion slows down as the gravity of matter holds it back. Eventually it stops and goes into reverse, culminating with collapse back to a singularity that marks time's end. Once thought likely, this fate now seems doubtful. Not only is matter too sparse to act as a brake, but some unseen form of energy—dark energy—appears to be stepping on the accelerator.

Big Whimper
The universe expands forever, becoming ever emptier and gloomier. Astronomers now consider this fate the likeliest. Although time never ends, it becomes increasingly pointless. The universe suffers "heat death"—a state of equilibrium in which every process is quickly undone, so that time has no clear forward progression and might not even come in well-defined units.

Big Rip
The universe tears itself to pieces. That can happen if dark energy is not constant, as most models suppose, but gains in power. Hypothesized in 1999, this extrapotent dark energy goes by the name of phantom energy. It drives the universe to expand by an infinite amount—even atoms get shredded—and finishes off time. In some scenarios, the end comes about 20 billion years from now.

Big Freeze
The universe fills up with phantom energy and reaches infinite density, while expanding by only a finite amount. Any surviving wisps of matter are locked in place, unable to move, and time seizes up. A localized big freeze can occur if our universe is a membrane that is moving in a higher-dimensional space (as postulated by string theory) and begins to whip around violently.

Big Brake
Dark energy shifts from driving cosmic expansion to retarding it, bringing the growth of the universe to a screeching halt—the rate of deceleration is infinite. First conjectured in 2004, the event is traumatic, with cosmic structures subjected to tidal forces of infinite strength. Although other quantities remain finite, the situation has unhappy consequences for time.

Big Lurch
Conceived of in 2004, a so-called sudden singularity does not require dark energy; all it takes is for ordinary matter to work itself up into a frenzy. Pressure forces go infinite, while the density and cosmic expansion rate remain in safe territory. Time might or might not carry on. Astronomical observations cannot rule out such a calamity as soon as nine million years from now.

If you fell into one, you would not only be torn to shreds, but your remains would eventually hit a singularity at the center of the hole, and your timeline would end. No new life would emerge from your ashes; your molecules would not get recycled. Like a character reaching the last page of a novel, you would not suffer mere death but existential apocalypse.

It took physicists decades to accept that relativity theory would predict something so unsettling as death without rebirth. To this day, they aren't quite sure what to make of it. Singularities are arguably the leading reason that physicists seek to create a unified theory of physics, which would merge Einstein's brainchild with quantum mechanics to create a quantum theory of gravity. They do so partly in the hope they might explain singularities away. But you need to be careful what you wish for. Time's end is hard to imagine, but time's not ending may be equally paradoxical.

EDGES OF TIME

WELL BEFORE Albert Einstein came along, philosophers through the ages had debated whether time could be mortal. Immanuel Kant considered the issue to be an "antinomy"—something you could argue both ways, leaving you not knowing what to think.

My father-in-law found himself on one horn of this dilemma when he showed up at an airport one evening only to find that his flight had long since departed. The people at the check-in counter chided him, saying he should have known that the scheduled departure time of "12 A.M." meant the first thing in the morning. Yet my father-in-law's confusion was understandable. Officially there is no such time as "12 A.M." Midnight is neither ante meridiem nor post meridiem. It is both the end of one day and start of the next. In 24-hour time notation, it is both 2400 and 0000.

Aristotle appealed to a similar principle when he argued that time can have neither beginning nor end. Every moment is both the end of an era and the start of something new; every event is both the outcome of something and the cause of something else. So how could time possibly end? What would prevent the last event in history from leading to another? Indeed, how would you even define the end of time when the very concept of "end" presupposes time? "It is not logically possible for time to have an end," asserts University of Oxford philosopher Richard Swinburne. But if time cannot end, then the universe must be infinitely

JASON LEE

long-lived, and all the riddles posed by the notion of infinity come rushing in. Philosophers have thought it absurd that infinity could be anything but a mathematical idealization.

The triumph of the big bang theory and the discovery of black holes seemed to settle the question. The universe is shot through with singularities and could suffer a distressing variety of temporal cataclysms; even if it evades the big crunch, it might get done in by the big rip, the big freeze or the big brake [*see box on opposite page*]. But then ask what singularities (big or otherwise) actually are, and the answer is no longer so clear. "The physics of singularities is up for grabs," says Lawrence Sklar of the University of Michigan at Ann Arbor, a leading philosopher of physics.

The very theory that begat these monsters suggests they cannot really exist. At the big bang singularity, for example, relativity theory says that the precursors of every single galaxy we see were squashed into a single mathematical point—not just a tiny pinprick but a true point of zero size. Likewise, in a black hole, every single particle of a hapless astronaut gets compacted into an infinitesimal point. In both cases, calculating the density means dividing by zero volume, yielding infinity. Other types of singularities do not involve infinite density but an infinite something else.

Although modern physicists do not feel quite the same aversion to infinity that Aristotle and Kant did, they still take it as a sign they have pushed a theory too far. For example, consider the standard theory of ray optics taught in middle school. It beautifully explains eyeglass prescriptions and funhouse mirrors. But it also predicts that a lens focuses light from a distant source to a single mathematical point, producing a spot of infinite intensity. In reality, light gets focused not to a point but to a bull's-eye pattern. Its intensity may be high but is always finite. Ray optics errs because light is not really a ray but a wave.

In a similar vein, nearly all physicists presume that cosmic singularities actually have a finite, if high, density. Relativity theory errs because it fails to capture some important aspect of gravity or matter that comes into play near singularities and keeps the density under control. "Most people would say that they signal that the theory is breaking down there," says physicist James B. Hartle of the University of California, Santa Barbara.

To figure out what goes on will take a more encompassing theory, a quantum theory of gravity. Physicists are still working on such a theory, but they figure that it will incorporate the central insight of quantum mechanics: that matter, like light, has wavelike properties. These properties should smear the putative singularity into a small wad, rather than a point, and thereby banish the divide-by-zero error. If so, time may not, in fact, end.

Physicists argue it both ways. Some think time does end. The trouble with this option is that the known laws of physics operate within time and describe how things move and evolve. Time's end points are off the reservation; they would have to be governed not just by a new law of physics but by a new type of law of physics, one that eschews temporal concepts such as motion and change in favor of timeless ones such as geometric elegance. In one proposal three years ago Brett McInnes of the National University of Singapore drew on ideas from the leading candidate for a quantum the-

JASON LEE

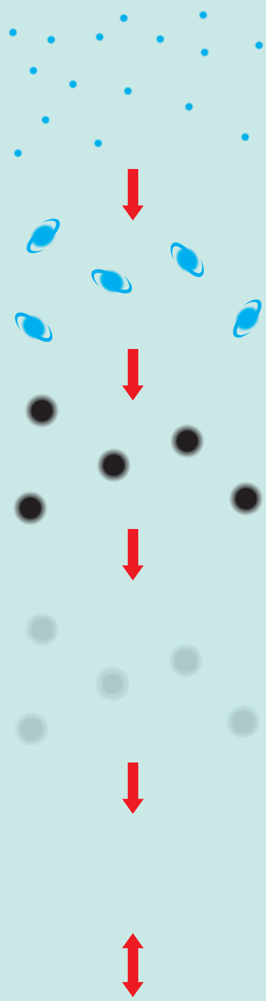
THE FOUR STAGES OF THE END OF TIME

The end of time might be a step-by-step process, as the universe regresses to a more primitive state in which time has no meaning. (The sequence shown here and on the following pages is not rigid; the steps might overlap or occur in a different order.)

[LOSS OF DIRECTIONALITY]

1 BROKEN ARROW OF TIME

Time will stop marching forward when the universe exhausts its useful energy and reaches a condition of general stasis. The scenario shown below occurs in an eternally expanding universe, but time can lose its directionality in other scenarios as well. From then on, the only activity will be random fluctuations of density and energy, causing clocks, if there are any left, merely to jiggle back and forth.



The universe begins as a nearly uniform gas.

It clumps under the force of gravity.

Matter collapses all the way down to black holes.

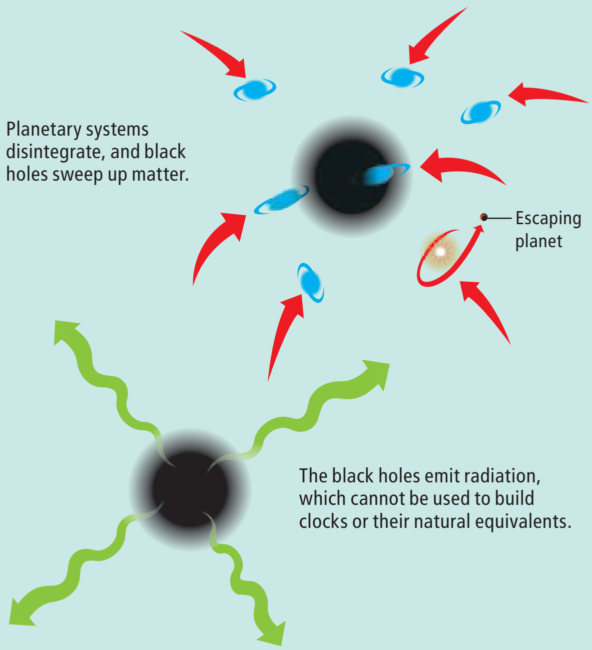
Black holes give off radiation and disappear.

Radiation dissipates, and only empty space remains.

From then on, nothing much ever changes.

2 [LOSS OF DURATION] TIME CANNOT BE TOLD

The concept of duration will become meaningless when all systems that mark out regular time intervals fall apart or get swallowed by black holes. Energy may leak back out of the black holes, but it does so as radiation—that is, as photons and other massless particles. Because such particles have no fixed scale and do not change with time, they cannot be used as the basis for new clocks.



ory of gravity—string theory. He suggested that the primordial wad of a universe had the shape of a torus; because of mathematical theorems concerning tori, it had to be perfectly uniform and smooth. At the big crunch or a black hole singularity, however, the universe could have any shape whatsoever, and the same mathematical reasoning need not apply; the universe would in general be extremely raggedy. Such a geometric law of physics differs from the usual dynamical laws in a crucial sense: it is not symmetrical in time. The end wouldn't just be the beginning played backward.

Other quantum gravity researchers think that time stretches on forever, with neither beginning nor end. In their view, the big bang was simply a dramatic transition in the eternal life of the universe. Perhaps the prebangian universe started to undergo a big crunch and turned around when the density got too high—a big bounce. Artifacts of this prehistory may even have made it through to the present day [see "Follow the Bouncing Universe," by Martin Bojowald; Scientific American, October 2008]. By similar reasoning, the singular wad at the heart of a black hole would boil and burble like a miniaturized star. If you fell into a black hole, you would die a painful death, but at least your timeline would not end. Your particles would plop into the wad and leave a distinct imprint on it, one that future generations might see in the feeble glow of light the hole gives off.

By supposing that time marches on, proponents of this approach avoid the need to speculate about a new type of law of physics. Yet they, too, run into trouble. For instance, the universe gets steadily more disordered with time; if it has been around forever, why is it not in total disarray by now? As for a black hole, how would the light bearing your imprint possibly manage to escape the hole's gravitational clutches?

The bottom line is that physicists struggle with antinomy no less than philosophers have. The late John Archibald Wheeler, a pioneer of quantum gravity, wrote, "Einstein's equation says 'this is the end' and physics says 'there is no end.' " Faced with this dilemma, some people throw up their hands and conclude that science can never resolve whether time ends. For them, the boundaries of time are also the boundaries of reason and empirical observation. But others think the puzzle just requires some fresh thinking. "It is not outside the scope of physics," says physicist Gary Horowitz of U.C. Santa Barbara. "Quantum gravity should be able to provide a definite answer."

HOW TIME SLIPS AWAY

THE HAL 9000 may have been a computer, but he was probably the most human character in *2001: A Space Odyssey*—expressive, resourceful, a bundle not just of wires but also of contradictions. Even his death was evocative of human death. It was not an event but a process. As Dave slowly pulled out his circuit boards, HAL lost his mental faculties one by one and described how it felt. He articulated the experience of regression in a way that people who die are often unable to. Human life is a complex feat of organization, the most complex known to science, and its emergence or submergence passes through the twilight between life and not life. Modern medicine shines a lantern into that twilight, as doctors save premature babies who once would have been lost and bring back people who have passed what was once a point of no return.

As physicists and philosophers struggle to grasp the end of time, many see parallels with the end of life. Just as life emerges out of lifeless molecules that organize themselves, time might emerge from some timeless stuff that brings itself to order [see "Is Time an Illusion?" by Craig Callender; Scientific American, June]. A temporal world is a highly structured one. Time tells us when events occur, for how long and in what order. Perhaps this structure was not imposed from the outside but arose from within. What can be made can be unmade. When the structure crumbles, time ends.

By this thinking, time's demise is no more paradoxical than the disintegration of any other complex system. One by one, time loses its features and passes through the twilight from existence to nonexistence.

The first to go might be its unidirectionality—its "arrow" pointing from past to future. Physicists have recognized since the mid-19th century that the arrow is a property not of time per se but of matter. Time is inherently bidirectional; the arrow we perceive is simply the natural degeneration of matter from order to chaos, a syndrome that anyone who lives with pets or young children will recognize. (The original orderliness might owe itself to the geomet-

JASON LEE

ric principles that McInnes conjectured.) If this trend keeps up, the universe will approach a state of equilibrium, or "heat death," in which it cannot get possibly get any messier. Individual particles will continue to reshuffle themselves, but the universe as a whole will cease to change, any surviving clocks will jiggle in both directions and the future will become indistinguishable from the past [see "The Cosmic Origins of Time's Arrow," by Sean M. Carroll; Scientific American, June 2008]. A few physicists have speculated that the arrow might reverse, so that the universe sets about tidying itself up, but for mortal creatures whose very existence depends on a forward arrow of time, such a reversal would mark an end to time as surely as heat death would.

LOSING TRACK OF TIME

MORE RECENT RESEARCH suggests that the arrow is not the only feature that time might lose as it suffers death by attrition. Another could be the concept of duration. Time as we know it comes in amounts: seconds, days, years. If it didn't, we could tell that events occurred in chronological order but couldn't tell how long they lasted. That scenario is what University of Oxford physicist Roger Penrose presents in a new book, *Cycles of Time: An Extraordinary New View of the Universe*.

Throughout his career, Penrose really seems to have had it in for time. He and University of Cambridge physicist Stephen Hawking showed in the 1960s that singularities do not arise only in special settings but should be everywhere. He has also argued that matter falling into a black hole has no afterlife and that time has no place in a truly fundamental theory of physics.

In his latest assault, Penrose begins with a basic observation about the very early universe. It was like a box of Legos that had just been dumped out on the floor and not yet assembled—a mishmash of quarks, electrons and other elementary particles. From them, structures such as atoms, molecules, stars and galaxies had to piece themselves together step by step. The first step was the creation of protons and neutrons, which consist of three quarks apiece and are about a femtometer (10^{-15} meter) across. They came together about 10 microseconds after the big bang (or big bounce, or whatever it was).

Before then, there were no structures at all—nothing was made up of pieces that were bound together. So there was nothing that could act as a clock. The oscillations of a clock rely on a well-defined reference such as the length of a pendulum, the distance between two mirrors or the size of atomic orbitals. No such reference yet existed. Clumps of particles might have come together temporarily, but they could not tell time, because they had no fixed size. Individual quarks and electrons could not serve as a reference, because they have no size, either. No matter how closely particle physicists zoom in on one, all they see is a point. The only sizelike attribute these particles have is their so-called Compton wavelength, which sets the scale of quantum effects and is inversely proportional to mass. And they lacked even this rudimentary scale prior to a time of about 10 picoseconds after the big bang, when the process that endowed them with mass had not yet occurred.

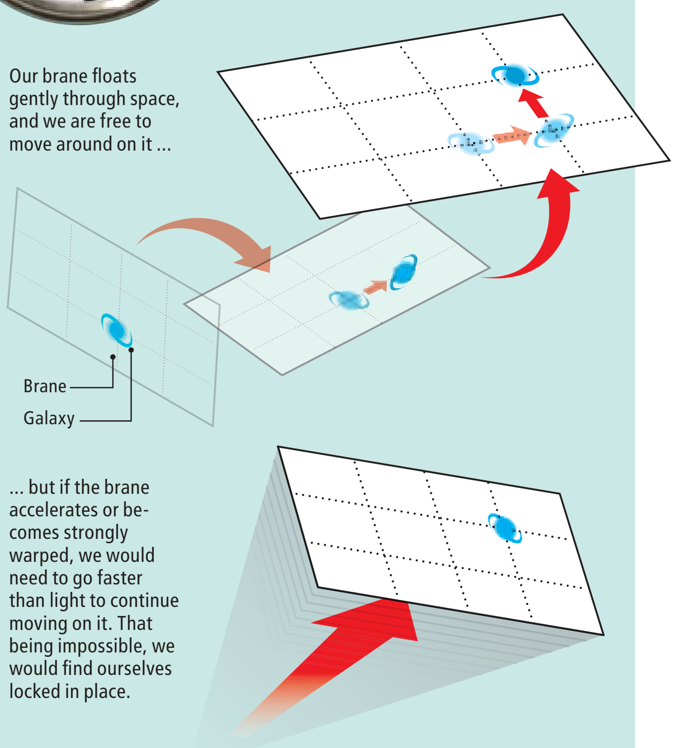
"There's no sort of clock," Penrose says. "Things don't know how to keep track of time." Without anything capable of marking out regular time intervals, either an attosecond or a femtosecond could pass, and it made no difference to particles in the primordial soup.

Penrose proposes that this situation describes not only the distant past but also the distant future. Long after all the stars wink out, the universe will be a grim stew of black holes and loose particles; then even the black holes will decay away and leave only the particles. Most of those particles will be massless ones such as photons, and again clocks will become impossible to build. In alternative futures where the universe gets snuffed out by, say, a big crunch, clocks don't fare too well, either.

You might suppose that duration will continue to make sense in the abstract, even if nothing could measure it. But researchers question whether a quantity that cannot be measured even in principle really exists. To them, the inability to build a clock is a sign that time itself has been stripped of one of its defining features. "If time is what is measured on a clock and there are no

3 [LOSS OF CAUSALITY] TIME SHADES INTO SPACE

Time may be reduced to just another dimension of space, breaking the link between cause and effect. One way that can happen is if our universe is a "brane" floating through a higher-dimensional spacetime, and this brane begins to whip around so fast that the time dimension bends over and becomes a spatial one, producing what we would experience as a "big freeze."

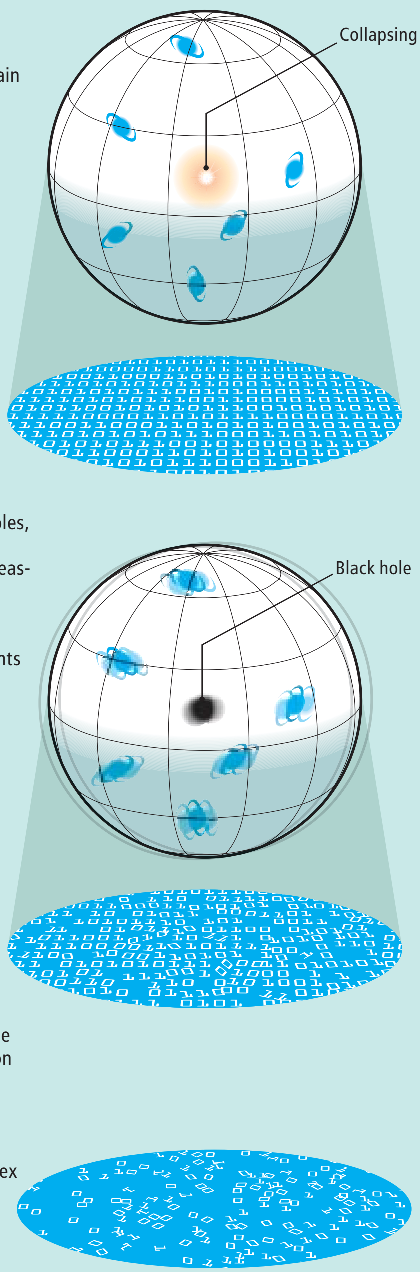


JASON LEE

[LOSS OF STRUCTURE]

4 GEOMETRY DISSOLVES

Time disappears altogether as the universe descends into anarchy. This anarchy breaks out at the deepest level of reality, even deeper than that of the known particles and forces. Processes become so complex that they cannot be said to occur at specific places and times. One way to grasp this idea is to consider the so-called holographic principle (*below*).



Our universe may really be 2-D, but certain regularities make it look 3-D—as if it were the projection of a hologram.

Near black holes, the universe becomes increasingly chaotic, causing the locations and timing of events to become ambiguous.

Eventually the 3-D projection breaks up altogether, and all that remains is a highly complex 2-D system.

JASON LEE

clocks, then there is no time," says philosopher of physics Henrik Zinkernagel of the University of Granada in Spain, who also has studied the disappearance of time in the early universe.

Despite its elegance, Penrose's scenario does have its weak points. Not all the particles in the far future will be massless; at least some electrons will survive, and you should be able to build a clock out of them. Penrose speculates that the electrons will somehow go on a diet and shed their mass, but he admits he is on shaky ground. "That's one of the more uncomfortable things about this theory," he says. Also, if the early universe had no sense of scale, how was it able to expand, thin out and cool down?

If Penrose is on to something, however, it has a remarkable implication. Although the densely packed early universe and ever emptying far future seem like polar opposites, they are equally bereft of clocks and other measures of scale. "The big bang is very similar to the remote future," Penrose says. He boldly surmises that they are actually the same stage of a grand cosmic cycle. When time ends, it will loop back around to a new big bang. Penrose, a man who has spent his career arguing that singularities mark the end of time, may have found a way to keep it going. The slayer of time has become its savior.

TIME STANDS STILL

EVEN IF DURATION becomes meaningless and the femtoseconds and attoseconds blur into one another, time isn't dead quite yet. It still dictates that events unfold in a sequence of cause and effect. In this respect, time is different from space, which places few restrictions on how objects may be arranged within it. Two events that are adjacent within time—when I type on my keyboard, letters appear on my screen—are inextricably linked. But two objects that are adjacent within space—a keyboard and a Post-It note—might have nothing to do with each other. Spatial relations simply do not have the same inevitability that temporal ones do.

But under certain conditions, time could lose even this basic ordering function and become just another dimension of space. The idea goes back to the 1980s, when Hawking and Hartle sought to explain the big bang as the moment when time and space became differentiated. Three years ago Marc Mars of the University of Salamanca in Spain and José M. M. Senovilla and Raül Vera of the University of the Basque Country applied a similar idea not to time's beginning but to its end.

They were inspired by string theory and its conjecture that our four-dimensional universe—three dimensions of space, one of time—might be a membrane, or simply a "brane," floating in a higher-dimensional space like a leaf in the wind. We are trapped on the brane like a caterpillar clinging to the leaf. Ordinarily, we are free to roam around our 4-D prison. But if the brane is blown around fiercely enough, all we can do is hold on for dear life; we can no longer move. Specifically, we would have to go faster than the speed of light to make any headway moving along the brane, and we cannot do that. All processes involve some type of movement, so they all grind to a halt.

Seen from the outside, the timelines formed by successive moments in our lives do not end but merely get bent so that they are lines through space instead. The brane would still be 4-D, but all four dimensions would be space. Mars says that objects "are forced by the brane to move at speeds closer and closer to the speed of light, until eventually the trajectories tilt so much that they are in fact superluminal and there is no time. The key point is that they may be perfectly unaware that this is happening to them."

Because all our clocks would slow down and stop, too, we would have no way to tell that time was morphing into space. All we would see is that objects such as galaxies seemed to be speeding up. Eerily, that is exactly what astronomers really do see and usually attribute to some unknown kind of "dark energy." Could the acceleration instead be the swan song of time?

YOUR TIME IS UP

BY THIS LATE STAGE, it might appear that time has faded to nothingness. But a shadow of time still lingers. Even if you cannot define duration or causal relations, you can still label events by the time they occurred and lay them out on a timeline. Several groups of string theorists have recently made progress on how time might be stripped of this last remaining feature. Emil J. Martinec and Savdeep S. Sethi of the University of Chicago and Daniel Robbins of Texas A&M University, as well as Horowitz, Eva Silverstein of Stanford University and Albion Lawrence of Brandeis University, among others, have studied what happens to time at black hole singularities using one of the most powerful ideas of string theory, known as the holographic principle.

A hologram is a special type of image that evokes a sense of depth. Though flat, the hologram is patterned to make it look as though a solid object is floating in front of you in 3-D space. The holographic principle holds that our entire universe is like a holographic projection. A complex system of interacting quantum particles can evoke a sense of depth—that is to say, a spatial dimension that does not exist in the original system.

But the converse is not true. Not every image is a hologram; it must be patterned in just the right way. If you scratch a hologram, you spoil the illusion. Likewise, not every particle system gives rise to a universe like ours; the system must be patterned just so. If the system initially lacks the necessary regularities and then develops them, the spatial dimension pops into existence. If the system reverts to disorder, the dimension disappears whence it came.

Imagine, then, the collapse of a star to a black hole. The star looks 3-D to us but corresponds to a pattern in some 2-D particle system. As its gravity intensifies, the corresponding planar system jiggles with increasing fervor. When a singularity forms, order breaks down completely. The process is analogous to the melting of an ice cube: the water molecules go from a regular crystalline arrangement to the disordered jumble of a liquid. So the third dimension literally melts away.

As it goes, so does time. If you fall into a black hole, the time on your watch depends on your distance from the center of the hole, which is defined within the melting spatial dimension. As that dimension disintegrates, your watch starts to spin uncontrollably, and it becomes impossible to say that events occur at specific times or objects reside in specific places. "The conventional geometric notion of spacetime has ended," Martinec says.

What that means in practice is that space and time no longer give structure to the world. If you try to measure objects' positions, you find that they appear to reside in more than one place. Spatial separation means nothing to them; they jump from one place to another without crossing the intervening distance. In fact, that is how the imprint of a hapless astronaut who passes the black hole's point of no return, its event horizon, can get back out. "If space and time do not exist near a singularity, the event horizon is no longer well defined," Horowitz says.

In other words, string theory does not just smear out the putative singularity, replacing the errant point with something more palatable while leaving the rest of the universe much the same. Instead it reveals a broader breakdown of the concepts of space and time, the effects of which persist far from the singularity itself. To be sure, the theory still requires a primal notion of time in the particle system. Scientists are still trying to develop a notion of dynamics that does not presuppose time at all. Until then, time clings stubbornly to life. It is so deeply engrained in physics that scientists have yet to imagine its final and total disappearance.

Science comprehends the incomprehensible by breaking it down, by showing that a daunting journey is nothing more than a succession of small steps. So it is with the end of time. And in thinking about time, we come to a better appreciation of our own place in the universe as mortal creatures. The features that time will progressively lose are prerequisites of our existence. We need time to be unidirectional for us to develop and evolve; we need a notion of duration and scale to be able to form complex structures; we need causal ordering for processes to be able to unfold; we need spatial separation so that our bodies can create a little pocket of order in the world. As these qualities melt away, so does our ability to survive. The end of time may be something we can imagine, but no one will ever experience it directly, any more than we can be conscious at the moment of our own death.

As our distant descendants approach time's end, they will need to struggle for survival in an increasingly hostile universe, and their exertions will only hasten the inevitable. After all, we are not passive victims of time's demise; we are perpetrators. As we live, we convert energy to waste heat and contribute to the degeneration of the universe. Time must die that we may live. ■

George Musser is a staff editor for Scientific American.

MORE TO EXPLORE

Toward the End of Time. Emil J. Martinec, Daniel Robbins and Savdeep Sethi in *Journal of High Energy Physics,* Vol. 2006, No. 8; August 16, 2006. Preprint available at **arxiv.org/abs/hep-th/0603104**

Is the Accelerated Expansion Evidence of a Forthcoming Change of Signature on the Brane? Marc Mars, José M. M. Senovilla and Raül Vera in *Physical Review D,* Vol. 77, No. 2; January 11, 2008. **arxiv.org/abs/0710.0820**

Cycles of Time: An Extraordinary New View of the Universe. Roger Penrose. Bodley Head, 2010.

Listen to the author discuss the paradoxes of the end of time at **www.ScientificAmerican.com/TheEnd**

[RESTART]

what comes next

The flip side to every ending is a new beginning. We asked the visionary scientists on our advisory board what new trends will shape the decades to come

ILLUSTRATIONS BY JASON HOLLEY

[COMPLEXITY]

THE AGE OF DIGITAL ENTANGLEMENT

■ BY DANNY HILLIS

ON NOVEMBER 19, 2009, a single circuit board inside a computer router in Salt Lake City failed. The glitch cascaded, preventing air traffic control computers nationwide from communicating. Hundreds of flights were canceled. On May 6, 2010, the Dow Jones industrial average inexplicably plummeted almost 1,000 points in minutes, only to mysteriously rise before the day ended. Had the "flash crash" not reversed itself, a global financial meltdown would have ensued.

We humans have linked our destinies with our machines. Our technology has gotten so complex that we no longer can understand it or fully control it. We have entered the Age of Entanglement.

When humans lived in the jungle, they thought that nature's displays arose from mystical qualities. In the Dark Ages humans blamed the gods for causing unforeseen events that altered people's lives. But the Enlightenment brought reason to bear; scientific analysis made sense of more and more of the world. We began to feel in control, and our understanding gave us the power to construct our own complex environment of technology.

The Internet is a case in point. Most people may not realize that they depend on the Internet when they place a telephone call or fly on an airplane. In our intertwined world, it is increasingly difficult to understand the very systems we have built or how to repair them. Weeks after the financial crash, regulators installed new trading circuit breakers they hoped would prevent another collapse, but they can't be certain the fixes will actually work.

Back in the 20th century, programmers could tell a computer exactly what to do. They exercised absolute control in a system they completely understood. Today programmers link complicated modules developed by others, without fully knowing how the pieces function. A program that, say, directs trucks to restock stores needs to find the locations of the trucks and warehouses, maps of the streets and the inventories of stores. The program follows this information by connecting to other programs via the Internet. It might also support systems that track packages, pay drivers and track truck maintenance.

Expand this picture to include factories and power plants, as well as salespeople, advertisers, insurers, regulators and stock traders, and you begin to see the entangled system behind so many daily decisions. Although we created it, we did not exactly design it. It evolved. We are dependent and not entirely in command. Each expert knows a piece of the puzzle, but the big picture is too big to comprehend.

It is time to start a countertrend. We should begin to build simple backup systems that one person can truly understand, to protect ourselves when critical systems fail. In decades gone by, ham radio operators could keep the world connected if commercial communications crumbled. We should develop a simple communications system independent of the Internet, so that civilization can continue to operate after a cyberattack, computer virus or unforeseen emergent behavior jams cyberspace.

As people realize that we are back in the jungle—a digital jungle of our own creation—some will revert to mysticism. Most people will just accept the complexity and learn how to cope with it. Others will try to live "off the grid," although few of them will give up Web access or cell phones or electric lights or penicillin.

Like it or not, the dependencies are too strong to allow us to disconnect. Our destinies are entangled with one another's and with our technologies.

HILLIS, co-founder of the Long Now Foundation, predicted widely that the Y2K "problem" would be a nonevent.

[BIOENGINEERING]

LIFE DESIGNED TO ORDER

■ BY ARTHUR CAPLAN

J. CRAIG VENTER announced in May that he and his colleagues had made a new living bacterium from a genome they decoded, artificially rebuilt and then stuck into the cored-out remains of the bacterium *Mycoplasma*. When the hybrid bug began to reproduce, it became the first artificial organism, putting to rest the ancient and tenacious conceit that only a deity or some special power can create the spark of life.

It was the most dramatic demonstration yet of the power of synthetic biology, a nascent field that promises to solve many of our most pressing problems. Researchers want to make bacteria that digest oil and chemical pollution from leaks and spills, or produce hydrogen or liquid fuels from sunlight, or eat cholesterol and other dangerous substances that accumulate in our bodies.

Though still in its infancy, this technology needs oversight now. Bad guys intent on making nasty bugs or good guys who are sloppy about safety could pose serious risks to our health and environment. Venter and his group were careful to use tiny molecular changes to "watermark" their creation; such identification should be mandatory for any scientist or company using the techniques of synthetic biology. Addressing these problems will take broad national and international efforts.

Some people may feel that creating new organisms somehow imperils the dignity of life. I don't think it does. At bottom this is a triumph of knowledge. We confirm the value we place on life when we understand better how it works.

CAPLAN is Emanuel and Robert Hart Professor of Bioethics at the University of Pennsylvania.

Comment on this article at www.ScientificAmerican.com/TheEnd

[INFORMATION TECHNOLOGY]

THE ERA OF INFINITE STORAGE

■ BY EDWARD FELTEN

IMAGINE CARRYING all the music ever recorded by the human race in your pocket. That will be possible by the end of this decade. If you want all the movies and TV programs, too, that will take only a few years more. Or imagine making an audio recording of your whole life, from beginning to end: that is affordable already. Video will be possible in a few years. Data storage devices such as hard drives and flash memory have gotten so dense and so cheap that for most purposes their storage capacity will soon be unlimited. The era of infinite storage is about to begin.

While the cost of memory is dropping exponentially, ubiquitous gadgets such as cell phones are also making data gathering easy. Add indexing software and a good search engine, and you will have an archive of everything you have seen and done. Add data analysis tools, and you will have a new lens on your life.

The way we think about information is changing, too. Rather than having to decide what to keep, we can keep everything. Rather than deciding what to record, we can record everything.

No longer will you have to struggle to remember the name of the restaurant where you ate three years ago in Cleveland. You'll consult your video archive and find out in no time. Some technology buffs already record every mundane detail of their lives and use software analysis to spot trends—helping them improve their diets, monitor their exercise regimens or figure out what affects their moods.

Infinite storage will challenge our notions of privacy. Much of the time you will show up somewhere on someone else's records. Each misstep and embarrassment will remain forever visible, unless you take steps to expunge it. We need a new consensus, and possibly new rules, to govern our storage and use of information. And we need them soon.

FELTEN is director of the Center for Information Technology Policy at Princeton University.

[NEUROSCIENCE]

AN ANSWER TO THE RIDDLE OF CONSCIOUSNESS

■ BY CHRISTOF KOCH

THE MIND-BODY PROBLEM has taunted humanity's greatest thinkers since the days of Plato and Aristotle. How can a chunk of matter inside the skull exude consciousness? Does consciousness require something nonphysical, an immaterial soul? Can we create a golem and endow it with feelings? For centuries scholars had to speculate in the absence of facts, but those days are over. Scientists are now revealing the material basis of the conscious mind. In coming years they will gradually fill in the details, making much of the armchair philosophizing moot.

Several avenues of research are providing compelling results. Neurologists are using functional brain imaging and EEGs to determine the extent to which a brain-injured patient who is awake but unresponsive to the world has any mental life or feelings. Scientists are isolating the neuronal correlates—specific firings among unique sets of neurons—that underpin any conscious recognition of stimuli from the senses, be it that of little yellow squares or that of a well-known movie star. The latest techno craze is optogenetics: researchers insert genes that code for light-sensitive proteins into neurons in an animal's brain, then shine brief pulses of colored light to turn the nerve cells on or off, either to scrutinize the brain at work or to manipulate it. Neuroscientists can now move from merely observing the brain to intervening in its delicate webbing.

These investigations are already yielding new theories of consciousness, based on information science and mathematics, that can describe what characteristics a physical system (such as a network of neurons) would have to have to be considered conscious. Such theories will provide quantitative answers to questions that have long stumped us: Can a severely compromised patient be aware? When does a newborn baby become conscious? Is a fetus ever conscious? Is a dog aware of itself as a thinking being? What about the Internet with its billions of interconnected computers? Our society will have answers soon. And that will be a boon.

KOCH is professor of cognitive and behavioral biology at the California Institute of Technology.

[ENERGY]

THE OBSOLESCENCE OF OIL

■ **BY MICHAEL WEBBER AND DANIEL KAMMEN**

CRUDE OIL has been the mainstay of our transportation sector for more than a century. That dominance might soon end, as several forces converge. New oil deposits are in places that are increasingly hard to reach. Environmental regulations are tightening and may tighten further in the wake of the BP oil spill in the Gulf of Mexico. Cars powered by electricity or natural gas are coming on line. And the U.S. Congress has mandated that one fifth of all liquid transportation fuel come from nonpetroleum biofuels by 2022. These factors almost ensure that demand for gasoline will peak (or has already peaked); a decline in demand for light sweet crude oil shouldn't be far behind.

A transition to other fuels is likely to begin. Whether the transition works out well or poorly for our economy and environment depends on decisions we make today. It is not preordained that we will use alternative fuels that are cleaner than gasoline, because many inexpensive options exist that are not. Heavy, solid fuels such as oil shale, tar sands and liquids from coal could fill the gap, potentially worsening environmental impacts. The temptation to use these solid fuels will be high, because deposits dwarf those of light sweet crude, and the technology to convert them to liquid form is getting less expensive with time.

The trouble, of course, is that each barrel of liquid fuel derived from these sources requires more energy to refine than light sweet crude does, which means carbon emissions per unit of energy produced will rise unless we implement carbon capture systems on a large scale. And because the mining and production techniques are fundamentally different from those for conventional petroleum, swaths of land and water could be affected.

It is possible to imagine a more hopeful scenario, in which electricity, natural gas, next-generation biofuels and other relatively clean energy sources, as well as improved fuel economy, gradually undermine the strategic value of light sweet crude. To achieve this brighter future, however, we need to manage the transition properly. A suite of energy policies could help us emerge with a cleaner, safer, more resilient and cheaper energy system.

If we can enact such policies, our grandchildren will look out from their quiet, clean, domestically fueled cars and laugh at the notion that nations actually fought over those useless reservoirs of oil.

WEBBER is associate director of the Center for International Energy and Environmental Policy at the University of Texas at Austin. KAMMEN is founding director of the Renewable and Appropriate Energy Laboratory at the University of California, Berkeley.

[POLICY]

ENERGY THAT DOESN'T HARM YOUR HEALTH

■ **BY R. JAMES WOOLSEY**

THE AGE OF OIL'S dominance in transportation may be ending, but at the present rate the end will come slowly. Meanwhile our consumption will continue to destroy the environment and create huge strategic and economic problems. The U.S. could make the transition faster and less painful by: improving the efficiency of internal-combustion engines; encouraging electric vehicles and the use of natural gas for fleet vehicles and interstate trucking; opening up the fuel market to competition from current biofuels such as ethanol and methanol; and funding research on new biofuels made from waste and algae.

Such bold moves would require political will, which is in short supply in Washington. That might change, though, if national leaders were also to emphasize the health benefits of switching from oil: less cancer, disease and obesity.

The harm of oil to public health takes several forms. Regulatory inaction under the Clean Air Act is letting oil companies use known carcinogens—the so-called aromatics such as benzene, toluene and xylene—to increase the octane component of gasoline, according to C. Boyden Gray, a former U.S. Special Envoy for Eurasian Energy, and Andrew Varcoe, a Washington, D.C., attorney. The added costs related to health care and shortened lives in the U.S. come to more than $100 billion annually, they conclude.

Switching to biofuels would make us healthier, too. Critics often assert that crops for biofuels displace crops for food. But 95 percent of the corn that is grown for consumption is grown for animal feed, not for humans. Feeding cattle the starch component of corn makes their meat fatter and thus supposedly better tasting. Yet the fat substantially raises our cholesterol.

Moreover, cornstarch is an unnatural food for cattle and induces indigestion that can lead to illnesses, prompting the use of massive amounts of antibiotics. This practice can in some cases lead to drug-resistant bacteria that can degrade medicine's effectiveness against infectious human diseases. We can produce biofuels from the corn's starch while still using the corn's protein for animal feed, without negative health effects.

Flooding the food market with cornstarch, rather than using it for biofuels, also makes fructose cheaper, lowering the cost of making the junk food that drives the obesity epidemic, particularly among children.

Oil doesn't just cause strategic and environmental problems; it also increases our risk of cancer and helps to foster clogged arteries, infectious diseases and childhood diabetes. What else can oil do for us?

WOOLSEY is chair of Woolsey Partners and a former director of the Central Intelligence Agency.

[EVOLUTION]

A NEW WINDOW ON HUMAN ORIGINS

■ BY LESLIE AIELLO

SCHOLARS of human evolution have long relied on the fossilized bones and cultural relics of ancient humans and on the biology and behavior of living humans and apes in their efforts to reconstruct the past. The sequencing this past May of the genome of our closest relative, the Neandertal, opens a remarkable new window on our collective prehistory.

With both human and Neandertal genomes, scientists can now study not only those outward physical manifestations of evolutionary change that have been written in bone and stone but also the actual hereditary information that encodes those traits. By doing this, we will learn on a genetic level exactly what separates us from all other creatures and how and when these defining characteristics arose. Such insights will provide a more detailed account of the evolution of our kind than most paleoanthropologists could have dreamed of a few years ago, before geneticists had developed the technology to assemble the genome of a human from deep time.

Comparing the Neandertal sequence to sequences from modern-day people, Svante Pääbo's team at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, found 200 regions of the modern human genome that have undergone adaptive evolution since the two groups diverged. These DNA segments—which include genes involved in metabolism as well as cognitive and skeletal development—hold the key to what makes modern humans unique. Geneticists do not yet know how recent changes affected the functioning of these genome regions, but it is only a matter of time before they uncover those connections.

My own area of research—metabolism and thermoregulation—is one of many that stand to benefit from this new source of data. Neandertals lived in frigid conditions in Ice Age Europe. Many of us have wondered whether physiological adaptations might have enabled them to stay warm without elaborate clothing. Once scientists sort out the genetics of thermoregulation, we can look for evidence of such adaptations. Many anthropologists also theorize that modern humans were able to outcompete the Neandertals in part because their bodies made more efficient use of food energy—an advantage when resources were unpredictable or hard to come by. The Neandertal genome offers a novel means of testing such hypotheses. It will also help us understand why modern humans have more lightly built skeletons and different shaped heads than Neandertals did and whether we really are more cognitively advanced than our big-brained relatives were, as some researchers argue.

More clues may come from the genomes of other extinct human species. Pääbo's team is currently sequencing DNA retrieved from a 30,000- to 50,000-year-old finger bone found in Denisova Cave in the Altai Mountains of Siberia, which may represent a new species. It also hints at the occurrence of more migrations of early humans into Eurasia from Africa than previously thought. As more research groups join the effort to sequence and analyze ancient human DNA, revelations from paleogenetics will no doubt continue to shape our understanding of the human odyssey for decades to come.

AIELLO is president of the Wenner-Gren Foundation for Anthropological Research in New York City.

[GENOMICS]

MEDICINE I CAN CALL MY OWN

■ BY GEORGE CHURCH

SINCE 2003, when the $3-billion Human Genome Project was officially completed, the cost of sequencing a human genome has plummeted a millionfold. The technology to manipulate and engineer genes has also become widely accessible. As a result, biology is now undergoing an explosion of spontaneous activity, reminiscent of when, in the early 1980s, largely self-taught nerds toiled in their garages to bring us the age of personal computers.

As this democratization of biotechnology continues, the one-size-fits-all medicine we have seen for the past 100 years will yield to medicine tailored to each individual. Doctors will prescribe a custom prevention program and make comprehensive diagnoses according to each patient's genes, bacteria, allergens, fungi, viruses and immune system. Just as remote villages now harness the power and complexity of the Internet, they will also be able to assemble health care solutions appropriate to their customs, geography and individuals. Studying the specific combinations of genes and environmental factors can lead to changes in diet, drugs and behavior, helping us extend our healthy years.

In the near future, a complex ecosystem of health care and software providers will empower doctors to treat each patient as a unique individual. Your stem cells will be fashioned into ad hoc treatments. Your genome will get sequenced every year or so to check for the emergence of cancer cells, autoimmune cells, inflammation, and so on and will help predict what treatment may work best if a disease appears. Not just knowing but shaping your biology will be part of your life.

CHURCH is director of the Center for Computational Genetics at Harvard Medical School.

[AGRICULTURE]

THE NEXT REVOLUTION IN FARMING

■ BY JOHN REGANOLD

WITH THE PLANET'S population projected to reach nine billion by midcentury, some experts claim that only conventional farming can produce enough food for everyone. But taking that path will cause irreparable damage to the environment. Fortunately, we have other options. By switching from resource-intensive to knowledge-intensive practices, we can put an end to unsustainable farming and have both healthy food for all and a healthy environment.

Conventional farming can erode and degrade the soil. Its artificial fertilizers are energy-intensive to produce and often pollute waterways, lakes and oceans, while its pesticides increase health risks to farm workers. Organic-farming techniques, on the other hand—whether used on certified-organic farms or integrated with conventional approaches—can eliminate or reduce the need for chemicals. For example, alternating grains with legumes helps to restore nitrogen in the soil, reducing the need for fertilizers, as do adding a third or fourth crop into the rotation, leaving more plant residue in the soil after harvest, or converting the land to grassland for grazing. In the U.S., we need to jigger federal farm subsidies—which now mostly reward farmers for growing corn, cotton, soybeans, wheat and rice—to encourage longer crop rotations.

Also, to keep the soil healthy and to reduce erosion, many farmers could employ no-till farming, in which a crop is planted without any previous tilling, or plowing. Finally, we need to cut waste. We squander 30 to 40 percent of all food, both in developing countries (where it spoils en route because of poor roads and storage systems) and in rich ones (where we discard it because it is slightly blemished, or leftover, or past its "use by" date, even if still perfectly good).

With these changes we could still provide 2,350 calories a day of healthy food for every person—as the United Nations's Food and Agriculture Organization recommends. To be successful, we need to focus global attention on food and ecosystem issues and to do more research. And, of course, we need the political will to make this farming revolution happen.

REGANOLD is Regents Professor of Soil Science at Washington State University.

RATIONAL THOUGHT — AND NOT

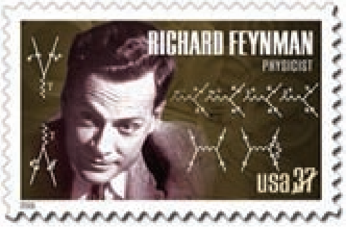
Speaker: **Michael Shermer, Ph.D.**

The Bermuda Triangle and Other Weird Things that People Believe — Should we prepare to deal with an energy vortex, time travel, aliens and UFOs, the lost continent of Atlantis, dark matter, black holes, and all manner of secret government experiments as we sail into the Bermuda Triangle? Join the unflappable Michael Shermer as he explains the legends and myths that have grown up around this area allegedly associated with the mysterious disappearance of ships and planes over the decades. Dr. Shermer will explain what really happens in the Bermuda Triangle, and having disposed of that topic, will elucidate many other mysteries such as UFOs and alien abductions, mind-reading and psychics who talk to the dead, reincarnation and life after death, out-of-body and near-death experiences, urban legends and satanic panics. Get the scoop on how the mind works to find patterns when none exist and imparts intentional agency to those patterns, leading *some* people to believe weird things.

Why Darwin Matters: Evolution, Intelligent Design, and the Battle for Science and Religion — Evolution happened, and the theory describing it is one of the most well-founded in all of science. Then why do half of all Americans reject it? There are religious and political reasons people fear evolution. Dr. Michael Shermer diffuses these fears by examining what evolution really is, how we know it happened, and how to test it. Get an insiders' guide to the evolution-creation debate. Dr. Shermer will show why creationism and Intelligent Design are not only bad science, they are bad theology, and why science should be embraced by people of all beliefs.

The Mind of the Market: Compassionate Apes, Competitive Humans, and Other Lessons from Evolutionary Economics — How did we evolve from ancient hunter-gatherers to modern consumer-traders? Why are people so irrational when it comes to money and business? Michael Shermer argues that evolution provides an answer to both of these questions through the new science of evolutionary economics. Learn how evolution and economics are both examples of complex adaptive systems. Along the way, Shermer answers provocative questions and poses more for your consideration, like how can nations increase trust within and between their borders, and what are the consequences of globalization? Get your evolutionary economics tools together.

CST# 2065380-40



THE INQUIRING PHYSICIST

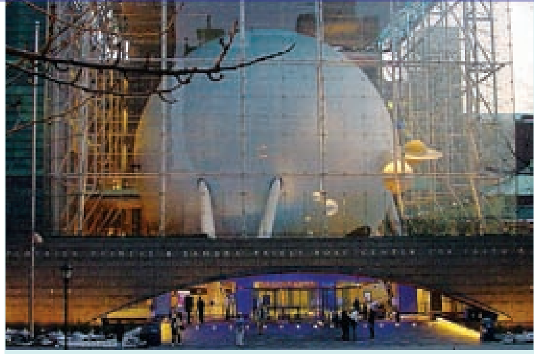
Speaker: **Lawrence Krauss, Ph.D.**

Quantum Man: Richard Feynman and Modern Science — Feynman, perhaps the greatest physicist of the last 60 years, left a legacy that governs work at the forefront of physics today. Find out about the man and his life. It took a man willing to break all the rules to tame a theory that broke all the rules.

Hiding in the Mirror: The Mysterious Allure of Extra Dimensions — We are fascinated by the idea that there is more out there than meets the idea. Scientists have long been fascinated by the possibility that there are more than three dimensions in nature. Come find out why.

An Atom from the Caribbean — We are all Stardust. Every atom in our bodies came from inside a fiery nuclear furnace of a star, which exploded so that some of its atoms might one day make it to Earth. Hear the story of a single oxygen atom, in a glass of water on board ship, from the beginning to the end of the Universe.

SCIENTIFIC AMERICAN TRAVEL



Optional tour price: $395. Includes transportation, entrance fees, lunch at the Rose Center, cocktail reception and dinner at Scientific American headquarters. This tour is limited to 25 people.

SCIENCE IN NEW YORK CITY

Saturday, May 7, 2011 (optional)

Wake up in the city that never sleeps, as we start at 9am in the Rose Center for Earth and Space (above) at the American Museum of Natural History for a private insider's tour. Get the inside scoop on research being done at the Rose Center — with a behind-the scenes tour of their telescope/optics labs; a spaceshow/journey to the stars in the Hayden Planetarium; a private 40-minute lecture about the Hubble Space Telescope from our host, Dr. Michael Shara; and a new perspective on space with the Scales of the Universe. Our five-hour day at the Rose Center includes a catered lunch. After our astronomy sojourn, we'll reconvene in lower mid-town Manhattan, at the Scientific American headquarters, for an early evening social reception/dinner with Scientific American staffers.

During our visit, the Curator of the Einstein exhibit, Michael M. Shara, Ph.D. will deliver the following lectures:

Einstein's Revolution—He was daring, wildly ingenious, passionately curious. He saw a beam of light and imagined riding it; he looked up at the sky and envisioned that space-time was curved. Albert Einstein reinterpreted the inner workings of nature, the very essence of light, time, energy, and gravity. His insights fundamentally changed the way we look at the universe — and made him the most famous scientist of the 20th century.

We know Einstein as a visionary physicist, but he was also a passionate humanitarian and anti-war activist speaking out on global issues from pacifism to racism, anti-Semitism to nuclear disarmament. "My life is a simple thing that would interest no one," he once claimed. But in fact, his letters, notebooks and manuscripts tell a dramatically different story.

Einstein saw the universe as a puzzle, and he delighted in trying to solve its mysteries. All he needed to contemplate the cosmos was his most valuable scientific tool — his imagination.

10 Discoveries from the Hubble Space Telescope—In the 20 years it has been in orbit, Hubble has revolutionized our understanding of how the universe works. Images from the telescope have become iconic forms of modern art. And lurking in each image is new science. Dr. Shara will describe 10 remarkable discoveries made with the Hubble, and show how its images reveal something we've never seen or understood before.

ARCHAEOLOGY/ ANTHROPOLOGY

Speaker: **Jerald T. Milanich, Ph.D.**

Belle Glade Cultures — Secrets from 500 BC to AD 1700 — Perhaps the most remarkable earthworks constructed by the pre-Columbian Indians of the Eastern United States dot the old shoreline of Lake Okeechobee. Excavations reveal many secrets of these complex sites and the people who built them. The importance of the Belle Glade societies is reflected in the gold and silver artifacts found in their sixteenth and seventeenth century mounds. Yet the Belle Glade culture has remained totally unknown except to archaeologists. Dr. Milanich clues us in.

Documenting Florida's Seminoles — Adventure Behind the Scenes — While houseboating in the Everglades in 1905, New York financier Anthony Weston Dimock and son Julian met Seminole Indians who had come from their isolated camps in the interior of South Florida to shop and trade. Julian, an accomplished photographer, set up his tripod and camera and began to take pictures. Through his lens he and his father would step into a new world, the world of the Seminole Indians. Over the next five years the Dimocks amassed an unprecedented photographic record of Seminole people and their surroundings. The photographs, recently rediscovered in the American Museum of Natural History's research library, and the Dimocks' adventures in southern Florida make for an amazing tale.

Archaeology of the Spanish Colonial Southeast U.S. After 1492 — By the time of the founding of Jamestown in the first decade of the 1600, Spanish St. Augustine was already up for urban renewal. Spain's sixteenth-century colonial activities in the Southeast and their impact on the American Indians who lived there are a fascinating and little-known story, now emerging through archaeological and archival research. The Spanish sailors and conquistadors who explored and colonized the Southeast all failed, some rather spectacularly. Impossibly lofty plans, poor knowledge of geography, and well established Native American groups all played a role. Join Dr. Milanich as he lays out the archaeologic background of the early Spanish Southeast America.

Q How does **geothermal drilling** trigger earthquakes?

Seismologist **David Oppenheimer** of the U.S. Geological Survey Earthquakes Hazards Team explains (as told to Katherine Harmon):

Traditional geothermal drilling bores into hot rock such as sandstone that has water or steam trapped in its pore spaces and natural fractures. When a drilled hole intersects these fractures, the water flashes into steam because of the sudden drop in pressure—like bubbles that come out of a soda bottle when the cap is removed. The steam surges into the well hole, and the steam pressure at the surface spins a turbine to generate electricity. Sometimes the plant returns some of the water back into the reservoir to keep water levels up. The drilling itself does not cause earthquakes, but the steam removal and water return can do so, by producing new instability along fault or fracture lines.

At a long-term geothermal project in northern California known as the Geysers, the USGS has been monitoring seismic activity since 1975. Even though the area does not appear to have any large faults running through it, we record about 4,000 quakes above magnitude 1.0 every year. We know they result from steam withdrawal or injection because when operators begin geothermal production in a new area, earthquakes begin and when production ends, the earthquakes stop. Many minor tremors occur, but quakes as large as magnitude 4.5 have been recorded. Residents of nearby Anderson Springs often feel tremors as small as magnitude 2.0 because the town sits only a couple of kilometers above the rock fractures.

Geologists suspect that even larger earthquakes could occur on nearby faults such as the Maacama, which is adjacent to the Geysers fields. The extraction of water and heat from the porous sandstone causes it to contract, much as a sponge shrinks when it dries out. When a large earthquake does occur, the public will ask whether the geothermal projects might have played a role in causing the rocks to shift along other faults. And researchers will have to use geodetic monitoring and other data to try to figure out whether it really was a factor in changing key stress dynamics.

In addition to the traditional geothermal plants at the Geysers, a pilot project, which was suspended last September, intended to draw steam directly from the volcanic, nonporous rock called felsite that lies below the sandstone and is its heat source. Because the felsite has no natural pores, it also contains no water. To recover the heat, the project's operators would have needed to fracture the rock and circulate water through it.

First, in the short phase of the project, they would have drilled into the felsite and injected water to fracture the rock, most likely generating earthquakes in the process. Then, aided by borehole cameras revealing in which direction the fractures formed, they would have drilled a second hole to intersect the new fractures and would have produced steam by pumping water through the hot fractures linking the wells. This dry-rock geothermal approach has the potential to harness much more heat than the traditional sandstone techniques, but it can also mean more earthquakes.

POWER PLANT near Santa Rosa, Calif., is fueled by underground steam. The emission is water vapor.

CHARLES O'REAR *Corbis*

To control the earthquake risk, drillers would have tried to keep the size of the fractures small and to maintain steady water flow rates. The threshold goal for earthquakes is 2.0 or lower on the Richter scale. Such deep-drilling operations would not want a repeat of events in Basel, Switzerland, where a widely felt magnitude 3.4 quake in 2006 ultimately stopped a similar geothermal project.

Unfortunately, areas that are less tectonically active also have less accessible subterranean heat sources. California, for example, has more heat (because of its location near tectonic plate margins) than, say, Texas. The whole country has *some* geothermal potential if we wanted to draw warmth for heating. But the resulting heat would not necessarily have the energy to spin large turbines for electricity generation.

All sources of energy—hydropower, nuclear, wind or coal—have advantages and disadvantages. Geothermal energy has the advantage of being clean and renewable, but earthquakes are a downside. ■

If you were asked to surrender your will, would you? Probably not. But have you considered the countless times people do surrender their will each and every day? “No,” you say, “I don’t, and I never would!”

Richard W. Wetherill
1906-1989

Well, think about how you surrender your will to the laws of nature. Do you argue with gravity, ignore friction, grab a live wire, lean to the left turning right?

People have learned to surrender to creation’s natural laws, but there is a law of nature that virtually everybody has been ignoring.

While people eagerly surrender to familiar laws such as gravity and friction, sometimes a mistake is made. For example, if they lose their balance by slipping on a wet surface, everybody instinctively struggles to conform to the appropriate natural laws.

Early in the past century, a natural ***law of behavior*** was identified by the late Richard W. Wetherill. In 1952 he presented it in the book, *Tower of Babel*.

He called it the ***law of absolute right***, and it specifies ***behavior that is rational and honest*** to replace choices based on a person’s likes and dislikes, wants and don’t wants, judgments and beliefs, thereby, over time, putting together his/her own plan of life.

Nature’s law of absolute right states that right action gets right results, and if wrong results occur, the law was somehow disregarded.

What kinds of results are presently occurring? The news media daily report on the tragedies of international warfare, political corruption, criminal activity, economic disasters, foreclosures, and afflictions labeled “cause unknown.”

You might be wondering, who thinks that conforming to a natural law could stop those wrong results?

The answer comes from persons who have surrendered their will to ***creation’s law of absolute right***. They enthusiastically report right results occurring, as they drop old behavior patterns and respond rationally and honestly to whatever happens.

The nonprofit group financing this public-service message is telling people that their safety and security exist in trusting the laws of creation rather than trusting the laws and beliefs of human origin. Every natural law requires the action it calls for, thereby enabling the law to complete its rightful purpose.

That is easily observed when using gravity as an example. When people stumble and fall, they do not form criticisms of gravity. They are more likely to look around for someone or something to blame—sometimes their own carelessness.

But to achieve success and avoid failure at whatever activity or task they are engaged in, people instinctively know they must obey nature’s laws of physics.

Prior to the identification of those laws, the ancients worshipped natural phenomena and/or idols. It required aeons until people identified the natural laws creating forces to guide their activities and that *those laws expressed the will of the creator*—not to be worshipped but to be obeyed.

Thus creation’s law of absolute right calls for rational and honest responses to whatever happens.

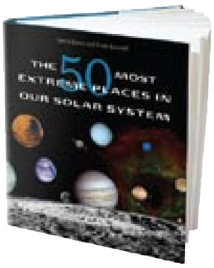
Visit our colorful Website www.alphapub.com where essays and books describe the changes called for by whoever or whatever created nature’s law of absolute right. The material can be read, downloaded, and/or printed free. Press a button to listen to the texts on the Website being read aloud with the exception of the texts of the seven books. *This public-service message is from a self-financed, nonprofit group of former students of the late Richard W. Wetherill. We are putting this information where it is available worldwide, and we invite your help to direct others to our Website so that they, too, can learn that conforming to this natural law creates a life that truly is well worth living.*

Extreme Astronomy ■ Misleading Math ■ Genome on the Cheap

BY KATE WONG

➡ THE 50 MOST EXTREME PLACES IN OUR SOLAR SYSTEM

by David Baker and Todd Ratcliff. Harvard University Press, 2010 ($27.95)



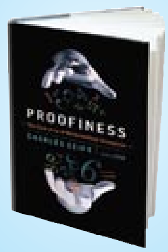
From icy volcanoes on Neptune to Eiffel Tower–size lightning bolts on Saturn, the wildest sights in our corner of the universe.

VALLES MARINERIS, MARS

EXCERPT

➡ PROOFINESS: THE DARK ARTS OF MATHEMATICAL DECEPTION

by Charles Seife. Viking, 2010 ($25.95)

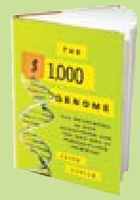


Math can be dangerous in the wrong hands, argues journalist Charles Seife. The art of using bad math to prove bogus arguments is what he terms "proofiness," and it is a common tactic of politicians, lawyers, advertisers and scientists. Otherwise intelligent people fall victim to proofiness for many reasons. One is that we humans excel at pattern recognition and tend to want to link effects to causes—even when links do not exist—which is why we struggle to accept random events, as Seife explains below.

"Our minds revolt at the idea of randomness. Even when a set of data or an image is entirely chaotic, even when there's no underlying order to be found, we still try to construct a framework, a pattern, through which we understand our observations. We see the haphazard speckling of stars in the sky and group them together into constellations. We see the image of the Virgin Mary in a tortilla or the visage of Mother Teresa in a cinnamon bun. Our minds, trying to make order out of chaos, play tricks on us.

"Casinos make so much money because they exploit this failure of our brains. It's what keeps us gambling. If you watch a busy roulette table or a game of craps, you'll almost invariably see someone who's on a 'lucky streak'—someone who has won several rolls in a row. Because he's winning, his brain sees a pattern and thinks that the winning streak will continue, so he keeps gambling. You'll also probably see someone who keeps gambling because he's been losing. The loser's brain presents a different pattern—that he's due for a winning streak. The poor sap keeps gambling for fear of missing out. Our minds seize on any brief run of good or bad luck and give it significance by thinking that it heralds a pattern to be exploited. Unfortunately, the randomness of the dice and of the slot machine ensure that there's no reality to these patterns at all. Each roll of the die, each pull of the lever gives a result that is totally unrelated to the events that came before it. That's the definition of random: there's no relationship, no pattern there to be discovered. Yet our brains simply refuse to accept this fact. This is *randumbness:* insisting that there is order where there is only chaos—creating a pattern where there is none to see."

ALSO NOTABLE



- **The $1,000 Genome: The Revolution in DNA Sequencing and the New Era of Personalized Medicines** by Kevin Davies. Free Press, 2010 ($26)
- **Climatopolis: How Our Cities Will Thrive in the Hotter Future** by Matthew E. Kahn. Basic Books, 2010 ($26.95)
- **Eavesdropping: An Intimate History** by John L. Locke. Oxford University Press, 2010 ($27.95)
- **Yellow Dirt: An American Story of a Poisoned Land and a People Betrayed** by Judy Pasternak. Free Press, 2010 ($26)
- **On Second Thought: Outsmarting Your Mind's Hard-Wired Habits** by Wray Herbert. Crown, 2010 ($25)
- **Designer Genes: A New Era in the Evolution of Man** by Steven Potter. Random House, 2010 ($25)
- **The Shape of Inner Space: String Theory and the Geometry of the Universe's Hidden Dimensions** by Shing-Tung Yau and Steve Nadis. Basic Books, 2010 ($30)
- **Choke: What the Secrets of the Brain Reveal about Getting It Right When You Have To** by Sian Beilock. Free Press, 2010 ($26)
- **Four Fish: The Future of the Last Wild Food** by Paul Greenberg. Penguin Press, 2010 ($25.95)
- **Almost Chimpanzee: Searching for What Makes Us Human, in Rainforests, Labs, Sanctuaries, and Zoos** by Jon Cohen. Times Books, 2010 ($27.50)
- **The Calculus Diaries: How Math Can Help You Lose Weight, Win in Vegas, and Survive a Zombie Apocalypse** by Jennifer Ouellette. Penguin Books, 2010 ($15)
- **Origins: How the Nine Months before Birth Shape the Rest of Our Lives** by Annie Murphy Paul. Free Press, 2010 ($26)
- **Brain Storm: The Flaws in the Science of Sex Differences** by Rebecca M. Jordan-Young. Harvard University Press, 2010 ($35)
- **Churchill's Secret War: The British Empire and the Ravaging of India during World War II** by Madhusree Mukerjee. Basic Books, 2010 ($28.95)

COURTESY OF NASA/USGS

Shaky Grounds

The fault lies not in ourselves but in the faults

BY STEVE MIRSKY

The adage "damned if you do, damned if you don't" does not quite capture the following pair of situations. It's more like "damned if you could (but you can't), damned if you couldn't (but you kind of did)."

First, the "damned if you could (but you can't)". On April 4 at 3:40 P.M., a magnitude 7.2 earthquake rocked Baja, Mexico, and was felt well north. The event elicited the following post on Twitter 16 minutes later from New Age lifemeister Deepak Chopra: "Had a powerful meditation just now—caused an earthquake in Southern California." (Lawrence Krauss, too, lays into Deepak on page 36 for his lack of understanding of quantum physics. There's plenty to bust Chopra about.)

Three minutes later Chopra added, "Was meditating on Shiva mantra & earth began to shake. Sorry about that". Sadly, at least one person died in the quake. Fortunately for Chopra, although ignorance of the law is famously no excuse in court, ignorance of the laws of nature is, and would almost certainly trump his public confession.

Some tweets later, on April 7, Chopra denied responsibility for the temblor, saying of his previous claim, "Was bad joke". If only Chopra's mentor, luxury car aficionado Maharishi Mahesh Yogi, were still alive, we could have asked if the shake rattled his Rolls. (I'll do the bad jokes around here, thank you.)

Meanwhile Italian scientists are in the unfortunate "damned if you couldn't (but you kind of did)" camp. These legitimate seismologists, volcanologists, physicists and engineers are being threatened with charges of manslaughter for failing to definitively predict an earthquake of magnitude 6.3 in the city of L'Aquila on April 6, 2009, which took more than 300 lives and injured an additional 1,600 area residents. The scientists find themselves in legal peril even though anything other than a loosely probabilistic assessment of earthquake risk is currently impossible, even with state-of-the-art meditation techniques.

The threatened researchers belong to the Major Risks Committee, an advisory group to the Civil Protection Agency. Major risk number one: membership in the Major Risks Committee.

After a series of tremors in late March, the committee met, after which a government official informed the press that "the scientific community tells us there is no danger, because there is an ongoing discharge of energy," apparently referring to the aforementioned tremors. Unfortunately, that was like concluding, while taking down your house's Christmas lights, that each little slip down the sloped roof somehow protects you from sliding off completely. (See a wide variety of slapstick movies that illustrate the physics of numerous small changes in roof-based potential energy followed by one major ground-state transition.) The official then prognosticated that "the situation looks favorable," a remark that perhaps reveals his previous experience with the Magic 8-Ball.

According to reporting in *Scientific American*'s sister publication *Nature,* minutes of the meeting show that the researchers were in fact much more circumspect, saying things such as "a major earthquake in the area is unlikely but cannot be ruled out" and "because L'Aquila is in a high-risk zone it is impossible to say with certainty that there will be no large earthquake." They also noted that buildings should be examined to gauge their structural integrity, thus correctly focusing on the most dangerous aspect of quakes—dwellings that any large, malevolent wolf with decent lung capacity could easily demolish to acquire pork.

Nearly 4,000 scientists from around the world have signed a letter to the president of Italy urging an end to the witch hunt. They want resources to be expended on "earthquake preparedness and risk mitigation rather than on prosecuting scientists for failing to do something they cannot do yet—predict earthquakes." (Let alone cause them.) As one of the signatories, University of Oxford earth scientist Barry Parsons, says in the *Nature* piece: "Scientists are often asked the wrong question, which is 'when will the next earthquake hit?' The right question is 'how do we make sure it won't kill so many people when it hits?'" Prosecutors should query the researchers on this issue before ascertaining guilt or innocence using the tried-and-true method of determining their buoyancy. ■

PHOTOGRAPH BY FLYNN LARSEN; ILLUSTRATION BY MATT COLLINS