SCIENTIFIC AMERICAN

June 2011 ScientificAmerican.com

Energy
How Safe Is Nuclear Power?

Computing
A Test for a Conscious Machine

Biotechnology
Test-Tube Meat

LIVING IN A Quantum World

Small-scale physics has a "spooky" power over the world at large

SPECIAL
BEST OF NOBEL PRIZE AUTHORS
FROM OUR PAGES
REPORT


NOT
BORN
YESTERDAY.
It can upload your photos, find your music and automatically download your
contacts.* Technology that will amaze you at a price that may surprise you.


It's not just luxury. It's smarter than that.
Learn more about the 2011 LINCOLN MKX, and SYNC® with MyLincoln Touch™ at
LINCOLN.COM
*Driving while distracted can result in loss of vehicle control. Only use mobile phones/MyLincoln Touch/other devices, even with voice commands, when it is safe to do so. Some features may be locked out while the vehicle is in gear.

SCIENTIFIC AMERICAN

June 2011 Volume 304, Number 6

ON THE COVER

Physicists usually describe the weirdness of quantum mechanics in terms of particles: particles that pass through two slits at once, for example, or those that influence one another directly without sending signals through the intervening space. Yet the very same phenomena affect larger bodies, too, and may be observable in crystals and even in life. Image by Kenn Brown, Mondolithic Studios.

64

FEATURES

Photograph by Kevin Van Aelst

Goldman Sachs

HOW AN INVESTMENT IN A HOUSING DEVELOPMENT

IS REBUILDING AN ENTIRE COMMUNITY IN NEW ORLEANS

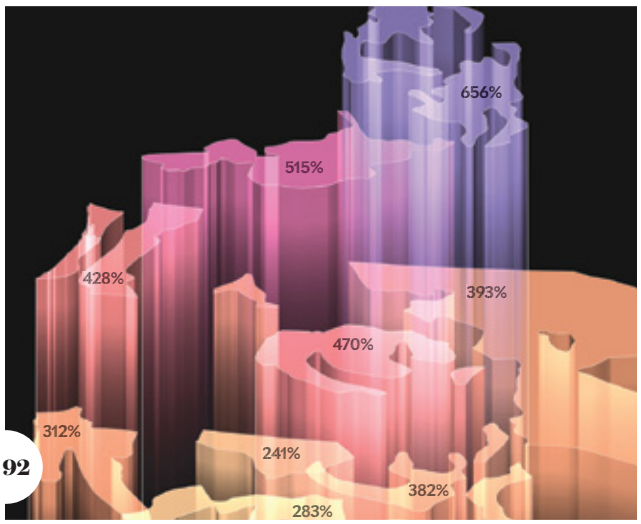
PROGRESS IS EVERYONE'S BUSINESS

After one of New Orleans' oldest public housing developments was devastated by Hurricane Katrina, we invested in rebuilding it from the ground up. Our Urban Investment Group partnered with an experienced developer, McCormack Baron Salazar, as well as former tenants, neighborhood organizations, and state and local housing agencies to enable families and businesses to return home. Today, Harmony Oaks is a community where neighbors can come together—on their new front porches, at the local community center or the nearest playground. See the story at **goldmansachs.com/progress**

Watch the story on your smartphone.

14

28



92

SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

Spotlight on Dark Matter
For four days in May, leading physicists and astronomers from around the world gathered in Baltimore to talk about the abundant but mysterious stuff that accounts for one quarter of the contents of the universe.
Go to www.ScientificAmerican.com/jun2011/dark-matter

Scientific American (ISSN 0036-8733), Volume 304, Number 6, June 2011, published monthly by Scientific American, a division 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.


24 HOURS OF LE MANS
LE MANS, FRANCE
JUNE 11TH TO 12TH, 2011
24 HEURES DU MANS
LIVE FOR
ENGINES ROAR AND ROADS BLUR BENEATH. JAWS TIGHTEN. THEN RELAX. CONCENTRATION REMAINS IN OVERDRIVE. STRAPPED IN BY A SEAT BELT, BUT THERE BY COURAGE. DAYLIGHT FADES AND NIGHT SHOCKS THE SENSES. ALL THE WHILE, THE HEART IS RESOLUTE. ENDURE.
GREATNESS
ROLEX
OYSTER PERPETUAL COSMOGRAPH DAYTONA
ROLEX
FOR AN OFFICIAL ROLEX JEWELER CALL 1-800-367-6539.
ROLEX ♛ OYSTER PERPETUAL AND COSMOGRAPH DAYTONA ARE TRADEMARKS.

Mariette DiChristina is editor in chief of *Scientific American*. Find her on Twitter @SAeditorinchief

Quantum Leap

GET READY FOR A CHANGE OF PERSPECTIVE WHEN YOU turn to Vlatko Vedral's cover story, "Living in a Quantum World," on page 38. "According to standard physics textbooks, quantum mechanics is the theory of the microscopic world," Vedral writes. And classical physics, in textbooks, "handles the largest of scales."

Not so, proclaims Vedral, who calls this idea "a myth." Quantum effects are harder to observe in the macroworld because of decoherence. But in the past decade experimentalists have seen quantum behaviors persisting on a macroscopic scale—and these effects turn out to be as pervasive as they are profound. Entanglement, a quantum property once seemingly confined only to small sets of particles, has been demonstrated in far larger systems—and even within living organisms.

Scientific American has, of course, covered many such profound discoveries in how the world works with the help of its scientist authors. More than 140 Nobel laureates have written for the magazine, often years before they won the honor. As laureates gather in Lindau, Germany, this month to share wisdom with a new generation of scientists, we mark the occasion with a special section, "A Nobel Celebration." We present a selection of some our favorite articles in the fields of medicine and physiology from the past 60 years, including George Wald writing about the origin of life, Francis Crick about DNA, and Carol W. Greider and Elizabeth H. Blackburn about telomeres. Turn to page 54 to enjoy the sweep of science from then through today. More is available at www.ScientificAmerican.com.

CITIZEN SCIENCE

Gretchen LeBuhn had a problem. The San Francisco State University researcher wanted to study flower visits by bees, given the effects of climate shifts and the destructive illness called colony collapse disorder. But such ecosystem studies are very challenging and expensive because of the large areas involved.

She sent a note to 15 gardening groups asking if they might grow packets of a certain type of sunflower. Once the flowers bloomed, the idea went, the gardeners would spend a few minutes at certain times making observations about bee visits and inputting the data about what they saw into a form on a Web site LeBuhn set up. She hoped she might get at least some help. But now she had a new problem: more than 75,000 volunteers.

LeBuhn told me about the Great Sunflower Project at SciFoo—an annual "unconference" run by Google, O'Reilly Media and *Scientific American*'s parent Nature Publishing Group. I realized that *Scientific American* just had to help connect those citizen scientists and researchers such as LeBuhn. There are many kinds of citizen science, among them: making field observations as in the sunflower project, analyzing images and video such as the terrific Zooniverse.org projects, data crunching with spare computing power, and more.

At www.ScientificAmerican.com, we have launched Citizen Science, which lists the most compelling activities. Soon we'll add our own. I hope you'll help make science happen. —*M.D.*

Illustration by Nick Higgins

KUWAIT PRIZE 2011
Invitation for Nominations

The **Kuwait Foundation for the Advancement of Sciences (KFAS)** institutionalized the **KUWAIT Prize** to recognize distinguished accomplishments in the arts, humanities and sciences. The Prizes are awarded annually in the following categories:

A. Basic Sciences
B. Applied Sciences
C. Economics and Social Sciences
D. Arts and Literature
E. Arabic and Islamic Scientific Heritage

The Prizes for **2011** will be awarded in the following fields:

1. Basic Sciences : Physiology
2. Applied Sciences : Nuclear Technology
3. Economic and Social Sciences : Financial Markets in the Arab World
4. Arts and Literature : Novels
5. Arabic and Islamic Scientific Heritage : Astronomy

Foreground and **Conditions** of the Prize:

1. Two prizes are awarded in each category:
   * A Prize to recognize the distinguished scientific research of a Kuwaiti citizen, and,
   * A Prize to recognize the distinguished scientific research of an Arab citizen.
2. The candidate should not have been awarded a Prize for the submitted work by any other institution.
3. Nominations for these Prizes are accepted from individuals, academic and scientific centers, learned societies, past recipients of the Prize, and peers of the nominees. No nominations are accepted from political entities.
4. The scientific research submitted must have been published during the last ten years.
5. Each Prize consists of a cash sum of K.D. 30,000/- (approx. U.S.$100,000/-), a Gold medal, a KFAS Shield and a Certificate of Recognition.
6. Nominators must clearly indicate the distinguished work that qualifies their candidate for consideration.
7. The results of KFAS decision regarding selection of winners are final.
8. The documents submitted for nominations will not be returned regardless of the outcome of the decision.
9. Each winner is expected to deliver a lecture concerning the contribution for which he was awarded the Prize.

Inquiries concerning the KUWAIT PRIZE and nominations including complete curriculum vitae and updated lists of publications by the candidate with **four copies** of each of the published papers should be received before **1/12/2011** and addressed to:

The Director General
The Kuwait Foundation for the Advancement of Sciences - P.O. Box: 25263, Safat - 13113, Kuwait
Tel: (+965) 22429780 / Fax: 22403891 / E-Mail: prize@kfas.org.kw

Accelerating Software Modernization with Artificial Intelligence

AI is radically transforming the way organizations evolve their software assets to achieve competitive advantage.

Artificial Intelligence (AI) is the quest to achieve computers that equal or exceed human performance on complex intellectual tasks. A phenomenal development in AI is the recent emergence of automated computer language translation programs, driven by the need to modernize the nearly half trillion lines of legacy software developed during the latter half of the 20th century.

Early software translators of the 1990s, like the earliest chess programs, were disappointing and limited. Leveraging AI technologies that evolved from the 1980s era USAF's Knowledge Based Software Assistant and emerging standards, computers can now understand and translate software applications with levels of proficiency that vastly exceed human performance. This technology is revolutionizing the way industries, such as finance, insurance, manufacturing, and healthcare as well as military and governments are modernizing their legacy systems.

Leading this field is The Software Revolution, Inc. (TSRI), a Kirkland, Washington based company. Building upon 32 years of continuous R&D, TSRI's robust *JANUS* Studio® tool suite provides large-scale, error-free legacy system modernizations at 100% levels of automation. By applying AI to abstract software models, TSRI delivers automated code conversion with unprecedented target code quality, economies of scale and schedule compression, accomplishing with small teams in months what would take years by other means. The following list of brief case studies represents five recent TSRI legacy system modernization projects.

• **European Air Traffic Management System (EATMS), Thales Air Systems:** This realtime system manages over 10 million passenger flights annually. Thales engaged TSRI to transform EUROCAT's 2 million lines of legacy Ada into Java. The result was a perfect functional replica of EUROCAT in its new language. TSRI's 100% automation eliminated the risk of errors inherent in a manual rewrite. EUROCAT will commence operation in significant airports across Europe and Asia at the end of 2011.

• **Patriot Missile, Fire Platoon Simulation & Battalion Simulation Support Systems, Raytheon:** TSRI used the *JANUS* Studio® tool suite to modernize four different Patriot systems including Patriot Japan. These modernizations included the transformation of nearly 200 thousand source lines of Fortran code to C++, re-factoring and documentation.

• **Major Healthcare Insurance Company:** This system consisted of over 180 thousand source lines of PowerBuilder and nearly 3 million lines of COBOL. In modernizing this system TSRI provided transformation, re-factoring and supported system integration. This project was completed in only 15 months.

• **Major US Bank:** This legacy application contained over 3 million source lines of Fortran and over 160 thousand lines of DCL. TSRI automatically generated a *Transformation Blueprint*™ to assist in the systems design architecture, performed the code documentation and provided engineering support.

• **Advanced Field Artillery Tactical Data System (AFATDS), Stanley and Associates (Now CGI Federal):** A version of the US Army's legacy AFATDS system consisting of over 5 million source lines of ADA-83. TSRI employed *JANUS* Studio® to transform this system into Java in only 10 months. TSRI delivered the modern system to Stanley in August 2010.

Information Systems Transformation: *Architecture-Driven Modernization Case Studies* provides more detailed information on these case studies.

For more information visit **www.tsri.com**

Information Systems Transformation:
Architecture-Driven Modernization Case Studies
By William M. Ulrich and Philip Newcomb
ISBN: 978-0123749130

About the book:
Architecture-Driven Modernization (ADM) gives you everything you need to know to update costly obsolete systems, transform data, and save millions of dollars.

Philip Newcomb
Founder and CEO of TSRI

Mr. Newcomb is an internationally recognized expert in the application of AI and formal methods to software engineering. After leaving Boeing he led a team of software engineers to develop TSRI's *JANUS* Studio® tool suite. Mr. Newcomb is the author of numerous papers, books and industry standards.

TSRI is a Platform Member of the OMG and leading contributor to the ADM Task Force (ADMTF) standards. TSRI's services and *JANUS* Studio® tool suite have served as the leading exemplar for the OMG's emerging ADMTF standards.

Automated Modernization
of Information Systems

Why TSRI?

- Highest Code Quality
- Greatest Schedule Compression
- Agile Customizable Solution
- Unequaled Track Record
- Legacy Code Transformation
- Re-factoring & Documentation
- Web & Cloud Enablement
- Software Blueprinting

*free** Get your legacy system ***Transformation Blueprint™*** **preview.**

* Qualified buyers only

Accelerating Legacy Modernization

+1 (425) 284-2770 | information@tsri.com

www.TSRI.com

TSRI
the software revolution, inc.

Mobile Enabled
IPhone | Android

editors@sciam.com

February 2011

SUBSIDIES AND HORMONES

In "How to Fix the Obesity Crisis," David H. Freedman proposed behavior modification as a solution, but it cannot be applied to 200 million overweight people. Freedman also seems to support subsidies for fruits and vegetables and other government-sponsored programs. But where is the money going to come from?

For decades now the U.S. government has subsidized corn production. Corn is used as inexpensive feed to fatten cows in feedlots and to make a cheap sweetener called high-fructose corn syrup. Fat cows and high-fructose corn syrup are key ingredients in most fast food, including hamburgers and sugary soft drinks—the foods that Freedman correctly acknowledges contribute greatly to the obesity epidemic. By subsidizing corn, the U.S. is making fast food cheaper than healthy food. What if we transferred the subsidies from corn to healthy, sustainable crops?

Now schools would have to choose healthier food because it would be cheaper than junk food, and it would be a simpler decision for the poor to choose the healthier food. Although the full solution to obesity would undoubtedly involve a change to our entire culture, an easy first step would be to stop subsidizing the food that is helping to make us so overweight.

Gunnar Newquist
Cell and Molecular Biology graduate program
University of Nevada, Reno

"By subsidizing corn, the U.S. is making fast food cheaper than healthy food."
GUNNAR NEWQUIST *UNIVERSITY OF NEVADA, RENO*

It was disappointing that your cover article on obesity did not include any mention of recombinant bovine growth hormone, or rBGH, which is banned in virtually every developed country on earth but not in the U.S. The corporate lobbies that control our legislature have done an excellent job of sweeping all controversy about these artificial hormones under the rug—especially because rates of obesity in countries that ban rBGH are much lower than the rates here in the U.S.

Charles Carignan
Windham, N.H.

As an expert on the psychology of eating and weight and a four-book author on the subject, I thoroughly applaud Freedman's covering the wide range of biological and social factors involved. But one major factor was left out: the underlying, often unconscious, intrapsychic conflicts eaters have about eating healthfully, losing weight, being thin or giving up food as comfort. In more than 30 years of working with troubled eaters, I have rarely met one who does not have unresolved, mixed feelings about substantially changing their eating or their weight. Psychotherapy works to identify and resolve these conflicts so that people stop sabotaging their progress and instead form a healthy relationship with food and their body.

Karen R. Koenig
Sarasota, Fla.

LIFE IS RANDOM

I'm wondering how chromatin, the thick fiber formed from DNA folding on itself, knows where to become loose or tight to enable DNA transcription, as Tom Misteli describes in "The Inner Life of the Genome." I imagine that some signal goes out from the activated gene, along the chain of histones ["spools" around which DNA twists], to loosen ties between the histones. After transcription is completed, another signal would need to follow from said gene to retighten the chain. Maybe chromatin-remodeling complexes simply carry and execute these signals?

Matthew Morycinski
Vancouver, B.C.

MISTELI REPLIES: The chromatin fiber opens and closes continuously because of the stochastic action of chromatin-remodeling complexes that roam the cell nucleus. Once a chromatin region is open, it will stay open for a certain period. If during that time an activating transcription factor binds, we might see gene activation; if no factor binds, the chromatin will "close" again. In response to signals such as hormones, transcription factors often become modified so that they have higher affinity to bind to their target sites. This leads to increased and prolonged binding at their gene targets, thus sustaining the transcriptional response. When the signal abates, the transcription factors fall off the target gene, thus reducing its activity. An incoming factor may also be a histone modifier protein that more permanently marks a region to be open or closed.

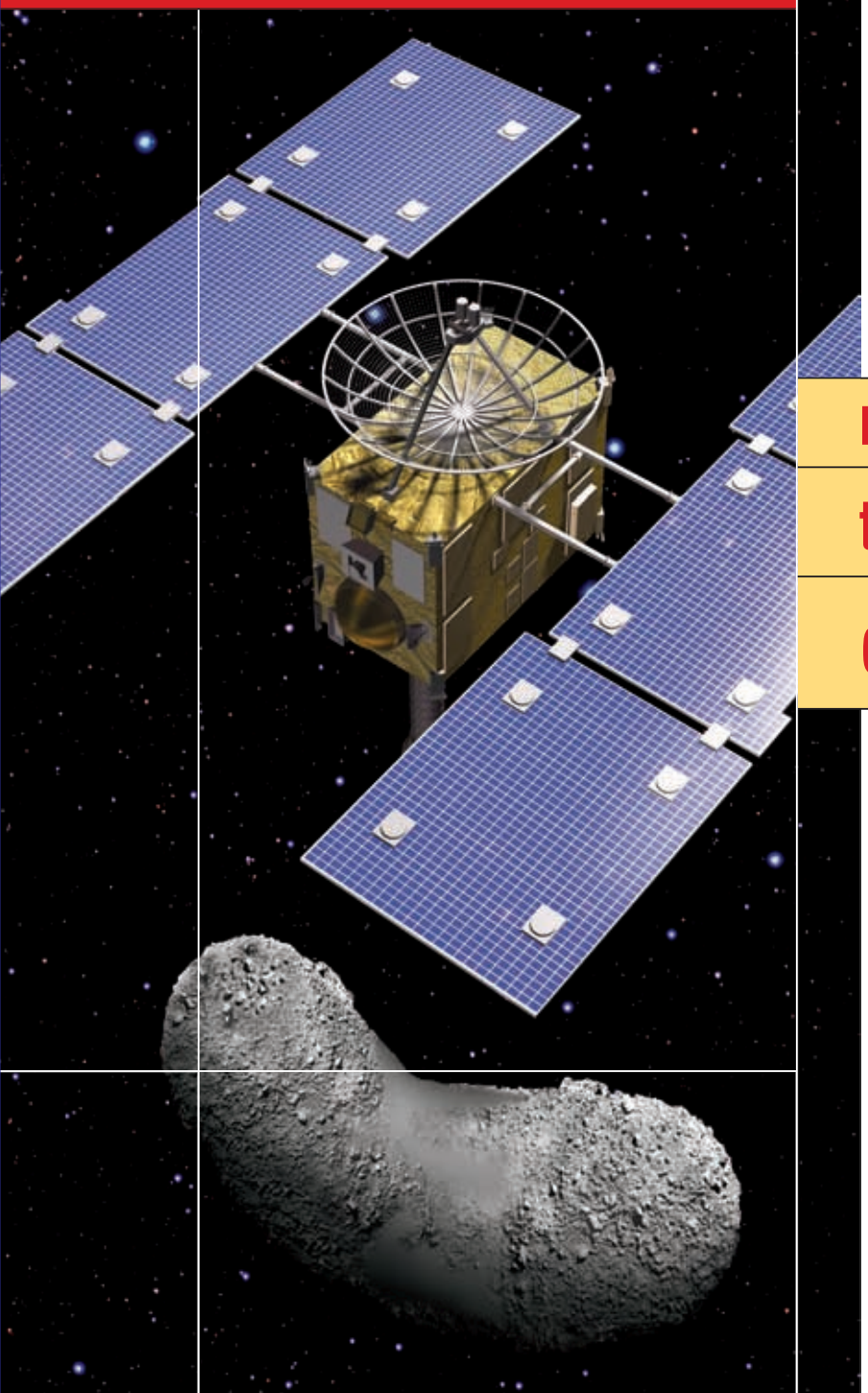
There is increasing evidence that signal transduction pathways directly talk to chromatin-remodeling complexes and histone modifiers. How this exactly works and how these complexes find their specific targets remain key questions in the field.

MEDICAL GHOSTWRITING

"Fear and Its Consequences" [Science Agenda] makes the critical points that the benefits of vaccines outweigh the risks, that a large percentage of a population must be vaccinated to keep diseases in check, and that science, not fear, should guide public opinion. But I do not think it is just politics and misinformation in the media that have reduced public trust in science; it is the industry's own manipulation of science that has caused a crisis in public trust of science and scientists.

In the case of drug trials, there have been reports of companies that have hired ghostwriters to write favorable articles and then paid respected doctors to put their names on those articles, enabling them to be published in peer-reviewed journals. I am unaware of similar misconduct in the case of vaccines, and there is no doubt that many vaccines have been enormously effective in ridding the world of dangerous

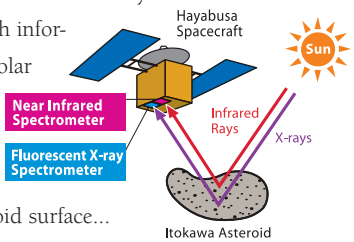
Advanced Hamamatsu sensors traveled billions of miles to analyze an asteroid surface...



The Hayabusa spacecraft, launched by the Japan Aerospace Exploration Agency (JAXA) in 2003, made a round trip of over six billion kilometers to the asteroid Itokawa to optically analyze its surface composition and also bring back physical samples.

Surface analysis via opto semiconductors

Last year the Japanese spacecraft Hyabusa returned from a seven-year mission to study the asteroid Itokawa. But long before it returned with material samples Hayabusa had already extracted much information from solar light and X-rays that reflected from the asteroid surface...



An onboard near infrared spectrometer system used Hamamatsu's *InGaAs image sensor* to identify minerals like pyroxene and olivine on the asteroid's surface.

And a fluorescent X-ray spectrometer system employed a Hamamatsu *CCD image sensor* to determine chemical composition, to recognize magnesium, aluminum, silicon and more.

Hamamatsu is opening the new frontiers of Light

In this long journey, with its rapid temperature changes and harsh, near-vacuum conditions, the sensors proved their reliability. And also their leading-edge technology.

Hamamatsu's InGaAs sensor (left) and CCD image sensor.

And that may be why Hamamatsu opto semiconductors are chosen for a broad spectrum of applications—in everything from X-ray astronomy to precise dental imaging, and everywhere from laboratories to production lines... Always seeking to open the new frontiers of light!

http://jp.hamamatsu.com/en/rd/publication/

HAMAMATSU

PHOTON IS OUR BUSINESS

diseases. But it is my opinion that the scientific community must do a much better job of policing its members if the public's trust in science is to be restored.

Andrew Benton
Blue Bell, Pa.

WORDS AND THOUGHTS

Lera Boroditsky's "How Language Shapes Thought" suggests that "different languages might impart different cognitive abilities." Although I do not disagree in general, her first example does not explain how the five-year-old Aboriginal girl acquired her sense of absolute cardinal direction. Sufficient study to master the vocabulary and grammar of Kuuk Thaayorre would not, in itself, impart the sense of absolute cardinal direction possessed by the little girl. One could certainly use English in the Aboriginal manner, but doing so would not inform the listener as to how the speaker knew the absolute cardinal direction. Absent evidence of a genetic explanation, the little girl must have learned her sense of direction from her culture.

Kenneth J. Kahn
Long Beach, N.Y.

ERRATA

"Charging against the Flu" [Advances], by Jessica Wapner, should have said that scientists used a 21-tesla magnet, not a 900-megahertz magnet, to examine the M2 protein of the influenza A virus. Also, NMR spectroscopy generates not a "charged field" but a magnetic field, and its description as providing "a snapshot of the molecules as they return to their normal charge" was inaccurate.

"Beer Batter Is Better" [Advances], by W. Wayt Gibbs and Nathan Myhrvold, described the batter temperature as 130 degrees Fahrenheit; it is 130 degrees Celsius.

The caption to the box "A Growing Problem" in David H. Freedman's "How to Fix the Obesity Crisis" defined body mass index (BMI) as "a ratio of height to weight." The correct definition is the ratio of weight (measured in kilograms) to the square of height (measured in meters squared).

Miguel A. L. Nicolelis's "Mind Out of Body" predicted the future existence of a "pocket pentabyte drive." The correct term for the unit of memory storage equivalent to 2^{50} bytes is petabyte.

SCIENTIFIC AMERICAN™
ESTABLISHED 1845

Editor in Chief
Mariette DiChristina

Executive Editor
Fred Guterl

Managing Editor
Ricki L. Rusting

Managing Editor, Online
Philip M. Yam

Design Director
Michael Mrak

Senior Writer
Gary Stix

Editors
Davide Castelvecchi, Mark Fischetti, Christine Gorman, Anna Kuchment, Michael Moyer, George Musser, Kate Wong

Contributing Editors
Mark Alpert, Steven Ashley, Graham P. Collins, John Rennie, Sarah Simpson

Editorial Product Manager
Angela Cesaro

Web Production Editor
Kerrissa Lynch

News Editor, Online
Robin Lloyd

Podcast Editor
Steve Mirsky

Associate Editors, Online
David Biello, Larry Greenemeier

News Reporters, Online
Katherine Harmon, John Matson

Blogs Editor
Bora Zivkovic

Art Director, Online
Ryan Reid

Copy Editor, Online
Michael Battaglia

Online Contributor
Christie Nicholson

Art Director
Ian Brown

Art Director, Information Graphics
Jen Christiansen

Photography Editor
Monica Bradley

Assistant Photo Editor
Ann Chin

Managing Production Editor
Richard Hunt

Senior Production Editor
Michelle Wright

Information Graphics Consultant
Bryan Christie

Art Contributors
Edward Bell, Caitlin Choi, Nick Higgins

Copy Director
Maria-Christina Keller

Senior Copy Editor
Daniel C. Schlenoff

Copy Editor
Aaron Shattuck

Editorial Administrator
Avonelle Wing

Senior Secretary
Maya Harty

Production Manager
Christina Hippeli

Advertising Production Manager
Carl Cherebin

Prepress and Quality Manager
Silvia De Santis

Custom Publishing Manager
Madelyn Keyes-Milch

Production Coordinator
Lisa Headley

President
Steven Inchcoombe

Executive Vice President
Michael Florek

Vice President and Publisher
Bruce Brandfon

Vice President and Associate Publisher, Marketing and Business Development,
Michael Voss

Managing Director, Consumer Marketing
Christian Dorbandt

Senior Marketing Manager/Retention
Catherine Bussey

Senior Marketing Manager, Online
David Courage

Senior Marketing Manager/Acquisition
Patricia Elliott

Director, Global Media Solutions
Jeremy A. Abbate

Manager, Integrated Media Sales
Stan Schmidt

Sales Development Manager
David Tirpack

Promotion Manager
Diane Schube

Promotion Art Director
Maria Cruz-Lord

Marketing Research Director
Rick Simone

Sales Representative
Chantel Arroyo

Director, Ancillary Products
Diane McGarvey

Custom Publishing Editor
Lisa Pallatroni

Online Associate Director
Mike Kelly

Online Associate Marketing Manager
Carey Tse

Online Marketing Product Manager
Zoya Lysack

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 ScientificAmerican.com/jun2011

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; 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.

THIS IS HOW

SPACE EXPLORATION MAKES EARTH INNOVATION TAKE OFF

The daily benefits of space exploration are all around us. GPS. ATMs. OMG – the list is endless! That's why Lockheed Martin eagerly supports math, science and engineering education for young people through their K-12 mentoring. Inspiring the next generation to innovate next generation space technologies is all a question of how. And it is the how that Lockheed Martin delivers.

lockheedmartin.com/how

LOCKHEED MARTIN

Coming Clean about Nuclear Power

Regulators and industry have one precious moment to recapture the public's trust

Ever since Japan's battered Fukushima Daiichi reactor complex began emitting radiation in March, calls to abandon nuclear power have risen in the U.S. and Germany, among other countries. If only it were so simple. Nuclear contributes 20 percent of the U.S. power supply and a significant share in other developed countries. If we gave it up, what would replace it? Pollution from fossil-fueled power plants shortens the life span of as many as 30,000 Americans a year. Coal companies lop off mountaintops, hydraulic fracturing for natural gas threatens water supplies, and oil dependence undermines the nation's energy security. Then there is the small matter of greenhouse gas emissions. Clean renewable technologies will take years to reach the scale needed to replace the power we get from splitting atoms.

San Onofre nuclear plant in southern California

Nuclear power's benefits for climate and security are clear. But still the public worries about safety—and no wonder. The industry and the U.S. Nuclear Regulatory Commission (NRC) claim that nuclear power is safe, but their lack of transparency does not inspire confidence. For example, an Associated Press investigation in March revealed 24 cases from December 2009 to September 2010 in which plant operators did not report equipment defects to the NRC. The industry and regulators must regain the public's trust.

That does not necessarily mean more regulations. Plenty of safety rules have been put in place since the 1979 Three Mile Island accident. The trouble is that regulations are not being enforced rigorously. The NRC has to mete out stiff penalties for violations and make every action transparent to us all. It will have a chance to demonstrate its resolve when it submits its review of all 104 commercial reactors to the White House, due this month. A crucial test will be what the review says about several plants that are already on the agency's watch list for safety issues.

Evacuation plans are a sore point for many citizens. The agency advised Americans in Japan to stay 50 miles away from Fukushima, yet within the U.S. the emergency evacuation radius is only 10 miles. What is the proper limit? Are evacuation plans subjected to serious tests? If exercises showed that residents around a plant could not leave quickly enough, the NRC should consider shutting it down. A good test case is the Indian Point plant 38 miles north of New York City. Evacuating the 20 million people who live within 50 miles staggers belief. To its credit, the NRC will work with New York governor Andrew Cuomo to review the plant's safety ahead of the scheduled relicensing review in 2013.

The NRC must also be scrupulous about licensing new plants. If an operator proposes a site that is too close to an earthquake fault, or too close to oceanfront that is vulnerable to a tsunami or hurricane storm surge, or downriver from a huge dam that could burst, then the NRC should reject the bid. Similarly, if the utility could not protect spent fuel pools or casks from being breached during a severe accident, which happened in Japan, the NRC should not license it. Saying no to a suspect plant would do more than anything else to restore public confidence.

The industry argues that advanced technology will ensure safety. The 22 new reactors proposed in the U.S. use so-called Gen III+ designs that are safer than today's reactors, which date to the 1970s or earlier. Building them could displace new coal plants or relieve the pressure to extend the life of old reactors that should instead be retired. Yet, as the article "Planning for the Black Swan," by Adam Piore, on page 48 notes, the new plants may have weaknesses. Manufacturers should pursue even safer, meltdown-proof designs that they have experimented with but shelved, such as liquid fluoride thorium reactors and pebble bed reactors. China is developing both. In the end, however, no technology is 100 percent safe, and better designs cannot eliminate the need for careful siting and emergency planning.

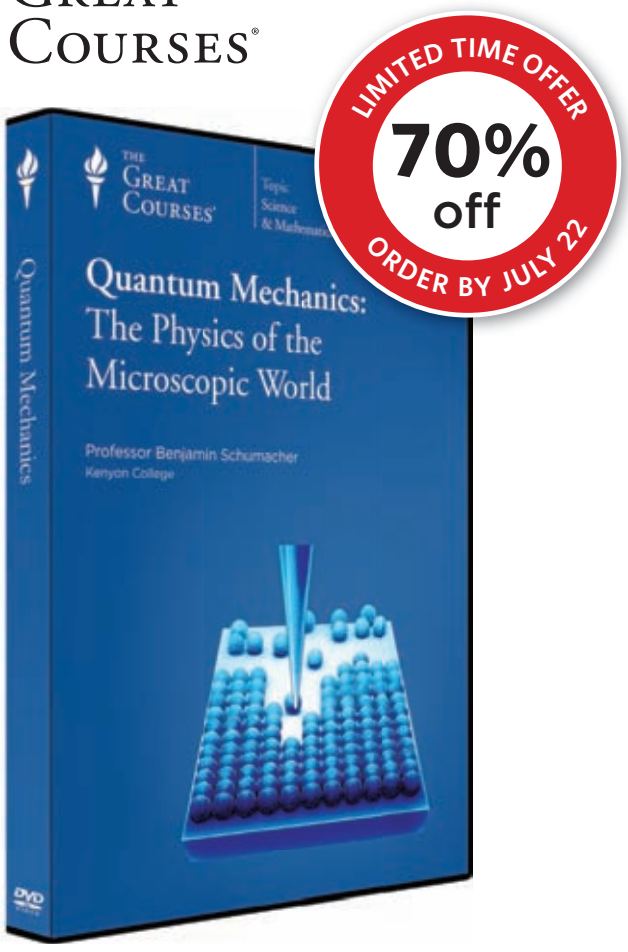
Americans need clarity from the federal government, too. Reactors across the country have accumulated 72,000 tons of spent fuel. Some utilities have packed four times as many spent fuel rods into temporary holding pools than the structures were designed to contain. The government poured $9 billion and decades of effort into the planned permanent repository at Yucca Mountain in Nevada, with little to show for it. Then President Barack Obama scuttled the project. The waste continues to pile up. At some point, officials will have to face down the citizen refrain of "not in my backyard."

Nuclear power has a good safety record, but when it fails it can fail catastrophically. Now is the time to make tough, transparent decisions that could regain public trust. Otherwise, the public might make the ultimate call: "no more nukes." SA

COMMENT ON THIS ARTICLE ONLINE
ScientificAmerican.com/jun2011

DAVID McNEW—*Getty Images*

THE GREAT COURSES®



Quantum Mechanics Made Clear

In its relatively short history, quantum mechanics has radically changed our perspective on reality and has come to play a critical role in today's most important technologies. Now, discover astonishing insights into this remarkable field with **Quantum Mechanics: The Physics of the Microscopic World**.

Award-winning Professor Benjamin Schumacher—a founder of quantum information theory and a fellow of the American Physical Society—introduces you to the complex phenomena of quantum mechanics in a way that is both enlightening and easily accessible. Generously illustrated with diagrams, demonstrations, and experiments, these 24 fascinating lectures are a great way to master the secrets of this extraordinary discipline.

Offer expires 07/22/11

1-800-832-2412

WWW.THEGREATCOURSES.COM/6SA

Quantum Mechanics: The Physics of the Microscopic World

Taught by Professor Benjamin Schumacher
KENYON COLLEGE

LECTURE TITLES

1. The Quantum Enigma
2. The View from 1900
3. Two Revolutionaries—Planck and Einstein
4. Particles of Light, Waves of Matter
5. Standing Waves and Stable Atoms
6. Uncertainty
7. Complementarity and the Great Debate
8. Paradoxes of Interference
9. States, Amplitudes, and Probabilities
10. Particles That Spin
11. Quantum Twins
12. The Gregarious Particles
13. Antisymmetric and Antisocial
14. The Most Important Minus Sign in the World
15. Entanglement
16. Bell and Beyond
17. All the Myriad Ways
18. Much Ado about Nothing
19. Quantum Cloning
20. Quantum Cryptography
21. Bits, Qubits, and Ebits
22. Quantum Computers
23. Many Worlds or One?
24. The Great Smoky Dragon

Quantum Mechanics: The Physics of the Microscopic World
Course no. 1240 | 24 lectures (30 minutes/lecture)

SAVE $185

DVD ~~$254.95~~ NOW $69.95
+$10 Shipping & Handling
Priority Code: 51345

Designed to meet the demand for lifelong learning, The Great Courses is a highly popular series of audio and video lectures led by top professors and experts. Each of our more than 300 courses is an intellectually engaging experience that will change how you think about the world. Since 1990, over 9 million courses have been sold.

Commentary on science in the news from the experts

John P. A. Ioannidis is C. F. Rehnborg Professor in Disease Prevention, professor of medicine and of health research and policy, and director of the Stanford Prevention Research Center at the Stanford University School of Medicine.

An Epidemic of False Claims

Competition and conflicts of interest distort too many medical findings

False positives and exaggerated results in peer-reviewed scientific studies have reached epidemic proportions in recent years. The problem is rampant in economics, the social sciences and even the natural sciences, but it is particularly egregious in biomedicine. Many studies that claim some drug or treatment is beneficial have turned out not to be true. We need only look to conflicting findings about beta-carotene, vitamin E, hormone treatments, Vioxx and Avandia. Even when effects are genuine, their true magnitude is often smaller than originally claimed.

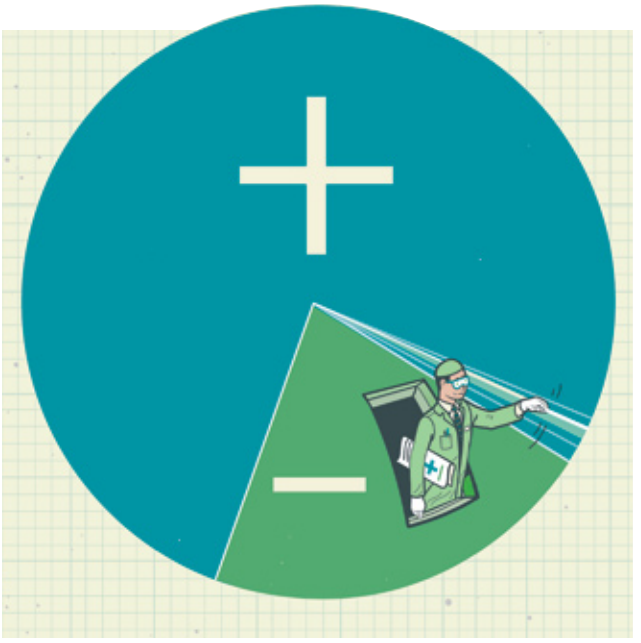
The problem begins with the public's rising expectations of science. Being human, scientists are tempted to show that they know more than they do. The number of investigators—and the number of experiments, observations and analyses they produce—has also increased exponentially in many fields, but adequate safeguards against bias are lacking. Research is fragmented, competition is fierce and emphasis is often given to single studies instead of the big picture.

Much research is conducted for reasons other than the pursuit of truth. Conflicts of interest abound, and they influence outcomes. In health care, research is often performed at the behest of companies that have a large financial stake in the results. Even for academics, success often hinges on publishing positive findings. The oligopoly of high-impact journals also has a distorting effect on funding, academic careers and market shares. Industry tailors research agendas to suit its needs, which also shapes academic priorities, journal revenue and even public funding.

The crisis should not shake confidence in the scientific method. The ability to prove something false continues to be a hallmark of science. But scientists need to improve the way they do their research and how they disseminate evidence.

First, we must routinely demand robust and extensive external validation—in the form of additional studies—for any report that claims to have found something new. Many fields pay little attention to the need for replication or do it sparingly and haphazardly. Second, scientific reports should take into account the number of analyses that have been conducted, which would tend to downplay false positives. Of course, that would mean some valid claims might get overlooked. Here is where large international collaborations may be indispensable. Human-genome epidemiology has recently had a good track record because several large-scale consortia rigorously validate genetic risk factors.

The best way to ensure that test results are verified would be for scientists to register their detailed experimental protocols before starting their research and disclose full results and data when the research is done. At the moment, results are often selectively reported, emphasizing the most exciting among them, and outsiders frequently do not have access to what they need to replicate studies. Journals and funding agencies should strongly encourage full public availability of all data and analytical methods for each published paper. It would help, too, if scientists stated up front the limitations of their data or inherent flaws in their study designs. Likewise, scientists and sponsors should be thorough in disclosing all potential conflicts of interest.



Some fields have adopted one or several of these mechanisms. Large international consortia are becoming commonplace in epidemiology; journals such as *Annals of Internal Medicine* and the *Journal of the American Medical Association* instruct authors to address study limitations; and many journals ask about conflicts of interest. Applying the measures widely won't be easy, however.

Many scientists engaged in high-stakes research will refuse to make thorough disclosures. More important, much essential research has already been abandoned to the pharmaceutical and biomedical device industries, which may sometimes design and report studies in ways most favorable to their products. This is an embarrassment. Increased investment in evidence-based clinical and population research, for instance, should be designed not by industry but by scientists free of material conflicts of interest.

Eventually findings that bear on treatment decisions and policies should come with a disclosure of any uncertainty that surrounds them. It is fully acceptable for patients and physicians to follow a treatment based on information that has, say, only a 1 percent chance of being correct. But we must be realistic about the odds. SA

COMMENT ON THIS ARTICLE ONLINE
ScientificAmerican.com/jun2011

Illustration by Ben Gibson

WHILE MOST RESIDENTS OF QATAR ARE BUSY AVOIDING THE SUN,
Hashim Al-Sada is busy inventing ways to harness it.

Inspired by a documentary about global warming, Hashim Al-Sada began work on a self-initiated and self-financed research and development project. Three years later, his work in the field of portable solar energy technology has received multiple international awards and recognition, and has attracted the attention of many leading corporations, governments and academic institutions. Even as he broadens the scope of his research, he also sets aside time to work as a summer science camp supervisor to help mentor and encourage the region's next generation of scientists.

Qatar Foundation is proud to be home to leaders like Hashim Al-Sada. Together, we are making Qatar a center of knowledge that is helping the entire world move forward. Learn more about Hashim's work and discover the people of Qatar Foundation at www.qfachievers.com.

مؤسسة قطر
Qatar Foundation
www.qf.org.qa

Unlocking human potential.

TECHNOLOGY

Hack My Ride

Increasingly sophisticated onboard computers may put cars in danger of cyberattacks

Worrying about hackers breaking into your laptop and cell phone is bad enough, but soon your car may be vulnerable, too. With each new model year, the automobile becomes less a collection of mechanical devices and more a sophisticated network of computers linked to one another and to the Internet. Earlier this year a group of researchers proved that a hacker could conceivably use a cell phone to unlock a car's doors and start its engine remotely, then get behind the wheel and drive away. In work presented in March to a committee of the National Academies, Stefan Savage, a computer science professor at the University of California, San Diego, and Tadayoshi Kohno of the University of Washington, placed malicious software on an unspecified car's computer system using its own Bluetooth and cell phone connections. The software could have been used to co-opt the car's computer system, including its engine. The research "shows the need for security measures in vehicular onboard networks," says Olaf Henniger, a researcher at Germany's Fraunhofer Institute for Secure Information Technology.

Henniger and his colleagues are working to create just that. He is a member of EVITA, an effort that was launched in 2008 with the help of BMW Group, Fujitsu and others to develop a security blueprint that carmakers can follow to build more secure onboard networks. The project, which is scheduled to wrap up at the end of the year, has already developed prototypes that would encrypt or authenticate data exchanged within the car, with other cars and with equipment on roadways.

Whether car companies are willing to invest in the additional security remains to be seen, says Anup Ghosh of George Mason University's Center for Secure Information Systems. Many manufacturers say their vehicles are already safe. Ford has a built-in firewall to protect its SYNC system against network attacks and separates its vehicle-control network from its infotainment network, says Rich Strader, director of the company's Information Technology, Security and Strategy practice. General Motors says its mobile app never communicates directly with the car but instead connects to OnStar's network, which requires authentication.

The research does not mean that cars are suddenly vulnerable to network attacks. Savage, Kohno and their colleagues are merely reporting the result of several years of experiments. Still, it seems the unending chess match between hackers and security experts has found a new field of play. *—Larry Greenemeier*

ALEX STOKES *Alamy (monitor)*; GETTY IMAGES *(dashboard and background)*

FURTHER READINGS AND CITATIONS ScientificAmerican.com/jun2011/advances

ARE YOU KIDDING YOURSELF?

YOU THINK YOU'VE GOT PLENTY OF TIME TO LOWER YOUR HIGH CHOLESTEROL, BUT EVERY 34 SECONDS IN THE U.S. SOMEONE HAS A HEART ATTACK.

If you've been waiting to lower your high cholesterol, stop kidding yourself. High cholesterol is a significant risk factor for heart attacks.

When healthy diet and exercise are not enough, adding Lipitor may help. Along with diet:

- Lipitor has been shown to lower bad cholesterol 39% to 60% (average effect depending on dose).
- 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. These risk factors include smoking, age, family history of early heart disease, high blood pressure and low good cholesterol.

Lipitor is backed by over 18 years of research.

Talk to your doctor about your risk and about Lipitor. Learn more at lipitor.com or call 1-888-LIPITOR (1-888-547-4867).

Please see additional important information on next page.

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.

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.

LIPITOR®
atorvastatin calcium
tablets

DON'T KID YOURSELF

Find out more at lipitor.com

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**.

Uninsured? Need help paying for Pfizer medicines? Pfizer has programs that can help. Call **1-866-706-2400** or visit **www.PfizerHelpfulAnswers.com.**

Pfizer helpful answers®

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

MARINE BIOLOGY

The Smallest Hitchhikers

Marine microbes may hold the key to the ocean's disappearing plastic

We know that at the heart of at least two ocean basins—the North Pacific and the North Atlantic—tiny plastic fragments the size of confetti or smaller are accumulating on the sea surface by the tens of thousands, the remnants of discarded grocery bags, cups, bottles and other waste.

Last year a group of researchers publishing in the journal *Science* reported a mystery: during a 22-year survey of plastic accumulation in the western North Atlantic, the scientists saw no increase in the amount of plastic, despite a surge in annual global plastic production from about 75 million to 245 million metric tons over the same period. Where was it going? New research shows marine microbes may be feasting on the debris.

On a recent cruise to the North Atlantic's Sargasso Sea, scientists from the Sea Education Association (SEA) in Woods Hole, Mass., collected bits of plastic that, to the naked eye, looked relatively smooth and clean. But when they zoomed in on the one-centimeter-size slivers using an electron microscope, a new world appeared. "We saw that they were just covered with microbes," says Tracy Mincer of the Woods Hole Oceanographic Institution.

What's more, he observed individual microbes sinking into the plastic's surface, eroding a footprint roughly twice their diameter. "They look just like hot coals burning through snow," says Mincer, whose colleague presented the findings at the Fifth International Marine Debris Conference in Honolulu in March.

Mincer cautions that these observations are preliminary, but if they are confirmed, they would be the first evidence of marine microbes able to degrade plastic at sea. Whereas Mincer notes that bacteria's ability to digest plastic in the warm, moist, nutrient-rich clime of landfills is well established, the ocean's surface has long been considered too inhospitable an environment for biodegradation to occur. It is cold, turbulent and, particularly in the Sargasso Sea, devoid of nutrients.

The new research is crucial to understanding the fate of plastic at sea, says Kara Lavender Law of SEA, who is lead author of the *Science* paper that first reported the missing plastic. "If we can find how it's broken down into its molecular components, that's a really important revelation," she says.

—Amanda Rose Martinez

BEHAVIOR

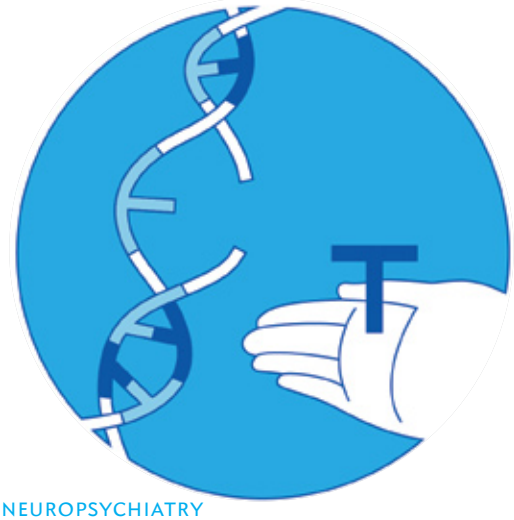
A Batter for a Batter

Hot weather primes pitchers for vengeance

The black-and-blue rule of baseball—if your pitcher beans our batter, our pitcher will bean yours—it turns out, is highly dependent on the weather. Richard P. Larrick, a professor at Duke University's Fuqua School of Business, and his colleagues examined every at bat in every Major League Baseball game since 1952, keeping an eye peeled for retribution pitches. They then calculated that of the roughly 190,000 at bats that occur every season, about 1,550 result in the batter being struck by a pitch. When they overlaid game data with weather data, they discovered that batters have a 27 percent chance of being hit by a retribution pitch in 95 degree Fahrenheit weather, compared with an only 22 percent chance in 55 degree F weather. "We don't think that heat increases aggression in general," Larrick says, "but that it increases a special type of aggression: retribution."

The findings jibe with results from previous studies on the psychological effects of heat, which have shown that people in hotter rooms have a lower threshold for revenge and are more likely to view others' actions as hostile. That may explain why violent crime increases in the summer months, although researchers have yet to determine whether temperature plays a role or if attacks go up because more people are interacting on the streets. Larrick says that his research could help get to the bottom of the mystery. "Studying baseball is helpful because it removes the confounding variables of real life. It's controlled," he says—as long as fans stay in their seats. *—Michael Easter*

GARY BELL *Corbis (plastic garbage)*; DIANE DIEDERICH *Getty Images (baseball)*



NEUROPSYCHIATRY

Treating Tourette's

A gene mutation that causes low histamine levels may be behind some tic disorders

Tourette's syndrome is most pronounced in children. The physical and vocal tics, which can alienate kids from peers, are difficult to treat. First-line drugs are limited in their efficacy, whereas more effective antipsychotics have many potential long-term side effects, including weight gain and movement disorders. Investigators may be moving closer to a new treatment option involving drugs that already exist.

Last year researchers identified a new gene mutation associated with the disorder. Known mutations have only explained a small number of Tourette's cases, so the investigators, led by Matthew State, co-director of the Yale Neurogenetics Program, studied a rare family in which the father and his eight children all had Tourette's. In these family members, the gene involved in the production of histamine in the brain was shorter than normal, generating lower levels of the compound, which is involved in inflammatory response. State believes these lower levels can cause tics, and he is looking for this and further histamine-related mutations in other people with Tourette's.

Now scientists have found parallels between this family and histamine-deficient mice, which furthers the connection to Tourette's. Most individuals with Tourette's have low prepulse inhibition, meaning that they are more easily startled or distracted than the average person, says Christopher Pittenger, director of the Yale OCD Research Clinic. In May he was to present new data to the Society of Biological Psychiatry that both this family and mice missing the histamine gene had low prepulse inhibition and tics. Other experiments have shown that histamine-boosting drugs decrease ticlike behaviors in mice.

Histamine is known for contributing to allergic reactions and keeping us awake at night, which is why antihistamines are available over the counter. But it is also a neurotransmitter found throughout the brain, including in a region associated with Tourette's.

The findings suggest an alternative to antipsychotics, which reduce tics by blocking dopamine. As dopamine levels drop, histamine levels rise. Increasing histamine directly, without blocking dopamine, may work as well and avoid many of the side effects of antipsychotics. "Other people with Tourette's may have other changes in their histamine system, so it's quite possible that a histamine-boosting drug may have benefits, but it's still very early," says Kevin McNaught, vice president for medical and scientific programs at the New York–based Tourette Syndrome Association.

Drugs that increase histamine are already being tested to treat other neurological conditions, as well as attention-deficit hyperactivity disorder, which is often found in people with Tourette's.

—Sonya Collins

QUOTABLE

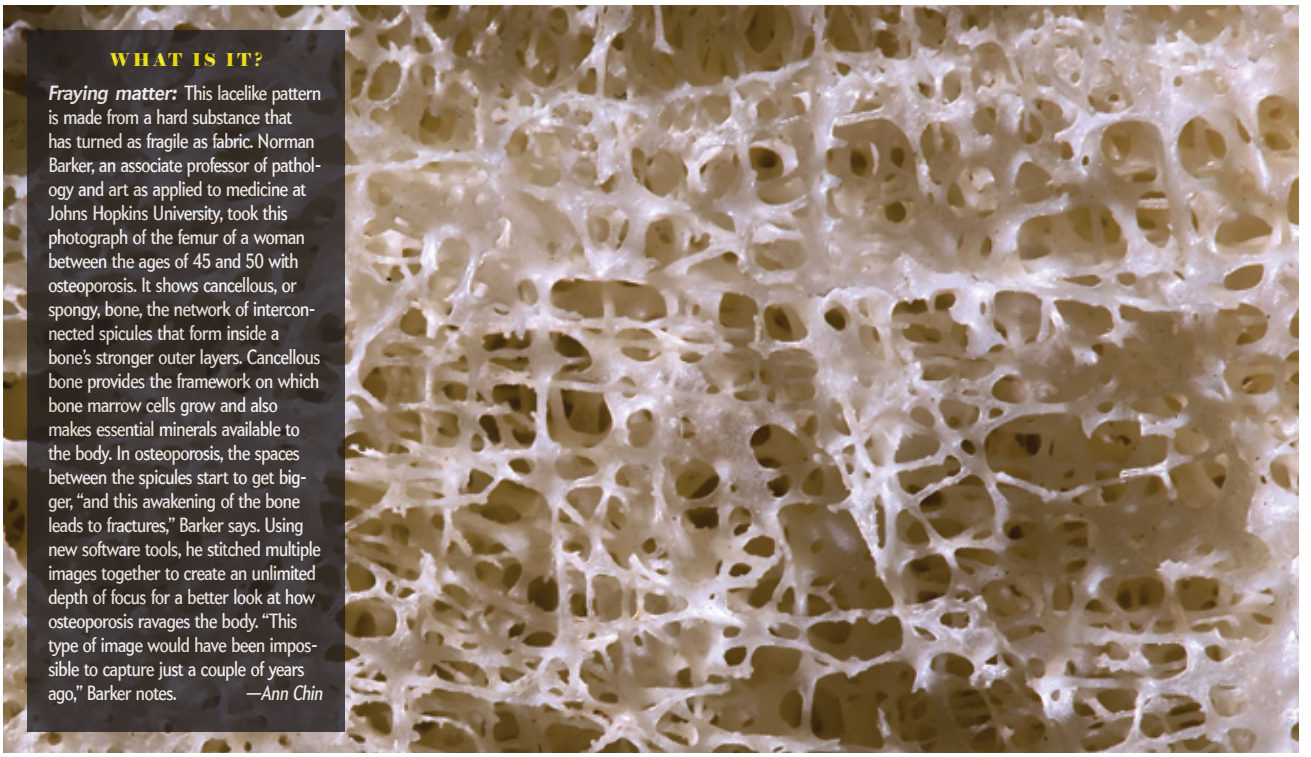
"Now we know there's a better gift for [Valentine's Day] than chocolates."

—Lazar Greenfield, president-elect of the American College of Surgeons, in an editorial on the mood-enhancing effects of semen on women after unprotected sex. He resigned in April.

Illustrations by Thomas Fuchs

WHAT IS IT?

Fraying matter: This lacelike pattern is made from a hard substance that has turned as fragile as fabric. Norman Barker, an associate professor of pathology and art as applied to medicine at Johns Hopkins University, took this photograph of the femur of a woman between the ages of 45 and 50 with osteoporosis. It shows cancellous, or spongy, bone, the network of interconnected spicules that form inside a bone's stronger outer layers. Cancellous bone provides the framework on which bone marrow cells grow and also makes essential minerals available to the body. In osteoporosis, the spaces between the spicules start to get bigger, "and this awakening of the bone leads to fractures," Barker says. Using new software tools, he stitched multiple images together to create an unlimited depth of focus for a better look at how osteoporosis ravages the body. "This type of image would have been impossible to capture just a couple of years ago," Barker notes. *—Ann Chin*

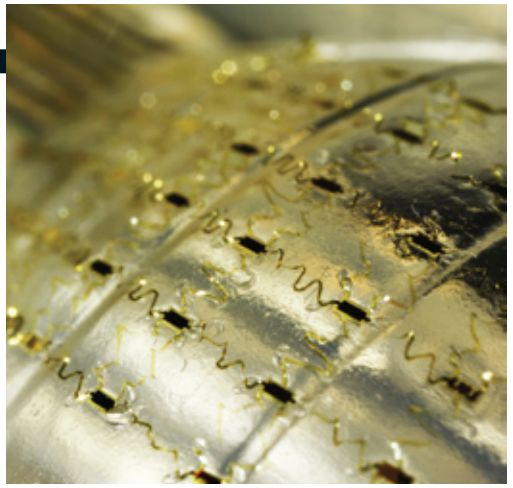


NORMAN BARKER

ENGINEERING

Spies Inside

A new generation of electrodes is small and flexible enough to fit inside the heart or brain



Multitasker: The surface of one of Rogers's balloon catheters is covered with electrodes.

Electricity controls much of the human body: consider the electrical firing of neurons and the current transmitted by the heart. Yet historically the electrodes that have been used in medicine to monitor and regulate essential activity have been biologically incompatible because they are stiff, big and water-sensitive.

Now scientists are setting new standards with their designs for flexible, stretchable and waterproof circuits and electrodes that mimic the properties of human tissues. These new methods can also monitor and control biological electrical activity more naturally and easily. John A. Rogers, a materials scientist at the University of Illinois at Urbana-Champaign, has developed a technique that thinly slices silicon wafers or LEDs with a chemical etcher. Then, to make them stretchy as well as flexible, he bends them into wavelike shapes and attaches them to rubber platforms. Finally, Rogers waterproofs them by encapsulating them in a polymer. The resulting electrodes "can wrap onto the surface of a tissue almost like a sheet of Saran Wrap," he says.

He recently used this technique to develop a tool for treating atrial fibrillation, a cardiac arrhythmia that afflicts two million Americans. The research was published in March in *Nature Materials* (a journal of Nature Publishing Group, which owns *Scientific American*). To identify the location of an arrhythmia, surgeons typically insert a catheter containing a single electrode into a vein and coax it up to the heart. There it tracks electrical activity in a process that can take up to an hour. Finally, with a separate catheter, they fix the arrhythmia by burning the malfunctioning tissue.

"That mapping and zapping procedure is time-consuming, has limited accuracy and requires a lot of skill in the surgeon," Rogers says. He has developed a simpler solution: a balloon catheter covered in stretchy electrodes that can be inserted into a vein in the leg or chest, moved up inside the heart and inflated. There it simultaneously takes dozens of electrical readings and also monitors blood flow, tissue contact and body temperature. In Rogers's latest models, the balloon can also perform the curative ablation itself.

"It would be a real advantage to be able to take measurements using a large number of electrodes at one time," says cardiologist Matthew Reynolds, associate director of electrophysiology at the Boston VA Healthcare System. "And if you can layer on top of that the ability to measure other things, then that would be unique." Rogers and his colleagues, who have just launched a start-up company to commercialize the technology, plan to begin human testing within nine months.

Rogers is now turning his attention to other areas of medicine. In work he has just submitted for publication, Rogers used plastic wrap–like electrode sheets to pinpoint seizure-causing brain regions in severe epileptics. He was able to collect data in real time, covering a larger surface area with improved sensitivity as compared with current techniques. He is also working on skin devices that monitor temperature, pulse rate and blood oxygenation in sports or military applications. The hope is that they will fuse so well with the body as to go completely unnoticed, like a second skin.

—Melinda Wenner Moyer

STAT

150

The estimated number of big brown bats it takes to eat 1.3 million pest insects in one year

4 to 8 grams: The amount of insects that one little brown bat can devour in a night

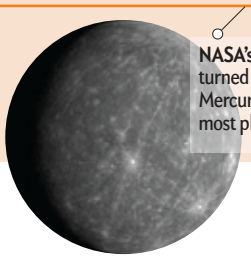
NEWS SCAN

Genius

Sound analysis of sperm whale "clicks" suggests they might have names, similar to the individual, identifying whistles that dolphins display. And we thought they just sang to one another.

PETA urged San Francisco to rename its seedy Tenderloin district to something that did not "evoke the horrors of the meat trade." "What, am I going to say, 'Yo, I'm headed down to the Mixed Salad?'" one resident told the *San Francisco Examiner*. *—George Hackett*

Illinois's Tevatron accelerator lab, set to close later this year, finds possible evidence of what may be a new elementary particle or force of nature. Talk about going out with a bang.



NASA's MESSENGER spacecraft returned the first close-up pictures of Mercury taken from orbit. The innermost planet is pockmarked with craters.

A study showed that social rejection affects the same part of the brain as physical pain, bringing new meaning to the lyrics of "Love Hurts."

Folly

COURTESY OF JOHN A. ROGERS *(University of Illinois, Urbana-Champaign (catheter);* FLIP NICKLIN *Minden Pictures (whale tail);* COURTESY OF NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/CARNEGIE INSTITUTION OF WASHINGTON *(Mercury)*

COMMENT AT ScientificAmerican.com/jun2011

Thanks to Priority Mail Flat Rate™ Envelopes, overspending on unnecessary overnighting is over.

Ship for a fraction of the price of overnighting with Flat Rate Envelopes. It's one Flat Rate to any state, just $4.95. Only from the Postal Service.™

Scan this code with your smartphone to request your free Flat Rate Shipping Kit.* Or visit prioritymail.com/kit65

Priority Mail® Flat Rate
A simpler way to ship.

UNITED STATES POSTAL SERVICE®

*Offer ends 8/31/11 and is only available while supplies last. Offer valid for one customer per address.

TECHNOLOGY

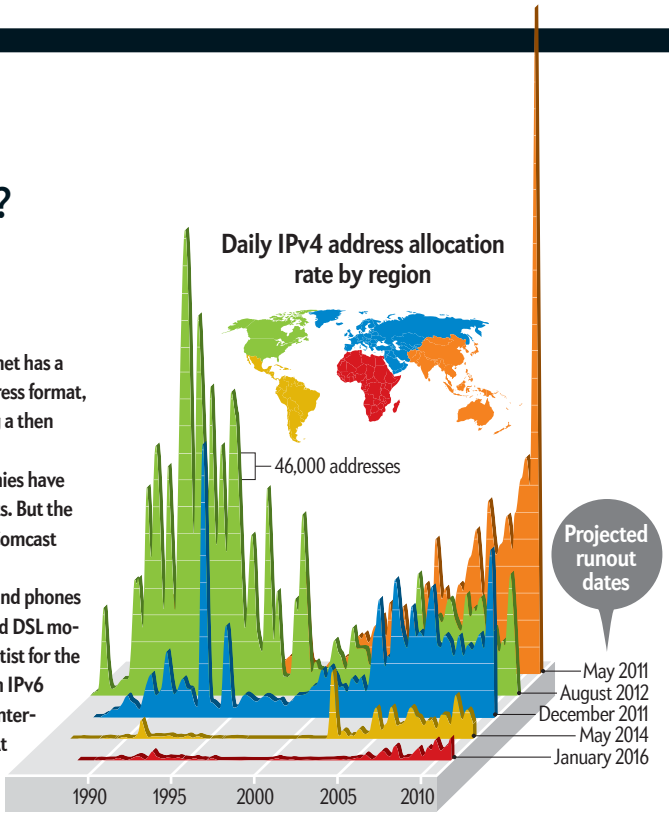
Will the Internet Stop on June 8?

Companies and individuals have gobbled up nearly every Internet protocol address available

Every computer, modem, server and smartphone that connects to the Internet has a unique Internet protocol (IP) address, which enables users to find it. The address format, known as IPv4, was standardized in 1977 as a 32-digit binary number, making a then seemingly unlimited 4.3 billion addresses (2^{32}) available.

Now they're almost gone. In the past few years Internet and Web companies have begun snapping up a new set of addresses, known as IPv6, that have 128 digits. But the companies have not made them live. That changes on June 8, when Google, Comcast and others will turn on IPv6 addresses for a 24-hour test.

Most likely the transition will go smoothly. All but the oldest computers and phones can handle both schemes, although the IPv6 option may not be turned on. Old DSL modems or cable modems may not be compatible, says Geoff Huston, chief scientist for the Asia Pacific Network Information Center. In these cases, if you try to access an IPv6 address, you will either experience a delay or never connect. For a few years Internet companies will have to support both formats, which could slow access. "At some point, IPv6 will dominate, and everyone will be optimized for it," Huston says. When that day will come, no one can say. —*Mark Fischetti*



SOURCE: GEOFF HUSTON APNIC

Graphic by Jen Christiansen

FIELD NOTES

Material Poet

An artist trained in science talks about "cloning" million-year-old glaciers

COURTESY OF TRUNG LE

PROFILE

NAME
Shawn Brixey

TITLE
Arts Chair, Center for Digital Arts and Experimental Media, University of Washington

LOCATION
Seattle

When I was still a young sculptor's apprentice, it suddenly hit me that I no longer wanted to make images and objects like my art school masters, creations that would, at most, be representations of my imagination. I thought, perhaps naively, that if I dove into physics, astronomy, cosmology and neuroscience, I could catapult over these limitations and pioneer a vastly more creative practice.

In my recent work, I mostly make poems out of matter and energy. Some are small exotic projects that at first blush seem nearly impossible. I built a work that exploits the phenomenon of sonoluminescence, in which extremely high pressure sound waves in liquids create tiny sources of electromagnetic energy. The installation converts text from a computer keyboard to synthesized speech with enough sonic force to form and hold a tiny bubble at the center of a jar of water. The sound causes the bubble to implode and then form again 50,000 times a second. Through a process that is still not fully understood, the implosions generate a bright point of visible light. It is a star in a jar created by spoken word.

I'm preparing a very large work now for the entrance of the University of Alaska [UAF] Museum of the North in Fairbanks. The inspiration was the old saw that no two snowflakes are alike. The reason for that is that they are precise atomic recordings of their lifetimes. Each is the story of its fall.

The same is true of ancient ice crystals. But with the help of some geophysicists at UAF, I have developed a process for "cloning" fragments of ice-core samples taken from million-year-old glaciers. We make thin, tapered plastic containers, each about two square feet, and fill them with ultrapurified water. Even at –40 degrees [Fahrenheit], this supercooled water remains liquid because it lacks a seed to trigger the process of crystallizing into ice. When you drop in a small fragment of ancient ice, it provides that seed: the water instantly organizes itself to mimic the prehistoric pattern.

A film on the outside of each container polarizes the light passing through the ice. In combination with the taper, this makes the crystal structure of the cloned glacial fragment visible as an intricate, holo-gramlike pattern of color. Given the rate at which Arctic glaciers are receding, cloning them may soon be as good a view as we can get. *—As told to W. Wayt Gibbs*

BOTANY

Off the Tree, Ready to Eat

Scientists have figured out the genetic basis of seedless fruit

Sweet treats: Cherimoya fruit

Mark Twain called the cherimoya and its cousin the sugar apple "the most delicious fruit known to men." Though little more than exotic edibles to most Americans, such fruits of the *Annona* family have been cultivated by people in Central and South America for generations. Even in pre-Columbian times, *Annona* fruits were enjoyed for their sherbetlike texture and a flavor that resembles a mixture of banana and pineapple. But they also contain numerous hard seeds that make the fruit difficult to eat. And even though seedless fruits such as grapes and watermelons have been cultivated for thousands of years, botanists have not been able to identify exactly why the seeds fail to form.

Then one day a Spanish sugar-apple farmer identified a strange, seedless fruit and brought it to the attention of botanists in Madrid. The scientists consulted Charles Gasser, a molecular biologist at the University of California, Davis, and in a paper published in the *Proceedings of the National Academy of Sciences USA,* the two labs identified the genetic mutation that enables the plant to produce fruit without seeds. "This study gives us the molecular basis for seedlessness, which is the first time this has been done for a fruit plant," Gasser says.

With this knowledge, Gasser observes, humans may be able to create other varieties of seedless fruits, such as cherimoyas and tomatoes, that have so far defied conventional breeding techniques. Seeds are crucial to fruit formation because they typically emit hormone signals that bring the fruit into being. Occasionally fruit-bearing plants, such as the banana, will contain a genetic mutation that allows fruit formation without seed development. In others, such as watermelons, a small part of the seed remains intact and sets off the hormone cascade that tells the fruit to develop. Now we have a new piece of the puzzle. —*Carrie Arnold*

PHYSICS

A Mystery Wrapped in a Crystal

Scientists have shed new light on how these structures melt

The fact that first graders grow crystals for science projects might lead you to think that physicists know how these snazzy shapes form and unform. Alas, there is still a big blank spot in physics textbooks where the theory of crystal melting should be. "The reason a crystalline structure melts is very subtle," says Georg Maret of the University of Konstanz in Germany, who received this year's Gentner-Kastler Prize from the German Physical Society and the French Physics Society for melting away some of that ignorance.

The difficulty is that crystals stabilize themselves. When an atom gets pulled out of place, its neighbors tug it back. Even if the atom jiggles wildly enough to break free, where can it go? Other atoms block its escape routes. For a crystal to turn to liquid, it seems that a type of swarm intelligence causes atoms to move all at once and in sync.

To figure it out, physicists have tried their hand at the special case of two-dimensional crystals. No such thing really exists in nature, although oil films floating on water come close. In the 1970s theorists realized that flat crystals are inherently less stable than 3-D ones. Because each atom has fewer neighbors, the forces holding it in place are weaker. And when one does wriggle free, only a couple of other atoms have to get out of its way rather than a long row of them, as in 3-D. For these and other reasons of geometry, physicists have reasoned that 2-D crystals should melt in two distinct stages, passing through a hexatic phase, in which hexagonal groups of atoms flow freely, as in a fluid, yet remain oriented in the same direction, as in a crystal.

Amethyst crystals

It has taken experimental physicists 30 years to test this theory. Maret's team, borrowing from the experimental techniques of first graders, built a kind of Tinkertoy model of a crystal, representing atoms by micron-size balls made of a mix of plastic and iron oxide and suspended in a fluid. Though larger than atoms, the balls were still small enough to behave much like them. They jiggled randomly and, when placed in a magnetic field, exerted magnetic forces on one another. Dialing up the field was like lowering the temperature: it caused the balls to snap together into a crystalline grid. "Maret's work is the cleanest, simplest system where you can really study how you go from solid to hexatic, hexatic to liquid," says theorist David R. Nelson of Harvard University, who helped to develop the theory Maret has now confirmed.

The same principles of collective behavior should help physicists crack the harder nut of 3-D crystals. Like growing crystals, growing theories of crystals takes patience. —*George Musser*

AURORA PHOTOS (*cherimoya*); MARK SYKES *Photo Researchers, Inc.* (*crystals*)

COMMENT AT ScientificAmerican.com/jun2011

Hear the buzz?

It's about the new Electric Rabbit.

The display screen shows how many corks you can pull before re-charging. The compact design is up to 3 inches shorter than other electric corkscrews. The recessed spiral fits neatly over a wine bottle. The Electric Rabbit has plenty to be abuzz about.

Where To Go Electric Rabbit Hunting:

Crate & Barrel, Macy's, Bloomingdales, Dillards, Bon Ton, Carson Pirie Scott, Sur La Table, Chef's Catalog, Spec's, Le Gourmet Chef, Kitchen Kapers.com, Total Wine & More, BevMo!

metrokane

metrokane.com

DO THE MATH

No X-aggeration

How companies can gather information and still preserve privacy

Companies and individuals are often at odds, concerned either with collecting information or with preserving privacy. Online stores and services are always eager to know more about their customers—income, age, tastes—whereas most of us are not eager to reveal much.

Math suggests a way out of this bind. A few years ago Rakesh Agrawal and Ramakrishnan Srikant, both data-mining researchers, developed an idea that makes telling the truth less worrisome. The idea works if companies are content with accurate aggregate data and not details about individuals. Here is how it goes: you provide the numerical answer to certain intrusive online questions, but a random number is added to (or subtracted from) it, and only the sum (or difference) is submitted to the company. The statistics needed to recover approximate averages from the submitted numbers is not that difficult, and your privacy is preserved.

Thus, say you are 39 and are asked your age. The number sent to the site might be anywhere in the range of 19 to 59, depending on a random number between –20 and +20 that is generated (by the company if you trust it, by an independent site or by you). Similar fudge factors would apply to incomes, zip codes, years of schooling, size of family, and so on, with appropriate ranges for the generated random number.

Another, older example from probability theory illustrates a variant of the idea. Imagine you are on an organization's Web site, and the organization wishes to find out how many of its subscribers have ever X-ed, with X being something embarrassing or illegal. Not surprisingly, many people will lie if they answer the question at all. Once again, random masking comes to the rescue. The site asks the question, "Have you ever X-ed? Yes or no," but requests that before answering it, you privately flip a coin. If the coin lands heads, the site requests that you simply answer yes. If the coin lands tails, you are instructed to answer truthfully. Because a yes response might indicate only a coin's landing heads, people presumably would have little reason to lie.

The math needed to recover an approximation of the percentage of respondents who have X-ed is easy. To illustrate: if 545 of 1,000 responses answer yes, we would know that about 500 of these yesses were the result of the coin's landing heads because roughly half of all responses would, by chance, be heads. Of the other approximately 500 people whose coin landed tails, about 45 of them also answered yes. We conclude that because 45 or so of the approximately 500 who answered truthfully have X-ed, the percentage of X-ers is about $45/500$, or 9 percent.

In some situations, variants of this low-tech technique, in conjunction with appropriate legislation, would work—or so thinks this 6′9″ X-er. —*John Allen Paulos*

Paulos is professor of mathematics at Temple University (www.math.temple.edu/paulos).

STAT

$22.9 billion

The estimated value of bats to the U.S. agricultural industry, according to an April study in the journal *Science*

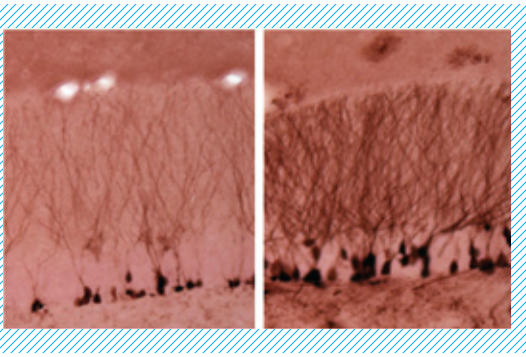
70 percent: Estimated size of winter bat colony declines across the U.S. since 2006 in areas most affected by white nose syndrome, the infectious disease that has been killing bat populations

COMMENT AT ScientificAmerican.com/jun2011

NEUROSCIENCE

How Brains Bounce Back

After a traumatic injury, neurons that govern memory can regenerate



COURTESY OF UNIVERSITY OF TEXAS SOUTHWESTERN MEDICAL CENTER

Growth spurt: A brain injury can spur the development of new neurons (*right*). At the left is an uninjured brain.

For most of the past century the scientific consensus held that the adult human brain did not produce any new neurons. Researchers overturned that theory in the 1990s, but what role new neurons played in the adult human brain remained a mystery. Recent work now suggests that one role may be to help the brain recover from traumatic brain injury.

Cory Blaiss, then at the University of Texas Southwestern Medical Center, and her colleagues genetically engineered mice such that the researchers could selectively turn neurogenesis on or off in a brain region called the hippocampus, a ribbon of tissue located under the neocortex that is important for learning and memory. They then administered blunt-force trauma to the brain and compared the performance of brain-injured mice that could produce new neurons to brain-injured mice that could not. They sent each mouse through a water maze that required it to find a platform obscured beneath the surface of murky water. The researchers found that after injury only mice with intact neurogenesis could develop an efficient strategy to find the hidden platform, a skill that is known to rely on spatial learning and memory. They concluded that without neurogenesis in the hippocampus, the recovery of cognitive functions after brain injury was significantly impaired.

The finding may lead to much needed therapeutic techniques. Deficits in learning and memory are nearly universal after a traumatic brain injury. The ability to stimulate more robust neurogenesis could lead to faster healing times or perhaps even more complete recovery of cognitive functions, a potentially life-changing prospect for the millions of people who suffer from traumatic brain injury every year. —*Tim Requarth and Meehan Crist*

LINGUISTICS

Join the F***ing Club

Why swearwords have taken over *Billboard*'s top 10 chart

Earlier this spring the *Billboard* pop music chart marked a milestone of sorts. Three of its top 10 hits prominently featured the same four-letter word: Cee Lo Green's "F**k You," Pink's "F**kin' Perfect" and Enrique Iglesias's "Tonight (I'm Lovin' You)," where the curse word appeared in the chorus. What's going on here?

When it comes to popular culture, experts say, swearwords make fans feel as though they are part of a select club. "There's a power to the words because they make you feel as if you fit in, and they identify you as part of a specific demographic," says Timothy Jay, a professor of psychology at the Massachusetts College of Liberal Arts who has studied swearing for decades. Brain mapping shows that when we yell a choice word in anger, the brain's right hemisphere, which reacts to emergencies and helps us process emotion, kicks into gear. Additionally, we get a little goose from the limbic system, which regulates emotion and behavior.

Parental worries about the prevalence of bad language may be overblown. Although swearing appears to be everywhere, it is actually still quite rare. Even if kids are cursing at a younger age, foul language accounts for only 0.3 to 0.7 percent of our daily speech. Experimental psychologist Elisah D'Hooge and her colleagues at Ghent University in Belgium are attempting to explain why. In a study to be published this June in the journal *Psychological Science,* her team reports that we have a "verbal self-monitor" between the mental production of speech and the actual uttering of words that keeps us from making mistakes even when we are distracted. Our self-monitor "cares about context" and is "especially sensitive" to intercept words that might be inappropriate in a particular social situation, D'Hooge says.

In one of her experiments studying the effect of crude words on the speed of speech, participants were shown a picture on which a neutral word appeared and then a taboo word. For example, a picture of a horseshoe was paired with the word "crab," as well as with "slut." The participants were then asked to name the pictures as quickly as possible. Results showed that participants paused longer but made fewer errors when naming the picture when a taboo word was superimposed. That means their verbal self-monitor was more "stringent" when encountering the offensive word, D'Hooge says.

Nevertheless, the monitor is flexible. In the 1940s, for example, saying "goddamn it" was a no-no, but it became more acceptable in the 1960s, when new words, such as the "f" word emerged as taboo. There will always be some situations in which our verbal self-monitor will go on high alert, showing its "context-sensitive" side. "It can be cool to use the 'f' word a lot when you're a 16-year-old boy hanging out with your friends, but it will be a lot less cool to use the word in the presence of your mum," D'Hooge observes. Unless, of course, she's a pop singer. —*Joan Raymond*

QUOTABLE

"Humans tend to believe we are unique, but that belief is not based on facts."

—Behavioral biologist Satoshi Hirata, quoted in the journal *Nature,* on his finding that chimps, like humans, give birth to babies that face backward. He is one of the few researchers ever to have witnessed chimp parturition firsthand.

COMMENT AT ScientificAmerican.com/jun2011

SCIENTIFIC AMERICAN Travel

BRIGHT HORIZONS 11

JANUARY 14–21, 2012 ✸ EAST CARIBBEAN ✸ www.InsightCruises.com/sciam11

Arecibo Observatory

Exercise your science curiosity in the surprisingly suitable Caribbean. Cast off on Bright Horizons 11 and explore a slate of science topics inspired by the islands. Based on Holland America Line's m.s. Eurodam, our community of science experts and science buffs head for tropical climes, January 14–21, 2012, round-trip Fort Lauderdale, Florida.

Take a cue from our island journey and delve into the form and function of flowers and plant evolution on islands with Dr. Spencer Barrett. Open a door to thought provoking developments in primatology with Dr. Frans de Waal. Enjoy the fruit of crossdisciplinary work in bioarchaeology when Dr. Patrick McGovern details discoveries about ancient fermented beverages. Dr. Marc Davis guides us through physical cosmology and the latest on the search for exoplanets. Explore sun science and energy futures, and grasp "Einstein in a Nutshell" through Dr. Richard Wolfson's sessions.

We'll go behind the scenes at the Arecibo radio telescope on an optional excursion with briefings on the radio astronomy, planetary radar and climatology research there. Plus, we'll boldly go where ordinary visitors are not permitted at the telescope, using the password "Scientific American".

See what's brewing in astrophysics and climatology, primatology, botany, and bioarchaeology. Add vivid colors and beautiful beaches, elegant dining and gracious service, sunsets and fun with friends, and you have the Bright Horizons 11 picture. Please join us! For full details, email concierge@insightcruises.com or call (650) 787-5665.

Cruise prices vary from $699 for an Interior Stateroom to $2,699 for a Deluxe Suite, per person. For those attending our program, there is a $1,475 fee. Government taxes, port fees, and InSight Cruises' service charge are $183.80 per person. **For more info please call 650-787-5665 or email us at Concierge@InSightCruises.com**

THE ANCIENTS AND CHEMISTRY

The Quest for Fermented Beverages

Royal Purple: The Dye of Gods and Kings

The First Wine: An Archaeochemical Detective Story

Ancient Beer: A Global Perspective

PRIMATOLOGY

A Darwinian View of the Moral Emotions in Man and Animals

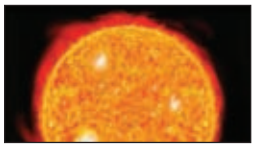
On the Possibility of Animal Empathy

What Primates Know About and Learn From Each Other

ENVIRONMENTAL SCIENCE

Global Warming: State of the Science

Energy Futures



ASTROPHYSICS, ASTRONOMY, AND RELATIVITY

Einstein in a Nutshell

Wild Sun!

The Search for Exoplanets

Gravitational Lensing

Galaxies and the Clustering of Galaxies

Why Does our Universe Have a Beginning?

BOTANY

Plant Sex Made Easy

Darwin's Legacy: the Form and Function of Flowers

Plant Evolution on Islands

Plant Invasions — More Than Just a Nuisance

SPEAKERS

Spencer C.H. Barrett, Ph.D.
Marc Davis, Ph.D.
Frans B.M. de Waal, Ph.D.
Patrick E. McGovern, Ph.D.
Richard Wolfson, Ph.D.

ARECIBO OBSERVATORY

Explore the contributions and potential of radio astronomy at the celebrated Arecibo Observatory. Get an unparalleled behind-the-scenes tour of the iconic facility, and absorb an in-depth look at the unique contributions derived from Arecibo research and development.

Join us as we wind through the rainforest-blanketed karst terrain of Northern Puerto Rico. We'll get a sense of the massive physical scope of the Arecibo radio telescope. We'll boldly go where ordinary visitors are not permitted. NAIC scientists will update us about the radio astronomy, planetary radar discoveries, and climatology research at the observatory. From the monitoring of near-earth objects to cosmology, astrophysics, and global warming research, you'll gain insight into the vital activities at Arecibo. This optional six-hour tour includes transportation, lunch, and entrance fees and costs $275.

NASA'S KENNEDY SPACE (KSC) CENTER

NASA's launch headquarters, on the Space Coast, is the only place on Earth where you can tour launch areas, meet a veteran astronaut, and grasp the true enormity of the Space Program. Experience fun and wonder with Bright Horizons companions in this private pre-cruise, custom, full-day tour. Get ready to walk among and beneath giant rockets, discover what it takes to launch the Space Shuttle from preparation to liftoff, and soak in Kennedy Space Center's "The Right Stuff" vibe.

The KSC excursion is $575 pp and includes all of the above plus breakfast, lunch, and dinner; one-night hotel; and transportation to/from the KSC to our hotels in Ft. Lauderdale.

CST# 2065380-40

Virginia Hughes is a science journalist based in Brooklyn who specializes in brain science, genetics and biotechnology. She writes for the blog The Last Word on Nothing (www.lastwordonnothing.com).

Shades of Grief

When does mourning become a mental illness that doctors should treat?

Sooner or later most of us suffer deep grief over the death of someone we love. The experience often causes people to question their sanity—as when they momentarily think they have caught sight of their loved one on a crowded street. Many mourners ponder, even if only abstractedly, their reason for living. But when are these disturbing thoughts and emotions normal—that is to say, they become less consuming and intense with the passage of time—and when do they cross the line to pathology, requiring ongoing treatment with powerful antidepressants or psychotherapy, or both?

Two proposed changes in the "bible" of psychiatric disorders—the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM*)—aim to answer that question when the book's fifth edition comes out in 2013. One change expected to appear in the *DSM-5* reflects a growing consensus in the mental health field; the other has provoked great controversy.

In the less controversial change, the manual would add a new category: Complicated Grief Disorder, also known as traumatic or prolonged grief. The new diagnosis refers to a situation in which many of grief's common symptoms—such as powerful pining for the deceased, great difficulty moving on, a sense that life is meaningless, and bitterness or anger about the loss—last longer than six months. The controversial change focuses on the other end of the time spectrum: it allows medical treatment for depression in the first few weeks after a death. Currently the *DSM* specifically bars a bereaved person from being diagnosed with full-blown depression until at least two months have elapsed from the start of mourning.

Mortal toll: For most people, extreme grief subsides with time. For some, however, it may continue unabated or lead to depression.

Those changes matter to patients and mental health professionals because the manual's definitions of mental illness determine how people are treated and, in many cases, whether the therapy is paid for by insurance. The logic behind the proposed revisions, therefore, merits a further look.

ABNORMAL GRIEF

The concept of pathological mourning has been around since Sigmund Freud, but it began receiving formal attention more recently. In several studies of widows with severe, long-lasting grief in the 1980s and 1990s, researchers noticed that antidepressant medications relieved such depressive feelings as sadness and worthlessness but did nothing for other aspects of grief, such as pining and intrusive thoughts about the deceased. The finding suggested that complicated grief and depression arise from different circuits in the brain, but the work was not far enough along to make it into the current, fourth edition of the *DSM,* published in 1994. In the 886-page book, bereavement is relegated to just one paragraph and is described as a symptom that "may be a focus of clinical attention." Complicated grief is not mentioned.

Over the next few years other studies revealed that persistent, consuming grief may, in and of itself, increase the risk of other illnesses, such as heart problems, high blood pressure and cancer. Holly G. Prigerson, one of the pioneers of grief research, organized a meeting of loss experts in Pittsburgh in 1997 to hash out preliminary criteria for what she and her colleagues saw as an emerging condition, which they termed traumatic grief. Their view of its defining features: an intense daily yearning and preoccupation with the deceased. In essence, it is the inability to adjust to life without that person, notes Mardi J. Horowitz, professor of psychiatry at the University of California, San Francisco, and another early researcher of the condition. Prigerson, then

MICHAEL BLANN Getty Images

Endless Mourning

Complicated Grief Disorder, in which severe mourning lasts for at least six months, is poised to become one of the new entries in the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders,* when the psychiatric "bible" for mental health providers comes out in 2013. Diagnosis is expected to be based on two major criteria. First, people who have lost a loved one must continue to yearn for the deceased on a daily basis or to a disabling degree. Second, at least five of the following symptoms must be so severe that they significantly interfere with an individual's ability to function:

- Extreme confusion about one's role in life
- Difficulty accepting the loss
- Avoiding anything that is a reminder of the death
- Inability to trust others since the death occurred
- Bitterness or anger related to the loss
- Difficulty moving on with life
- Numbness since the loss
- Feeling that life is meaningless now
- Feeling stunned, dazed or shocked by the loss

an assistant professor at the Western Psychiatric Institute and Clinic in Pittsburgh, hoped the meeting would begin the process of finding enough evidence to support changing the *DSM*. "We knew that grief predicted a lot of bad outcomes—over and above depression and anxiety—and thought it was worthy of clinical attention in its own right," says Prigerson, now a professor of psychiatry at Harvard Medical School.

A spate of studies since then—not only of widows but of parents who had lost a child, tsunami survivors and others—has further confirmed and refined that initial description. In 2008 researchers got their first hint of what complicated grief disorder looks like at the neurological level. Mary-Frances O'Connor of U.C.L.A. scanned the brains of women who had lost their mother or a sister to cancer within the past five years. She compared the results of women who had displayed typical grief with those suffering from prolonged, unabated mourning. When, while inside the scanner, the study participants looked at images of the deceased or words associated with the death, both groups showed a burst of activity in neurological circuits known to be involved in pain. The women with prolonged grief, however, also showed a unique neural signature: increased activity in a nub of tissue called the nucleus accumbens. This area, part of the brain's reward center, also lights up on imaging scans when addicts look at photographs of drug paraphernalia and when mothers see pictures of their newborn infant. That does not mean that the women were addicted to their feelings of grief but rather that they still felt actively attached to the deceased. Meanwhile clinical studies have shown that a combination of cognitive therapy approaches used to treat major depression and post-traumatic stress may help some people with complicated grief work through it.

As these and other studies began to pile up, a few researchers turned to complex statistical analysis to validate more precisely the exact combination of features that define the condition. In 2009, more than 10 years after the Pittsburgh panel, Prigerson published data collected from nearly 300 grievers she had followed for more than two years. By analyzing which of some two dozen psychological symptoms tend to cluster together in these participants, she devised the criteria for complicated grief: the mandatory presence of daily yearning plus five out of nine other symptoms for longer than six months after a death [*see box at right*]. This is exactly the type of rigorous, quantitative study that is needed before a condition makes it into the *DSM*. "People who meet the criteria for complicated grief do not necessarily meet criteria for either depression or post-traumatic stress disorder," says Katherine Shear, a professor of psychiatry at Columbia University. "If you didn't have this disorder [in the *DSM*], then those people would not get treatment at all."

CONTROVERSIAL TREATMENT

The case for diagnosing people as depressed and treating them accordingly when they are still newly bereaved is more contentious. Although some symptoms of grief and depression overlap (sadness, insomnia), the two conditions are thought to be distinct. Grief is tied to a particular event, for example, whereas the origins of a bout of clinical depression are often more obscure. Antidepressants do not ease the longing for the deceased that grievers feel. So in most cases, treating grieving people for depression is ineffective.

A few studies, however, have suggested that mourning may trigger depression in the same way that other major stresses—such as being raped or losing one's job—can bring about the condition. If so, some people who grieve may also be clinically depressed. It seems unfair, advocates of changing the *DSM* argue, to make mourners wait so long for medical help when anyone else can be treated for depression after just two weeks of consistent depression. "On the basis of scientific evidence, they're just like anybody else with depression," says Kenneth S. Kendler, a member of the *DSM-5* Mood Disorder Work Group, which reviews all proposed changes to the manual related to anxiety, depression and bipolar disorder (a condition characterized by extreme mood swings). It is for this reason that the group recently suggested deleting the clause that specifies a two-month wait before mourners can receive a diagnosis of, and therefore treatment for, depression.

Critics of the move counter that it will lead to unwarranted diagnoses and overtreatment. "It's a disastrous and foolish idea," says Allen Frances, who chaired the task force that produced the fourth edition of the *DSM*. He worries about how the *DSM-5* may be used by sales representatives from pharmaceutical companies to urge doctors to write more prescriptions. Indeed, Frances believes that changes in the edition that he oversaw inadvertently sparked an unwarranted explosion of diagnoses for bipolar disorder in children. Prigerson, for her part, predicts a general backlash against the idea that mourners might ever need psychiatric treatment. "There will be vitriolic debates when the public fully appreciates the fact that the *DSM* is pathologizing the death of a loved one within two weeks," she says.

In many ways, parsing the differences between normal grief, complicated grief and depression reflects the fundamental dilemma of psychiatry: mental disorders are diagnosed using subjective criteria and are usually an extension of a normal state. So any definition of where normal ends and abnormal begins will be the object of strongly held opinions. As Frances says, "There is no bright line—it is always going to be a matter of judgment." SA

COMMENT ON THIS ARTICLE ONLINE
ScientificAmerican.com/jun2011

SOURCE: "PROLONGED GRIEF DISORDER: PSYCHOMETRIC VALIDATION OF CRITERIA PROPOSED FOR *DSM-V* AND *ICD-11*," BY H. G. PRIGERSON ET AL., IN *PLOS MEDICINE*, VOL. 6, NO. 8; AUGUST 2009

David Pogue is the personal-technology columnist for the *New York Times* and an Emmy Award–winning correspondent for *CBS News*.

Critical Mass

The wisdom of crowds can be brilliant. It can also be corrupt

In the beginning, Web site owners posted words and pictures on their pages. Today we refer to that primitive time as Web 1.0.

In the modern world of Web 2.0, though, the audience provides the material. Many of the biggest names on the Web fall into this category: Facebook, eBay, Craigslist, YouTube, Flickr, and so on. In each case, the Web site owner provides nothing but a forum for strangers to connect.

One of the most fascinating tributaries of the Web 2.0 river is the citizen review site. One Web site after another harnesses the collective wisdom of thousands of delighted or disappointed customers. Never again will you make a mistake by choosing the wrong vacation spot (TripAdvisor), restaurant (Yelp), movie (IMDB), car (Edmunds), contractor (Angie's List), app (iTunes), book (Amazon), doctor (RateMDs) or malt beverage (RateBeer).

If you are that hotel operator, restaurateur, car dealership or whatever, the rise of the citizen review site is a sobering development. No longer are you on top of the mountain, blasting your marketing message down to the masses through your megaphone. All of a sudden, the masses are conversing with *one another*. If your service or product isn't any good, they'll out you. If you are a prospective customer, on the other hand, citizen review sites seem like gifts from heaven. These days if you go to a restaurant with slow service, it's your own darned fault. You could have avoided that outcome by consulting the masses in advance.

BEST REVIEW SITES FOR (NEARLY) EVERYTHING
ScientificAmerican.com/jun2011/pogue

It makes you wonder how relevant, exactly, the solo critic is anymore. I mean, if you read a movie review in the newspaper, well, you are taking your chances. Maybe the movie critic just broke up with someone or hated the movie's director back in film school or just doesn't share your taste. But when you're reading the summarized assessments of 11,000 people who have seen the same movie, it's much harder to go wrong. The kooks on either end cancel each other out, and the big middle ground gives you a pretty accurate assessment of the movie's real worth. (On IMDB—the Internet Movie Database—*High School Musical 3* earned 3.8 out of 10 stars from the 19,600 people who have voted. This reviewer feels that's absolutely right.)

But what about the fake-review scandals that surface with alarming regularity? Yelp, TripAdvisor, Amazon and other sites have all endured accusations that phony reviews are poisoning their posts. Big dollars are at stake. No wonder merchants, using fake names, sometimes post positive reviews for their own products or companies or trash their competitors. (Internet wags have dubbed this practice "astroturfing." Get it? Fake grass roots?)

There are some sneaky biases at work, too. Ever notice how many apps on the iTunes Store seem to score mostly either one- or five-star reviews? How could so many apps be so polarizing?

They're not—it's just that online reviewers are a self-selecting bunch. You're more likely to review something if you're fired up about it, one way or another; the vast, quietly contented multitudes generally don't bother.

(For a while, Apple tried to address this problem by prompting customers to rate an app at the moment they deleted it. App developers cried foul. "You're making our reviews skew negative," they said, "by asking this question at the moment people are *deleting* our apps! If they liked it, they wouldn't be deleting it!")

How do we maintain the power of online reviews while minimizing the abuses? For starters, we can encourage voters to use their real names, as Amazon does. Yelp and TripAdvisor say they have staffers and software dedicated to zapping bogus reviews. Yes, it's an arms race, but review sites know that their credibility is essential to their survival.

You can improve your fraud-detection skills, too. Sometimes you can just tell when a review seems overly enthusiastic. And often you can click reviewers' names to see what else they have written. If there aren't any other posts, that's a red flag.

Finally, quantity matters. If only a couple of reviews seem especially positive or negative, your spider sense should tingle. On the other hand, dozens or hundreds of reviews reduce the effects of self-interested postings.

Listen: the old-fashioned system of professional critics wasn't foolproof, either. You never knew what conflict-of-interest shenanigans were at play. At least in the Web 2.0 world, the crowd's voice generally drowns out the solo voices of the untrustworthy. You're left with a pile of opinions that contains more truth than falsehood. SA

Illustration by John Ueland

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

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 natural laws that they call laws of physics. But there is a natural law that virtually everybody on the planet 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 people's likes and dislikes, wants and don't wants, judgments and beliefs, thereby, over time, forming their own plans of life.

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

What kinds of results are presently occurring? The news media daily report on the tragedies of international warfare, uprisings and riots, economic disasters, and afflictions labeled "cause unknown."

At this point you might be wondering, who thinks that conforming to a natural law could stop all 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—occasionally 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 laws of nature, creating forces to safely guide their activities.

We suggest that those laws express the will of the creator commanding our obedience to creation's plan of life with rational and honest responses to whatever happens.

FREE On-Line eBooks

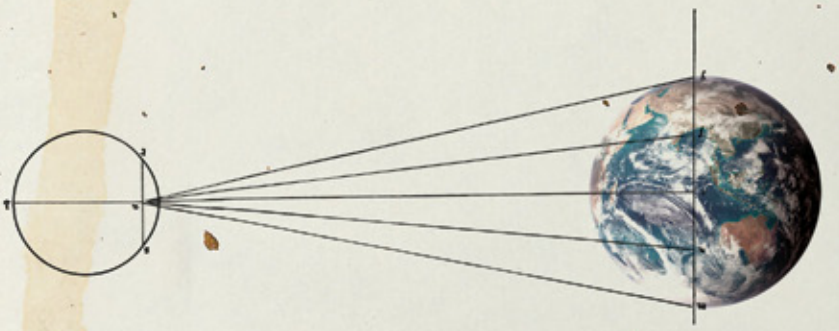
Read or download at www.alphapub.com

Several Natural-law essays and other books also describe the function of nature's law of absolute right. Read, download, and/or print the material FREE.

If you lack access to the Website, our books are also available in print at low cost. For an order form, write to The Alpha Publishing House, PO Box 255, Royersford, PA 19468.

This public-service message is from a self-financed, nonprofit group of former students of Mr. Wetherill.

Vlatko Vedral made his name developing a novel way of quantifying entanglement and applying it to macroscopic physical systems. He did his undergraduate and graduate studies at Imperial College London. Since June 2009 he has been in an entangled state of professorship at the University of Oxford and at the National University of Singapore. Besides physics, Vedral enjoys spending time with his three children and playing his Yamaha electric guitar with the Marshall amp turned up to 11.



PHYSICS

LIVING IN A QUANTUM WORLD

Quantum mechanics is not just about teeny particles. It applies to things of all sizes: birds, plants, maybe even people

By Vlatko Vedral

ACCORDING TO STANDARD PHYSICS TEXTBOOKS, QUANTUM MECHANICS IS THE THEORY OF THE MICROSCOPIC world. It describes particles, atoms and molecules but gives way to ordinary classical physics on the macroscopic scales of pears, people and planets. Somewhere between molecules and pears lies a boundary where the strangeness of quantum behavior ends and the familiarity of classical physics begins. The impression that quantum mechanics is limited to the microworld permeates the public understanding of science. For instance, Columbia University physicist Brian Greene writes on the first page of his hugely successful (and otherwise excellent) book *The Elegant Universe* that quantum mechanics "provides a theoretical framework for understanding the universe on the smallest of scales." Classical physics, which comprises any theory that is not quantum, including Albert Einstein's theories of relativity, handles the largest of scales.

Yet this convenient partitioning of the world is a myth. Few modern physicists think that classical phys-

IN BRIEF

Quantum mechanics is commonly said to be a theory of microscopic things: molecules, atoms, subatomic particles.
Nearly all physicists, though, think it applies to everything, no matter what the size.
The reason its distinctive features tend to be hidden is not a simple matter of scale.
Over the past several years experimentalists have seen quantum effects in a growing number of macroscopic systems.
The quintessential quantum effect, entanglement, can occur in large systems as well as warm ones—including living organisms—even though molecular jiggling might be expected to disrupt entanglement.

Illustration by Justin Van Genderen

ics has equal status with quantum mechanics; it is but a useful approximation of a world that is quantum at all scales. Although quantum effects may be harder to see in the macroworld, the reason has nothing to do with size per se but with the way that quantum systems interact with one another. Until the past decade, experimentalists had not confirmed that quantum behavior persists on a macroscopic scale. Today, however, they routinely do. These effects are more pervasive than anyone ever suspected. They may operate in the cells of our body.

Even those of us who make a career of studying these effects have yet to assimilate what they are telling us about the workings of nature. Quantum behavior eludes visualization and common sense. It forces us to rethink how we look at the universe and accept a new and unfamiliar picture of our world.

A TANGLED TALE

TO A QUANTUM PHYSICIST, classical physics is a black-and-white image of a Technicolor world. Our classical categories fail to capture that world in all its richness. In the old textbook view, the rich hues get washed out with increasing size. Individual particles are quantum; en masse they are classical. But the first clues that size is not the determining factor go back to one of the most famous thought experiments in physics, Schrödinger's cat.

Erwin Schrödinger came up with his morbid scenario in 1935 to illustrate how the microworld and macroworld couple to each other, preventing arbitrary lines from being drawn between them. Quantum mechanics says that a radioactive atom can be both decayed and not decayed at the same time. If the atom is linked to a bottle of cat poison, so that the cat dies if the atom decays, then the animal gets left in the same quantum limbo as the atom. The weirdness of the one infects the other. Size does not matter. The puzzle was why cat owners only ever see their pets as alive or dead.

In the modern point of view, the world looks classical because the complex interactions that an object has with its surroundings conspire to conceal quantum effects from our view. Information about a cat's state of health, for example, rapidly leaks into its environment in the form of photons and an exchange of heat. Distinctive quantum phenomena involve combinations of different classical states (such as both dead and alive), and these combinations tend to dissipate. The leakage of information is the essence of a process known as decoherence [see "100 Years of Quantum Mysteries," by Max Tegmark and John Archibald Wheeler; SCIENTIFIC AMERICAN, February 2001].

A QUANTUM PARADOX

Observing the Observer

The idea that quantum mechanics applies to everything in the universe, even to us humans, can lead to some strange conclusions. Consider this variant of the iconic Schrödinger cat thought experiment that Nobel laureate Eugene P. Wigner came up with in 1961 and David Deutsch of the University of Oxford elaborated on in 1986.

Suppose that a very able experimental physicist, Alice, puts her friend Bob inside a room with a cat, a radioactive atom and cat poison that gets released if the atom decays. The point of having a human there is that we can communicate with him. (Getting answers from cats is not that easy.) As far as Alice is concerned, the atom enters into a state of being both decayed and not decayed, so that the cat is both dead and alive. Bob, however, can directly observe the cat and sees it as one or the other. Alice slips a piece of paper under the door asking Bob whether the cat is in a definite state. He answers, "yes."

Note that Alice does *not* ask whether the cat is dead or alive because for her that would force the outcome or, as physicists say, "collapse" the state. She is content observing that her friend sees the cat either alive or dead and does not ask which it is.

Because Alice avoided collapsing the state, quantum theory holds that slipping the paper under the door was a reversible act. She can undo all the steps she took. If the cat was dead, it would now be alive, the poison would be in the bottle, the particle would not have decayed and Bob would have no memory of ever seeing a dead cat.

And yet one trace remains: the piece of paper. Alice can undo the observation in a way that does not also undo the writing on the paper. The paper remains as proof that Bob had observed the cat as definitely alive or dead.

That leads to a startling conclusion. Alice was able to reverse the observation because, as far as she was concerned, she avoided collapsing the state; to her, Bob was in just as indeterminate a state as the cat. But the friend inside the room thought the state did collapse. That person did see a definite outcome; the paper is proof of it. In this way, the experiment demonstrates two seemingly contradictory principles. Alice thinks that quantum mechanics applies to macroscopic objects: not just cats but also Bobs can be in quantum limbo. Bob thinks that cats are only either dead or alive.

Doing such an experiment with an entire human being would be daunting, but physicists can accomplish much the same with simpler systems. Anton Zeilinger and his colleagues at the University of Vienna take a photon and bounce it off a large mirror. If the photon is reflected, the mirror recoils, but if the photon is transmitted, the mirror stays still. The photon plays the role of the decaying atom; it can exist simultaneously in more than one state. The mirror, made up of billions of atoms, acts as the cat and as Bob. Whether it recoils or not is analogous to whether the cat lives or dies and is seen to live or die by Bob. The process can be reversed by reflecting the photon back at the mirror. On smaller scales, teams led by Rainer Blatt of the University of Innsbruck and by David J. Wineland of the National Institute of Standards and Technology in Boulder, Colo., have reversed the measurement of vibrating ions in an ion trap.

In developing this devious thought experiment, Wigner and Deutsch followed in the footsteps of Erwin Schrödinger, Albert Einstein and other theorists who argued that physicists have yet to grasp quantum mechanics in any deep way. For decades most physicists scarcely cared because the foundational issues had no effect on practical applications of the theory. But now that we can perform these experiments for real, the task of understanding quantum mechanics has become all the more urgent. —***V.V.***

Larger things tend to be more susceptible to decoherence than smaller ones, which justifies why physicists can usually get away with regarding quantum mechanics as a theory of the microworld. But in many cases, the information leakage can be slowed or stopped, and then the quantum world reveals itself to us in all its glory. The quintessential quantum effect is entanglement, a term that Schrödinger coined in the same 1935 paper that introduced his cat to the world. Entanglement binds together individual particles into an indivisible whole. A classical system is always divisible, at least in principle; whatever collective properties it has arise from components that themselves have certain properties. But an entangled system cannot be broken down in this way. Entanglement has strange consequences. Even when the entangled particles are far apart, they still behave as a single entity, leading to what Einstein famously called "spooky action at a distance."

Usually physicists talk about entanglement of pairs of elementary particles such as electrons. Such particles can be thought of, crudely, as small spinning tops that rotate either clockwise or counterclockwise, their axes pointing in any given direction: horizontally, vertically, at 45 degrees, and so on. To measure a particle's spin, you must choose a direction and then see whether the particle spins in that direction.

Suppose, for argument's sake, that electrons behaved classically. You might set up one electron to spin in the horizontal clockwise direction and the other in the horizontal counterclockwise direction; that way, their total spin is zero. Their axes remain fixed in space, and when you make a measurement, the outcome depends on whether the direction you choose aligns with the particle's axis. If you measure both of them horizontally, you see both of them spinning in opposite directions; if you measure them vertically, you detect no spin at all for either.

For quantum electrons, however, the situation is astonishingly different. You can set up the particles to have a total spin of zero even when you have not specified what their individual spins are. When you measure one of the particles, you will see it spinning clockwise or counterclockwise at random. It is as though the particle decides which way to spin for itself. Nevertheless, no matter which direction you choose to measure the electrons, providing it is the same for both, they will always spin in opposite ways, one clockwise and the other counterclockwise. How do they know to do so? That remains utterly mysterious. What is more, if you measure one particle horizontally and the other vertically, you will still detect some spin for each; it appears that the particles have no fixed axes of rotation. Therefore, the measurement outcomes match to an extent that classical physics cannot explain.

ACTING AS ONE

MOST DEMONSTRATIONS of entanglement involve at most a handful of particles. Larger batches are harder to isolate from their surroundings. The particles in them are likelier to become entangled with stray particles, obscuring their original interconnections. In accordance with the language of decoherence, too much information leaks out to the environment, causing the system to behave classically. The difficulty of preserving entanglement is a major challenge for those of us seeking to exploit these novel effects for practical use, such as quantum computers.

A neat experiment in 2003 proved that larger systems, too, can remain entangled when the leakage is reduced or somehow counteracted. Gabriel Aeppli of University College London and his colleagues took a piece of lithium fluoride salt and put it in an external magnetic field. You can think of the atoms in the salt as little spinning magnets that try to align themselves with the external field, a response known as magnetic susceptibility. Forces that the atoms exert on one another act as a kind of peer pressure to bring them into line more quickly. As the researchers varied the strength of the magnetic field, they measured how quickly the atoms became aligned. They found that the atoms responded much faster than the strength of their mutual interactions would suggest. Evidently some additional effect was helping the atoms to act in unison, and the researchers argued that entanglement was the culprit. If so, the 10^{20} atoms of the salt formed a hugely entangled state.

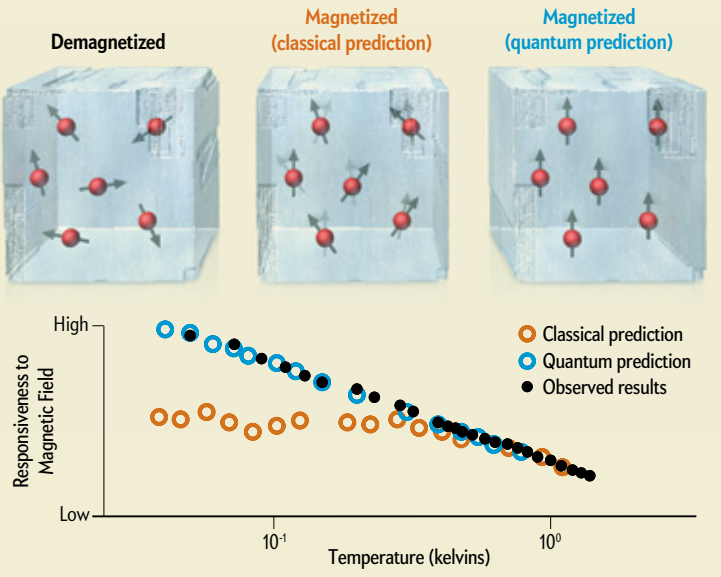
To avoid the confounding effects of the random motions asso-

MACROSCOPIC ENTANGLEMENT

Quantum Salt

Physicists used to think that distinctive quantum phenomena would operate only at the level of individual particles; great big clusters of particles would behave classically. Recent experiments show otherwise. For example, the atoms in a salt crystal typically point every which way (*below left*) and line up when physicists apply a magnetic field. They line up faster than they would if only classical physics operated (*below center*). Evidently the quantum phenomenon of entanglement—the "spooky action" that coordinates the properties of far-flung particles—is helping bring them into line (*below right*). The role of entanglement is revealed by a measure of the crystal's magnetic properties (*graph*).

How Salt Defies Classical Expectations



SOURCE FOR GRAPH: "ENTANGLED QUANTUM STATE OF MAGNETIC DIPOLES," BY S. GHOSH ET AL., IN *NATURE*, VOL. 425, SEPTEMBER 4, 2003

Illustration by George Retseck, Graphic by Jen Christiansen

ciated with heat energy, Aeppli's team did its experiments at extremely low temperatures—a few millikelvins. Since then, however, Alexandre Martins de Souza of the Brazilian Center for Physics Research in Rio de Janeiro and his colleagues have discovered macroscopic entanglement in materials such as copper carboxylate at room temperature and higher. In these systems, the interaction among particle spins is strong enough to resist thermal chaos. In other cases, an external force wards off thermal effects [see "Easy Go, Easy Come," by George Musser; News Scan, Scientific American, November 2009]. Physicists have seen entanglement in systems of increasing size and temperature, from ions trapped by electromagnetic fields to ultracold atoms in lattices to superconducting quantum bits [*see table below*].

These systems are analogous to Schrödinger's cat. Consider an atom or ion. Its electrons can exist close to the nucleus or farther away—or both at the same time. Such an electron acts like the radioactive atom that has either decayed or not decayed in Schrödinger's thought experiment. Independently of what the electron is doing, the entire atom can be moving, say, left or right. This motion plays the role of the dead or alive cat. Using lasers to manipulate the atom, physicists can couple the two properties. If the electron is close to the nucleus, we can make the atom move to the left, whereas if the electron is farther away, the atom moves to the right. So the state of the electron is entangled with the movement of the atom, in the same way that the radioactive decay is entangled with the state of the cat. The feline that is both alive and dead is mimicked by an atom that is moving both to the left and to the right.

Other experiments scale up this basic idea, so that huge numbers of atoms become entangled and enter states that classical physics would deem impossible. And if solids can be entangled even when they are large and warm, it takes only a small leap of imagination to ask whether the same might be true of a very special kind of large, warm system: life.

SCHRÖDINGER'S BIRDS

European robins are crafty little birds. Every year they migrate from Scandinavia to the warm plains of equatorial Africa and return in the spring, when the weather up north becomes more tolerable. The robins navigate this round-trip of some 13,000 kilometers with natural ease.

People have long wondered whether birds and other animals might have some built-in compass. In the 1970s the husband-wife team of Wolfgang and Roswitha Wiltschko of the University of Frankfurt in Germany caught robins that had been migrating to Africa and put them in artificial magnetic fields. Oddly, the robins, they found, were oblivious to a reversal of the magnetic field direction, indicating that they could not tell north from south. The birds did, however, respond to the inclination of the earth's magnetic field—that is, the angle that the field lines make with the surface. That is all they need to navigate. Interestingly, blindfolded robins did not respond to a magnetic field at all, indicating that they somehow sense the field with their eyes.

In 2000 Thorsten Ritz, a physicist then at the University of Southern Florida who has a passion for migratory birds, and his colleagues proposed that entanglement is the key. In their scenario, which builds on the previous work of Klaus Schulten of the University of Illinois, a bird's eye has a type of molecule in which two electrons form an entangled pair with zero total spin. Such a situation simply cannot be mimicked with classical

LEADING EXPERIMENTS

Entanglement Heats Up

Quantum effects are not limited to subatomic particles. They also show up in experiments on larger and warmer systems.

WHAT	WHEN	HOW WARM	WHO
Observed interference pattern for buckyballs, showing for the first time that molecules, like elementary particles, behave like waves	1999	900–1,000 kelvins	Markus Arndt, Anton Zeilinger et al. (University of Vienna)
Deduced entanglement of trillions of atoms (or more) from the magnetic susceptibility of metal carboxylates	2009	630 K	Alexandre Martins de Souza et al. (Brazilian Center for Physics Research)
Found that quantum effects enhance photosynthetic efficiency in two species of marine algae	2010	294 K	Elisabetta Collini et al. (University of Toronto, University of New South Wales and University of Padua)
Set a new world record for observing quantum effects in giant molecules, including an octopus-shaped one with 430 atoms	2011	240–280 K	Stefan Gerlich, Sandra Eibenberger et al. (University of Vienna)
Entangled three quantum bits in a superconducting circuit. The procedure can create quantum systems of any size	2010	0.1 K	Leonardo DiCarlo, Robert J. Schoelkopf et al. (Yale University and University of Waterloo)
Coaxed a tiny springboard about 40 microns long (just visible to the unaided eye) to vibrate at two different frequencies at once	2010	25 millikelvins	Aaron O'Connell, Max Hofheinz et al. (University of California, Santa Barbara)
Entangled strings of eight calcium ions held in an ion trap. Today the researchers can manage 14	2005	0.1 mK	Hartmut Häffner, Rainer Blatt et al. (University of Innsbruck)
Entangled the vibrational motion—rather than internal properties such as spin—of beryllium and magnesium ions	2009	0.1 mK	John D. Jost, David J. Wineland et al. (National Institute of Standards and Technology)

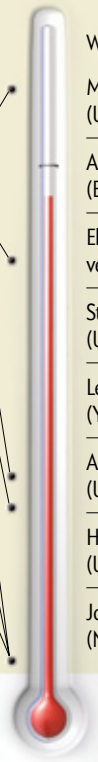


Illustration by George Retseck

physics. When this molecule absorbs visible light, the electrons get enough energy to separate and become susceptible to external influences, including the earth's magnetic field. If the magnetic field is inclined, it affects the two electrons differently, creating an imbalance that changes the chemical reaction that the molecule undergoes. Chemical pathways in the eye translate this difference into neurological impulses, ultimately creating an image of the magnetic field in the bird's brain.

Physicists thought the bustle of living cells would blot out quantum phenomena. Now they find that cells can nurture these phenomena—and exploit them.

Although the evidence for Ritz's mechanism is circumstantial, Christopher T. Rogers and Kiminori Maeda of the University of Oxford have studied molecules similar to Ritz's in the laboratory (as opposed to inside living animals) and shown that these molecules are indeed sensitive to magnetic fields because of electron entanglement. According to calculations that my colleagues and I have done, quantum effects persist in a bird's eye for around 100 microseconds—which, in this context, is a long time. The record for an artificially engineered electron-spin system is about 50 microseconds. We do not yet know how a natural system could preserve quantum effects for so long, but the answer could give us ideas for how to protect quantum computers from decoherence.

Another biological process where entanglement may operate is photosynthesis, the process whereby plants convert sunlight into chemical energy. Incident light ejects electrons inside plant cells, and these electrons all need to find their way to the same place: the chemical reaction center where they can deposit their energy and set off the reactions that fuel plant cells. Classical physics fails to explain the near-perfect efficiency with which they do so.

Experiments by several groups, such as Graham R. Fleming, Mohan Sarovar and their colleagues at the University of California, Berkeley, and Gregory D. Scholes of the University of Toronto, suggest that quantum mechanics accounts for the high efficiency of the process. In a quantum world, a particle does not just have to take one path at a time; it can take all of them simultaneously. The electromagnetic fields within plant cells can cause some of these paths to cancel one another and others to reinforce mutually, thereby reducing the chance the electron will take a wasteful detour and increasing the chance it will be steered straight to the reaction center.

The entanglement would last only a fraction of a second and would involve molecules that have no more than about 100,000 atoms. Do any instances of larger and more persistent entanglement exist in nature? We do not know, but the question is exciting enough to stimulate an emerging discipline: quantum biology.

THE MEANING OF IT ALL

TO SCHRÖDINGER, the prospect of cats that were both alive and dead was an absurdity; any theory that made such a prediction must surely be flawed. Generations of physicists shared this discomfort and thought that quantum mechanics would cease to apply at a still larger scale. In the 1980s Roger Penrose of Oxford suggested that gravity might cause quantum mechanics to give way to classical physics for objects more massive than 20 micrograms, and a trio of Italian physicists—GianCarlo Ghirardi and Tomaso Weber of the University of Trieste and Alberto Rimini of the University of Pavia—proposed that large numbers of particles spontaneously behave classically. But experiments now leave very little room for such processes to operate. The division between the quantum and classical worlds appears not to be fundamental. It is just a question of experimental ingenuity, and few physicists now think that classical physics will ever really make a comeback at any scale. If anything, the general belief is that if a deeper theory ever supersedes quantum physics, it will show the world to be even more counterintuitive than anything we have seen so far.

Thus, the fact that quantum mechanics applies on all scales forces us to confront the theory's deepest mysteries. We cannot simply write them off as mere details that matter only on the very smallest scales. For instance, space and time are two of the most fundamental classical concepts, but according to quantum mechanics they are secondary. The entanglements are primary. They interconnect quantum systems without reference to space and time. If there were a dividing line between the quantum and the classical worlds, we could use the space and time of the classical world to provide a framework for describing quantum processes. But without such a dividing line—and, indeed, without a truly classical world—we lose this framework. We must explain space and time as somehow emerging from fundamentally spaceless and timeless physics.

That insight, in turn, may help us reconcile quantum physics with that other great pillar of physics, Einstein's general theory of relativity, which describes the force of gravity in terms of the geometry of spacetime. General relativity assumes that objects have well-defined positions and never reside in more than one place at the same time—in direct contradiction with quantum physics. Many physicists, such as Stephen Hawking of the University of Cambridge, think that relativity theory must give way to a deeper theory in which space and time do not exist. Classical spacetime emerges out of quantum entanglements through the process of decoherence.

An even more interesting possibility is that gravity is not a force in its own right but the residual noise emerging from the quantum fuzziness of the other forces in the universe. This idea of "induced gravity" goes back to the nuclear physicist and Soviet dissident Andrei Sakharov in the 1960s. If true, it would not only demote gravity from the status of a fundamental force but also suggest that efforts to "quantize" gravity are misguided. Gravity may not even exist at the quantum level.

The implications of macroscopic objects such as us being in quantum limbo is mind-blowing enough that we physicists are still in an entangled state of confusion and wonderment. SA

MORE TO EXPLORE

Entangled Quantum State of Magnetic Dipoles. S. Ghosh et al. in *Nature,* Vol. 425, pages 48–51; September 4, 2003. Preprint available at arxiv.org/abs/cond-mat/0402456

Entanglement in Many-Body Systems. Luigi Amico, Rosario Fazio, Andreas Osterloh and Vlatko Vedral in *Reviews of Modern Physics,* Vol. 80, No. 2, pages 517–576; May 6, 2008. arxiv.org/abs/quant-ph/0703044

Decoding Reality: The Universe as Quantum Information. Vlatko Vedral. Oxford University Press, 2010.

SCIENTIFIC AMERICAN ONLINE

"I think I can safely say that nobody understands quantum mechanics," Richard Feynman once wrote. But have fun trying at **ScientificAmerican.com/jun2011/quantum**

NEUROSCIENCE

A Test for Consciousness

How will we know when we've built a sentient computer? By making it solve a simple puzzle

By Christof Koch and Giulio Tononi

COMPUTERS INCH EVER CLOSER TO BEHAVING LIKE INTELLIGENT HUMAN BEINGS—WITNESS the ability of IBM's Watson to beat the all-time champs of the television quiz show *Jeopardy*. So far, though, most people would doubt that computers truly "see" a visual scene full of shapes and colors in front of their cameras, that they truly "hear" a question through their microphones, that they feel anything—experience consciousness—the way humans do, despite computers' remarkable ability to crunch data at superhuman speed.

How would we know if a machine had taken on this seemingly ineffable quality of conscious awareness? Our strategy relies on the knowledge that only a conscious machine can demonstrate a subjective understanding of whether a scene depicted in some ordinary photograph is "right" or "wrong." This ability to assemble a set of facts into a picture of reality that makes eminent sense—or know, say, that an elephant should not be perched on top of the Eiffel Tower—defines an essential property of the conscious mind. A roomful of IBM supercomputers, in contrast, still cannot fathom what makes sense in a scene.

Understanding the attributes of a sentient machine will allow humans not only to understand the workings of our own brains but to prepare for that day, envisaged in science fiction, when we must learn to live with another form of conscious being that we ourselves created. This understanding may even allow us to address one of the most profound questions that has beset philosophers throughout the ages: What is consciousness?

IS IT MAN OR GOLEM?

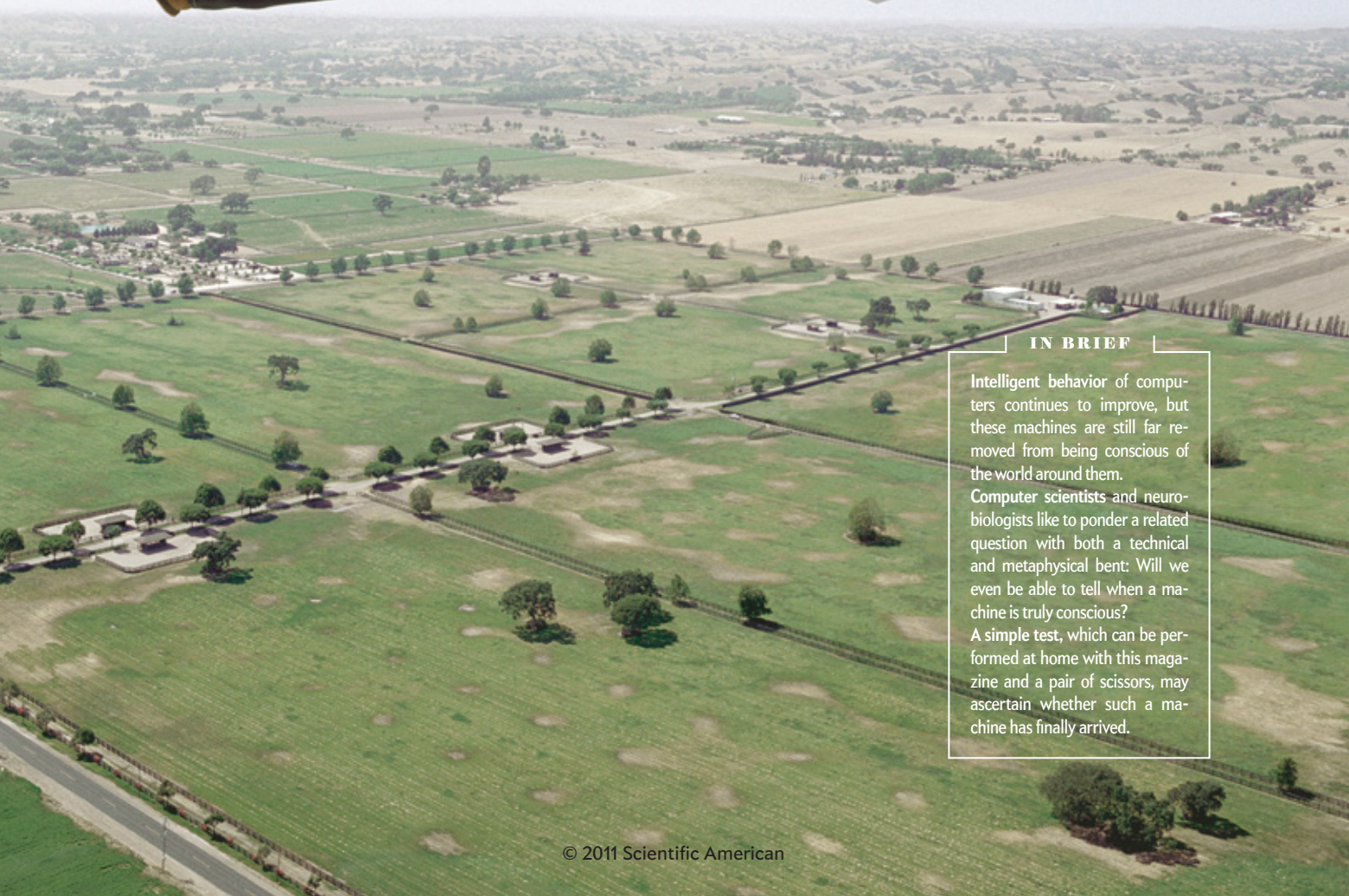
PHILOSOPHERS HAVE LONG PONDERED the question of whether a man-made simulacrum, be it the mythical golem or a machine in a box, can feel or experience anything. Then, in 1950, Alan Turing, the British mathematician who helped to break the Enigma code used by the feared Nazi submarine force in World War II, published a paper that launched the field of artificial intelligence. In an article in the journal *Mind,* Turing proposed replacing the impossi-

GEOF KERN

What's wrong with this picture? To judge that this image is incorrect, a machine would need to be conscious of many things about the world (unless programmed for just such a photograph).

Christof Koch is Lois and Victor Troendle Professor of Cognitive and Behavioral Biology at the California Institute of Technology and chief scientific officer at the Allen Institute for Brain Science in Seattle. He serves on *Scientific American Mind*'s board of advisers.

Giulio Tononi is David P. White Chair in Sleep Medicine and a Distinguished Professor in Consciousness Science at the University of Wisconsin–Madison.



IN BRIEF

Intelligent behavior of computers continues to improve, but these machines are still far removed from being conscious of the world around them.

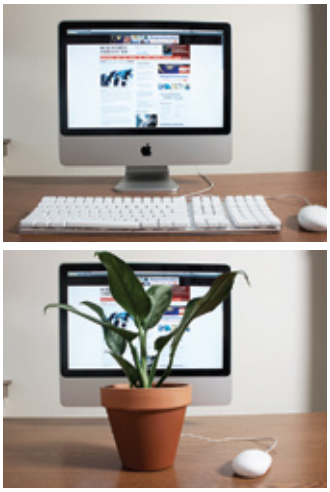
Computer scientists and neurobiologists like to ponder a related question with both a technical and metaphysical bent: Will we even be able to tell when a machine is truly conscious?

A simple test, which can be performed at home with this magazine and a pair of scissors, may ascertain whether such a machine has finally arrived.

bly vague question—Can machines think?—with a much more practical one—Can we build machines that, when queried via Teletype, cannot be distinguished from a human?

The version of the Turing test employed today has a human judge interacting via a computer screen with a human or a software program in the "natural language" that we use to communicate. The conversation between the judge and his or her partner can address any topic. If after some suitable interval, the judge cannot be sure whether the partner is human, at the very least it can be said to be as intelligent as a person, having passed the Turing test. Over the years chatterbots—conversational programs designed to simulate intelligent small talk—have, on occasion, deceived judges, but not for long.

The two of us come to the question of machine consciousness not as computer scientists but as neurobiologists interested in how brains give rise to subjective experience. We probe the brains of volunteers or patients with neurological disorders in magnetic scanners or record their brain waves with electroencephalography. We also carry out similar investigations of the brains of rodents and other animals. In doing so, we and many of our colleagues are homing in on the so-called neuronal correlates of consciousness: the minimal brain mechanisms that together suffice to cause any specific conscious sensation, such as observing a garish, orange sunset. Yet what the field has lacked until recently is a general theory that allows us to assess, in a principled way, whether a brain-injured patient, a fetus, a mouse or a silicon simulacrum can experience conscious sensations.



This not that: A test for consciousness could ask a nominally sentient machine which of two pictures are wrong, a task that would stump any present-day automaton.

What we call the integrated information theory of consciousness provides one way to tackle that challenge. It touches on a critical determinant of consciousness. Many people have an intuitive understanding that the subjective, phenomenal states that make up everyday experience—the way each of us experiences a smell, a visual scene, a thought or a recollection in a highly individual manner—must somehow relate to how the brain integrates incoming sensory signals with information from memory into a cohesive picture of the world. But how can this intuition be made more precise?

The integrated information theory addresses this need by putting forth two axioms. First, consciousness is highly informative. This is because each particular conscious state, when it occurs, rules out an immense number of other possible states, from which it differs in its own particular way. Think of all the frames from all the movies you have ever seen. Each frame, each view, is a specific conscious percept: when you perceive that frame, your brain rules out trillions of other possible images. Even after awakening in a dark room, seemingly the simplest visual experience, the percept of pitch-blackness implies that you do not see a well-lit living room, the intricate canopy of the jungle or any of countless other scenes that could present themselves to the mind.

Second, conscious information is integrated. When you become conscious of your friend's face, you cannot fail to notice that she is crying and wearing glasses. No matter how hard you try, you cannot separate the left half of your field of view from the right or switch to seeing things in black and white. Whatever scene enters consciousness remains whole and complete; it cannot be subdivided into independent and unrelated components that can be experienced on their own.

The unified nature of consciousness stems from a multitude of interactions among relevant parts of your brain. If areas of the brain become disconnected, as occurs in anesthesia or in deep sleep—consciousness wanes and perhaps disappears.

To be conscious, then, you need to be a single, integrated entity with a large repertoire of distinguishable states—the definition of information. A system's capacity for integrated information, and thus for consciousness, can be measured by asking how much information a system contains above and beyond that possessed by its individual parts. This quantity, called Φ, or phi (pronounced "fi"), can be calculated, in principle, for any system, whether it be a brain, a robot or a manually adjustable thermostat. Think of Φ as the irreducibility of a system to a mere collection of parts, measured in bits. For the level of Φ and consciousness to be high, a system must be made of parts that are specialized and well integrated—parts that do more together than they can alone.

If the elements of a system are largely independent, like the sensors in a digital camera or the bits in a computer's memory, Φ will be low. It will also be low if the elements all do the same thing because they are not specialized and are therefore redundant; Φ also stays low if the elements of a system interconnect at random. But for certain parts of the brain, such as the cerebral cortex—where neurons are richly endowed with specific connections—Φ will be high. This measure of a system's integration can also apply to silicon circuits encased in a metal box. With sufficiently complex connections among the transistors and memory elements, computers, as with the brain, would reach high levels of integrated information.

Other than measuring Φ from the machine's wiring—a difficult task—how can we know whether a machine is sentient? What is a practical test? One way to probe for information integration would be to ask it to perform a task that any six-year-old can ace: "What's wrong with this picture?" Solving that simple problem requires having lots of contextual knowledge, vastly more than can be supplied with the algorithms that advanced computers depend on to identify a face or detect credit-card fraud.

Pictures of objects or natural scenes consist of massively intricate relations among pixels and objects—hence the adage "a picture is worth a thousand words." The evolution of our visual system, our neurological development during childhood and a lifetime of experience enable us to instantly know whether all the components fit together properly: Do the textures, depths, colors, spatial relations among the parts, and so on, make sense?

A computer that analyzes an image—to see that the information in it does not cohere—requires far more processing than do linguistic queries of a computer database. Computers may have beaten humans at sophisticated games, but they still

ERIC WEEKS

lack the ability to answer arbitrary questions about what is going on in a photograph. The degree of information integration explains why. Although the hard disk in a modern computer exceeds the capacity of our lifetime of memories, that information remains unintegrated: each element of the system stays largely disconnected from the others.

SEE-THROUGH COWS

TAKE JUST ONE EXAMPLE, a photograph of your desk in your iPhoto library. Your computer does not know whether, amid the usual clutter on your desk, your iMac on the left and your iPad on the right make sense together. Worse, the computer does not know that while the iMac and the iPad go together well, a potted plant instead of the keyboard is simply weird; or that it is impossible for the iPad to float above the table; or that the right side of the photograph fits well with the left side, whereas the right side of a multitude of other photographs would be wrong. To your computer, all pixels are just a vast, disconnected tapestry of three numbers (corresponding to three colors), with no particular meaning. To you, an image is meaningful because it is chock-full of connections among its parts, at many levels, ranging from pixels to objects to scenes. And these relations not only specify which parts of the image go well together but which ones do not. According to our theory, this integrated web of related knowledge gives each image an identity by distinguishing it from myriad others and imbues you with the capacity to become conscious of the world.

The same integration would also tell even a six-year-old that many incongruous pictures are ridiculous: an ice-skater on a rug in the living room, a transparent cow or a cat chasing a dog. And therein lies the secret of determining whether a computer is conscious. These obvious violations of our expectations testify to the remarkable knowledge we have of the way in which certain events and objects occur together, but the vast majority do not.

Testing a computer's understanding of an image does not require the conventional Turing test protocol of typing in a query to a machine. Instead you can simply pick some images at random from the Web. Black out a strip running vertically down the central third of each one, then shuffle the remaining left and right sides of the pictures. The parts of the composites will not match, except in one case, in which the left side is evidently from the same picture as the right side. The computer would be challenged to select the one picture that is correct. The black strip in the middle prevents the use of simple image-analysis strategies that computers use today—say, matching lines of texture or color across the separated, partial images. The split-image test requires a high level of visual understanding and the ability to deduce how the pieces of the image fit together.

Another test inserts objects into several images so that these objects make sense in each except for one, and the computer must detect the odd one out. A hammer on a workbench belongs there, but a tool is never suspended in midair. And a keyboard placed in front of an iMac is the right choice, not a potted plant.

A variety of computer strategies that rely on matching low-level statistical data of image characteristics such as color, edges or texture might manage to defeat one of these tests, but presenting many different image tests would defeat today's machines. The specifics of the tests that would actually be of practical use require more work. This exercise, though, highlights the enormous amount of integrated knowledge that you perceive consciously and throws into sharp relief the very narrow and highly specialized knowledge possessed by current machine-vision systems. Yes, today's machines can pick out the face of a likely terrorist from a database of a million faces, but they will not know his age, gender or ethnicity, whether he is looking directly at the viewer or not, or whether he is frowning or smiling. And they will not know that if he is shaking hands with George Washington, the photograph is probably digitally doctored. Any conscious human can apprehend all these things and more in a single glance.

Knowing all this, what can we expect for the near future? To the extent that a particular task can be singled out and characterized in isolation from other tasks, it can be taken over by machines. Fast algorithms can rapidly search through huge databases and beat humans at chess and *Jeopardy*. Sophisticated machine-learning algorithms can be trained to recognize faces or detect pedestrians faster and better than we do by exposing the computer to a large number of relevant examples labeled by humans. We can easily envision scenarios in which increasingly specialized tasks will be relegated to machines. Advanced computer-vision systems are coming of age, and in less than a decade a robust and largely autonomous driving mode will become an option.

And yet we predict that such machine-vision systems will not answer a simple question about the scene in front of the car: Does the Chicago skyline, seen at a distance from the approaching highway, resemble a burned tree grove emerging from the mist? And it will not realize that a giant banana next to the gas station would be out of place (except perhaps in Los Angeles). Answering such questions—and million of others—or spotting what is wrong with the banana would require countless dedicated software modules that no one could build in anticipation of that particular question. If we are right, although advanced machine-vision systems based on a set of specialized, parallel modules will make driving largely automatic—and will similarly simplify many other daily tasks—these systems will not consciously see a scene ahead.

Yet a different kind of machine can be envisioned, too—one in which knowledge of the innumerable relations among the things in our world is embodied in a single, highly integrated system. In such a machine, the answer to the question "What's wrong with this picture?" would pop out because whatever is awry would fail to match some of the intrinsic constraints imposed by the way information is integrated within a given system.

Such a machine would be good at dealing with things not easily separable into independent tasks. Based on its ability to integrate information, it would consciously perceive a scene. And we suspect that to achieve high levels of integration, such a machine might well exploit the structural principles in the mammalian brain. These machines will easily pass the tests we have described, and when they do they will share with us the gift of consciousness—this most enigmatic feature of the universe. SA

MORE TO EXPLORE

Can Machines Be Conscious? Christof Koch and Giulio Tononi in *IEEE Spectrum*, Vol. 45, No. 6, pages 54–59; June 2008.

Consciousness as Integrated Information: A Provisional Manifesto. Giulio Tononi in *Biological Bulletin*, Vol. 215, No. 3, pages 216–242; December 2008.

SCIENTIFIC AMERICAN ONLINE

Join the magazine's Fool-the-Machine contest at
ScientificAmerican.com/jun2011/koch-contest

Adam Piore is a freelance writer in New York City and a former reporter for *Newsweek*. He also writes *Scientific American*'s Patent Watch column.

NUCLEAR ENERGY

PLANNING FOR THE BLACK SWAN

The surprising accident at Fukushima puts the spotlight on a new generation of U.S. nuclear reactors. Are they safe enough?

By Adam Piore

HALF A WORLD AWAY FROM JAPAN'S STRICKEN FUKUSHIMA Daiichi nuclear power plant, deep in the pine forests of Georgia, hundreds of workers are prepping the ground for an American nuclear renaissance they still believe is on the way. Bulldozers rumble across sunken plateaus of fresh, hard-packed backfill that covers miles of recently buried piping and storm drains. If plans stay on track, sometime next year two new nuclear reactors will begin to rise from the ground—the first reactors to be approved in the U.S. in more than 25 years.

That would be the starting gun for a renewed expansion of nuclear power in the U.S., which came to a virtual standstill after a partial meltdown at the Three Mile Island plant in 1979. Since then, the specter of climate change has turned nuclear power from an environmental menace to a potential source of carbon-free energy. Both Presidents George W. Bush and Barack Obama embraced the technology in the hope of triggering new construction. The U.S. Nuclear Regulatory Commission (NRC) is now reviewing proposals to build 20 more reactors in addition to the Georgia pair, adding to the 104 built decades ago.

More than half of these new reactors—including the two Vogtle units in Waynesboro, Ga.—would be AP1000s, the first of a new generation that incorporates "passive" safety features intended to avoid disasters like the one in Japan. In the event of an accident, the reactor relies on natural forces such as gravity and condensation to help keep its nuclear fuel from dangerously overheating—features the Fukushima plant lacked.

A few months ago it seemed a good bet that Georgia's two AP1000s would win the final stage of NRC approval for construction later this year. But the Fukushima calamity in March, in which a staggering 9.0 earthquake and massive tsunami left the hot cores of four reactors deprived of coolant, has once again put the prospect of nuclear catastrophe foremost in the public's

JIM R. BOUNDS Bloomberg via Getty Images (Shearon Harris nuclear plant in New Hill, N.C.)

IN BRIEF

Utilities have proposed 22 new U.S. reactors. The designs are under renewed scrutiny to determine whether they would survive extreme threats.

Safety features in the new designs kick in during accidents even when all electricity is lost and without the need for human intervention.

Questions about the lead contender, the Westinghouse AP1000, could complicate its final approval by the Nuclear Regulatory Commission.

Even if advanced designs can withstand huge earthquakes and tsunamis or a plane strike, utilities must still balance design costs against safety gains.

mind. Within weeks polls showed the number of Americans who supported new reactors had dropped from 49 to 41 percent compared with before the accident, reflecting a distrust of the technology regardless of assurances that risks are infinitesimal and reactor defenses are robust. The spectacle of Fukushima provided an object lesson in the limits of risk assessments.

Despite planning, nuclear power will always be vulnerable to black swan events—highly unlikely occurrences that have big repercussions. A rare event—especially one that has never occurred—is difficult to foresee, expensive to plan for and easy to discount with statistics. Just because something is only supposed to happen every 10,000 years does not mean it will not happen tomorrow. Over the typical 40-year life of a plant, assumptions can also change, as they did on September 11, 2001, in August 2005 when Hurricane Katrina struck, and in March after Fukushima.

The list of potential black swan threats is damningly diverse. Nuclear reactors and their spent-fuel pools are targets for terrorists piloting hijacked planes. Reactors may be situated downstream from dams that, should they ever burst, could unleash biblical floods. Some reactors are located close to earthquake faults or shorelines exposed to tsunamis or hurricane storm surges. Any one of these threats could produce the ultimate danger scenario like the ones that emerged at Three Mile Island and Fukushima—a catastrophic coolant failure, the overheating and melting of the radioactive fuel rods, and the deadly release of radioactive material. (Explosions ignited Chernobyl's core.)

Preparing for these scenarios is hard enough without having to stay within a budget. Utility companies have tried to reduce the enormous up-front expenses of building reactors. Even with streamlined licensing and construction, a nuclear plant now costs almost twice as much to build per megawatt as a coal plant and almost five times as much as a natural gas plant. The difference can be offset by lower operating costs—coal is almost four times more expensive than nuclear fuel, whereas gas costs 10 times as much—but those savings are realized only if nuclear plants can run at high capacity for many years. In the 1970s and 1980s plant shutdowns for maintenance and safety issues at times ruined the operational gains. For nuclear to compete, vendors have tried to slash construction costs and reduce shutdowns by making systems simpler and more reliable, without cutting safety margins.

Of course, it is impossible to build a reactor that is immune from any threat whatsoever, even if engineers encase it in colossal containment walls, bury it in a watertight vault and hire an army of psychics to predict the future. In designing the AP1000, engineers have no doubt tried to choose the best course through myriad constraints of physics, expense and disaster planning. What they have come up with is, by necessity, a product of compromises. In the wake of Fukushima, the question uppermost in people's minds is: Are nuclear reactors safe enough?

PASSIVE DEFENSE AGAINST CATASTROPHE

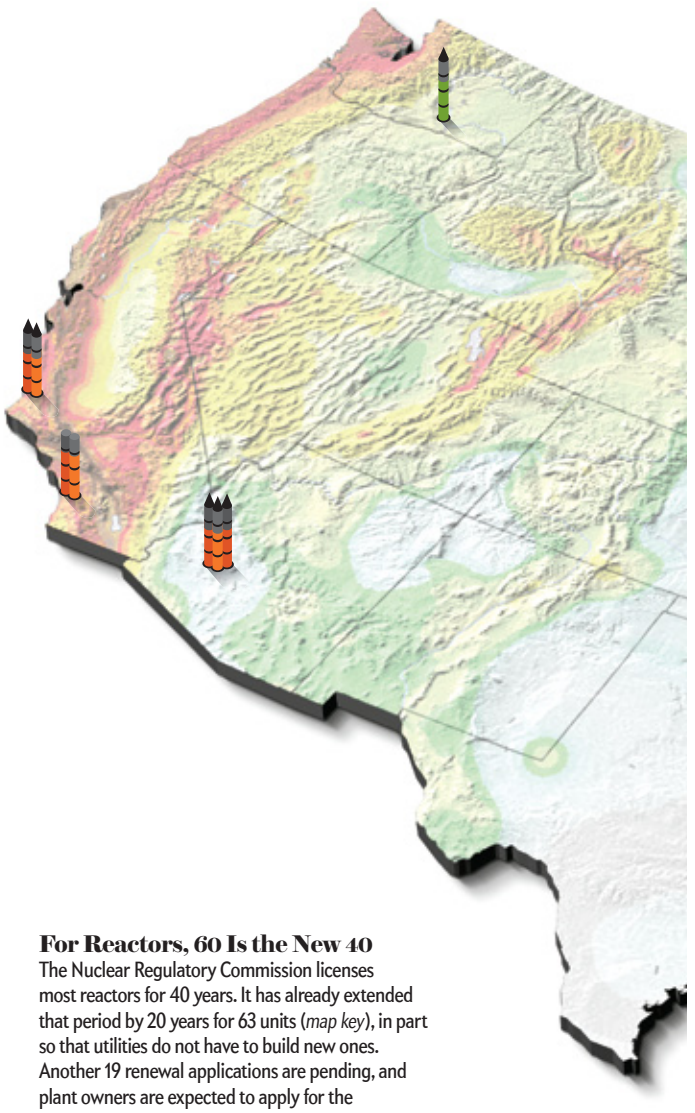
THE AP1000S and other "Gen III+" reactors under NRC review were designed with a different catastrophe in mind than the one in Japan. The 1979 partial-core meltdown at Three Mile Island near Harrisburg, Pa., was caused not by natural disaster but mainly by human error. Within months engineers were brainstorming reactor improvements, simplifying safety features and adding cooling backups that would kick in without human intervention. Gen III+ reactors such as the AP1000 are the result.

The water coolant inside the AP1000 circulates through a

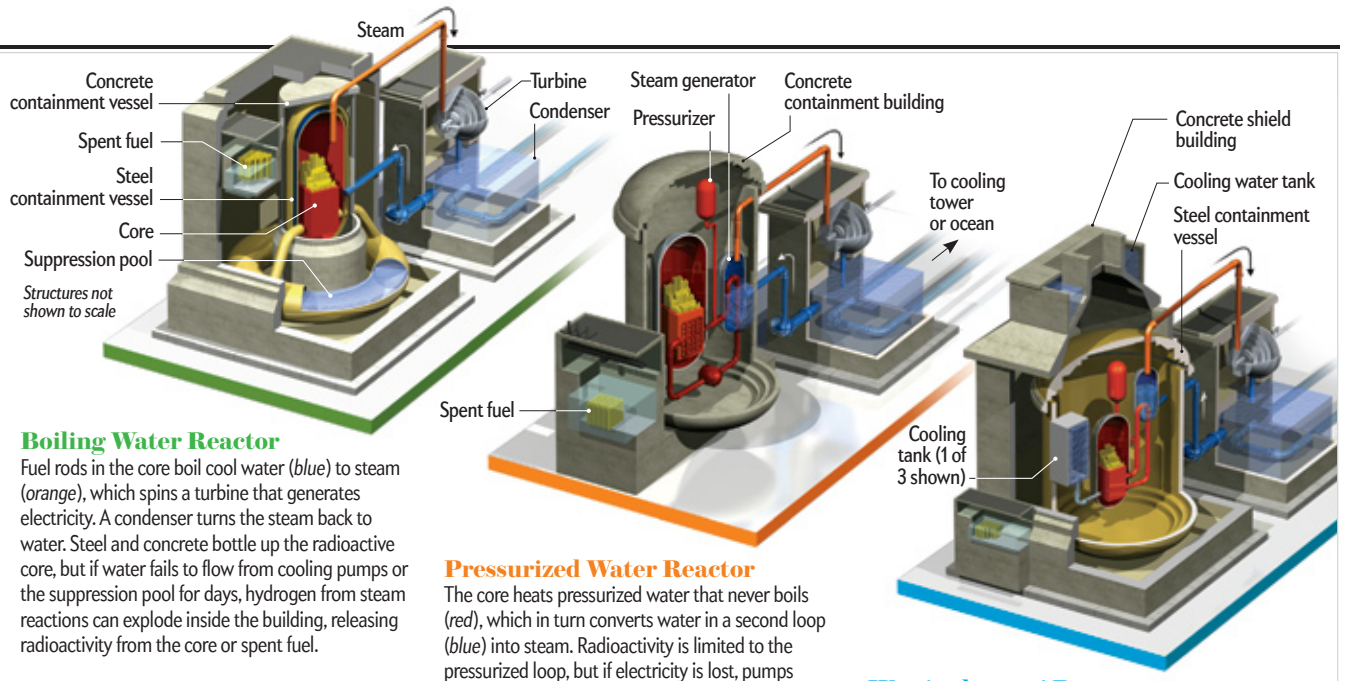
LAY OF THE LAND

Aging Fleet under Review

Nuclear power generates 20 percent of U.S. electricity supply. Most of the 104 reactors currently in use have been operating for 30 years or longer and, critics say, might not withstand a rare, but devastating, earthquake. The Nuclear Regulatory Commission will submit a safety review to the White House this month. Reactors that lie close to earthquake faults (*map*) are of concern. The reactors are either boiling water (*green*) or pressurized water (*orange*) designs; 23 have the same General Electric Mark I containment structures as Japan's crippled Fukushima Daiichi reactors. Utilities have proposed 22 new units with safer designs; more than half of them would be the AP1000 model (*blue*).



For Reactors, 60 Is the New 40
The Nuclear Regulatory Commission licenses most reactors for 40 years. It has already extended that period by 20 years for 63 units (*map key*), in part so that utilities do not have to build new ones. Another 19 renewal applications are pending, and plant owners are expected to apply for the remainder. Safety concerns or public opposition could derail these plans, however.



Boiling Water Reactor

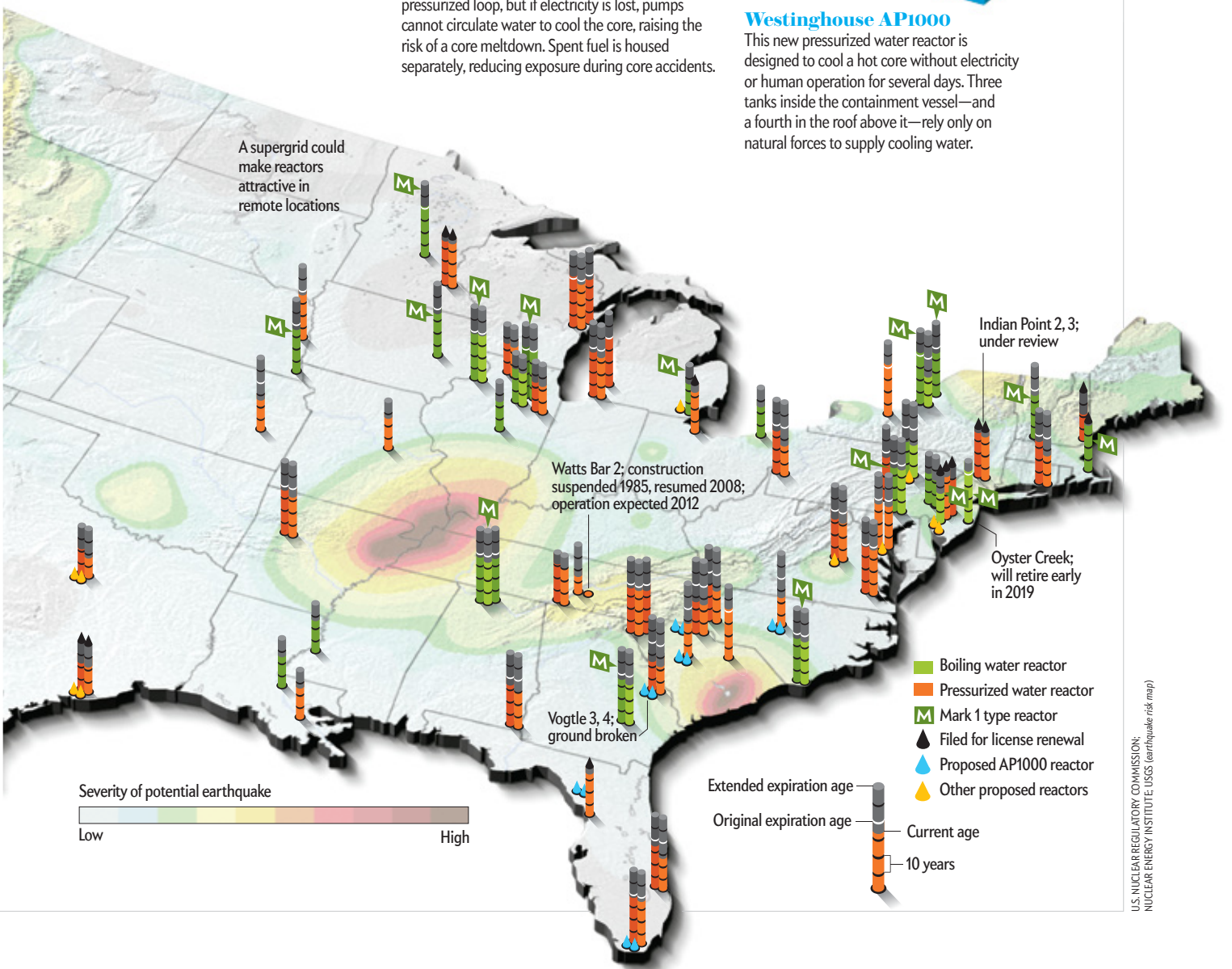
Fuel rods in the core boil cool water (*blue*) to steam (*orange*), which spins a turbine that generates electricity. A condenser turns the steam back to water. Steel and concrete bottle up the radioactive core, but if water fails to flow from cooling pumps or the suppression pool for days, hydrogen from steam reactions can explode inside the building, releasing radioactivity from the core or spent fuel.

Pressurized Water Reactor

The core heats pressurized water that never boils (*red*), which in turn converts water in a second loop (*blue*) into steam. Radioactivity is limited to the pressurized loop, but if electricity is lost, pumps cannot circulate water to cool the core, raising the risk of a core meltdown. Spent fuel is housed separately, reducing exposure during core accidents.

Westinghouse AP1000

This new pressurized water reactor is designed to cool a hot core without electricity or human operation for several days. Three tanks inside the containment vessel—and a fourth in the roof above it—rely only on natural forces to supply cooling water.



U.S. NUCLEAR REGULATORY COMMISSION; NUCLEAR ENERGY INSTITUTE; USGS (*earthquake risk map*)

Illustration by Don Foley (reactors and base map), Graphic by Jen Christiansen

Smoking gun: Explosions and radiation released at Japan's Fukushima Daiichi plant raised safety questions about old-style reactors operating in the U.S.

closed system of pipes. As the water passes over the reactor core, it absorbs heat but does not vaporize, because it is kept under high pressure. The pipes, in turn, are cooled by water from a secondary reservoir. If power is lost to the pumps, the reactor has a battery backup. If that fails, natural forces take over: water flows in from three emergency water tanks kept inside the reactor's domed, steel containment vessel, which looms over the core [*see diagram on preceding page*].

A blackout causes valves to open, and pressure and temperature differences between the core and tanks move cool tank water into the reactor vessel to cool the fuel rods. If needed, water from a huge, fourth tank in the ceiling of the outer concrete shield building can pour water directly onto the outside of the dome, carrying away heat by boiling off as steam. Inside the dome, steam that rises up from the reactor core strikes the cooled ceiling, condenses and falls back down to the core. This fourth tank holds 795,000 gallons of water, enough to last for three days, and can be refilled by hose, according to Howard Bruschi, Westinghouse's former chief technology officer. Vents in the building also draw in outside air, which cools the steel containment vessel.

The virtue of these backups—and what makes the AP1000 an improvement over older reactors—is that they require no electricity or human action. Proponents argue that the "station blackout" that hit Fukushima—a loss of electricity from the grid as well as on-site backup generators, which stopped all cooling pumps—would have been less of a problem had these systems been in place. Even if the backups worked for only a few days, that would give plant operators time to reestablish electrical power.

Whether the systems could prevent a core meltdown and a release of radiation to the atmosphere is a matter of debate. Proponents of the Gen III+ designs claim they are at least 10 times safer than the nation's 104 operating reactors. Other engineers are more conservative. Hussein S. Khalil, director of Argonne National Laboratory's Nuclear Engineering Division, would go no further than to state: "It's actually fair to say that the Gen III+ plants achieve through natural means a comparable degree of safety to upgrades that have been added to existing plants."

Industry critic Edwin Lyman, a senior staff scientist at the Union of Concerned Scientists, is not willing to concede even that. He has challenged specific cost-saving design choices made for both Westinghouse's AP1000 and General Electric's ESBWR (another new design). At the top of Lyman's concerns are the strength of the steel containment vessel and the concrete shield building around the AP1000. In Fukushima, as engineers injected water into the containment structure to cool the exposed rods, they kept a worried eye on the pressure from steam and potentially explosive hydrogen.

The AP1000 containment vessel, Lyman says, does not have sufficient safety margins. One yardstick he uses for the containment capacity of a reactor—and hence its ability to withstand a rise in pressure—is the ratio of a reactor's thermal power to its containment volume. For Westinghouse's AP600, a predecessor discontinued because it generated too little power to be attractive to utilities, that ratio stood at about 885 cubic feet per megawatt—roughly on par with most operating pressurized water reactors. But when Westinghouse enlarged the reactor to 1,100 megawatts for the AP1000, it did not expand the containment capacity proportionally; the ratio dropped to 605 cubic feet per megawatt, Lyman says. Containment vessels and buildings, he notes, "are expensive."

Westinghouse's Bruschi argues that the AP1000 is still well within the range required by NRC regulations. He added—and several independent nuclear engineers concurred—that the extra cooling provided by the passive systems most likely would reduce the pressure the containment would face during a severe accident. Lyman, though, worries about buildups of pressure that go beyond what many nuclear engineers anticipate.

Lyman is more comfortable with the design of the Areva EPR, a model developed in consultation with German and French utilities and European regulators and now under NRC review. Instead of passive backup systems, the Areva has four primary diesel generators and two secondary generators, all housed in separate, waterproof buildings located on opposite sides of the plant. That makes it extremely unlikely they would all fail at once, says Marty Parece, vice president of technology at Areva's Reactor and Services Business Group. Even if the generators did fail, the EPR has a thicker, double-walled containment building and a core catcher—a structure that would "catch" molten fuel, contain it and coat it with gravity-fed water. The catcher would prevent a melting, radioactive core from escaping through the floor.

SAFETY VS. COST

NUCLEAR DESIGNERS do not have the luxury of preventing any one type of catastrophe. They need to keep in mind many scenarios. The trouble is, different threats require different measures, and sometimes preparing for one detracts from another. Potentially the most damaging critique of the new AP1000 passive-safety reactors comes from John Ma, a senior structural engineer at the NRC. In 2009 the NRC made a safety change related to the events of September 11, ruling that all plants be designed to withstand a direct hit from a plane. To meet the new requirement, Westinghouse encased the building's concrete walls in steel plates.

REUTERS

Last year Ma, a member of the NRC since it was formed in 1974, filed the first "nonconcurrence" dissent of his career after the NRC granted the design approval. In it, Ma argues that some parts of the steel skin are so brittle that the "impact energy" from a plane strike or storm-driven projectile could shatter the wall. A team of engineering experts hired by Westinghouse disagreed, as did several engineers consulting for the NRC's Advisory Committee on Reactor Safeguards, which recommended the design be approved.

Other more radical designs, however, seem to offer greater safety margins. So-called pebble bed reactors, a Gen III+ design under development, rely on gas instead of water to carry heat away from the nuclear fuel and contain thousands of tiny grains of radioactive material embedded in spheres of graphite the size of tennis balls. The graphite slows the pace of fission, making the core less likely to overheat, and the cooling gas is less prone to cause an explosion than water that turns to steam. Several other so-called small modular reactors that generate less power but have a much lower cost than a large facility may also be worth considering because they generate less heat, making them easier to cool.

Most nuclear experts seem comfortable with the balance Westinghouse has struck between safety and cost and believe that its containment structure provides sufficient protection for most accidents. In the end, engineers have to decide how best to balance safety and cost.

A FAILURE OF IMAGINATION

FUKUSHIMA RAISES QUESTIONS that go beyond design preferences, however. One cause of the disaster was a failure of imagination, something that any regulator or designer is vulnerable to. The Fukushima plant was built to withstand a magnitude 8.2 earthquake, and the 9.0 quake was within its safety margin. But whereas the plant was built to survive tsunami waves of 18.7 feet, the waves that hit were 46 feet tall. Waves of that height are not without precedent: an earthquake and tsunami of comparable size struck the area in A.D. 869, says Thomas Brocher, director of the Earthquake Science Center at the U.S. Geological Survey in Menlo Park, Calif. When engineers make such "design-basis" errors—for a reactor, bridge or skyscraper—all bets are off.

Such a grave miscalculation seems less likely in the U.S. The NRC requires operators to demonstrate that their plants can withstand the largest flood, tsunami or earthquake possible based on all information that is known "plus an additional safety margin," says NRC spokesperson Brian Anderson. The standard is based on modeling that estimates the largest regional earthquake in the past 10,000 years. The additional margin of error generally works out to between 1.5 and two times that size, says Bozidar Stojadinovic, an earthquake engineering expert at the University of California, Berkeley, and an NRC consultant.

Still, engineers can prepare only for events they can foresee. Seismologists are always uncovering new earthquake risks. A few decades ago the possibility that an earthquake or tsunami would hit the Pacific Northwest was considered remote. Then scientists dated the demise of red cedar trees there to 1700, suggesting an earthquake had occurred that year, and uncovered records of a tsunami in Japan confirming it. Working backward, geologists determined that a magnitude 9.0 earthquake had hit an area that runs roughly from northern Vancouver Island to northern California. The realization forever changed the design basis for buildings constructed in the region. Two nuclear power plants had previously been built in the region—in Oregon and in northern California—but both had already been decommissioned.

Earthquakes are so infrequent on the East Coast of the U.S. that earthquake research has seemed far less urgent. Still, the Indian Point reactor north of New York City is within 50 miles of almost 6 percent of the U.S. population, a higher concentration than for any plant in the nation. Seismologists do not agree on which faults in the region are likely to cause a quake or how they might interact, says Boston College seismologist John E. Ebel. One 2008 study found that a number of small local faults believed to have been inactive could in fact contribute to a major quake.

Fukushima demonstrates the need for a "new paradigm," says Naj Meshkati, a professor of engineering at the University of Southern California and an expert on the effects of earthquakes on nuclear plants. "Our design basis has been based on improbable possibilities," he says. "But engineers are not so good at designing for a once-in-a-blue-moon event that hasn't happened." Such uncertainties make it impossible to know if a margin of error of twice the design basis is sufficient.

On the other hand, no man-made structure is 100 percent earthquake-proof, says Michael Corradini, a member of the NRC's advisory committee on reactor safeguards. "The question," he says, "is what are you willing to design for—and does society understand that and accept that factor of safety?"

How safe is safe enough? When it comes to nuclear power, a thoughtful answer must take into account the alternatives and the kind of risk you can live with. Coal produces half the nation's electricity and 80 percent of carbon dioxide emissions from its power plants, according to the U.S. Department of Energy; nuclear power produces 20 percent of its electricity and releases no carbon dioxide. Pollution from just two northeastern coal-fired plants was linked to tens of thousands of asthma attacks, hundreds of thousands of episodes of upper respiratory illnesses and 70 deaths annually, according to a 2000 study commissioned by the Clean Air Task Force. Natural gas burns cleaner, but evidence is mounting that some methods of extracting it pose environmental and human health risks of their own.

Uncertainty in the wake of the Japan accident could still derail plans for some new reactors, but the imperatives of global warming and our need for energy suggest the revival will continue. Secretary of Energy Stephen Chu endorsed the AP1000 in February 2010, after President Obama announced $8.3 billion in conditional loan guarantees. "The Vogtle project [in Georgia] will help America to recapture the lead in nuclear technology," Chu said. The track record of nuclear power also argues for the advocates. For all the anxiety of Three Mile Island, it did not amount to a single human casualty. Track records, of course, do not reflect events that have never happened but someday might. SA

MORE TO EXPLORE

Nuclear Power in a Warming World. Lisbeth Gronlund et al. Union of Concerned Scientists, December 2007. Available at www.ucsusa.org

The Future of Nuclear Power: An Interdisciplinary MIT Study. Massachusetts Institute of Technology, 2009. Available at http://web.mit.edu/nuclearpower

Nuclear Energy Institute: www.nei.org

U.S. Nuclear Regulatory Commission: www.nrc.gov

World Nuclear Association: www.world-nuclear.org

SCIENTIFIC AMERICAN ONLINE

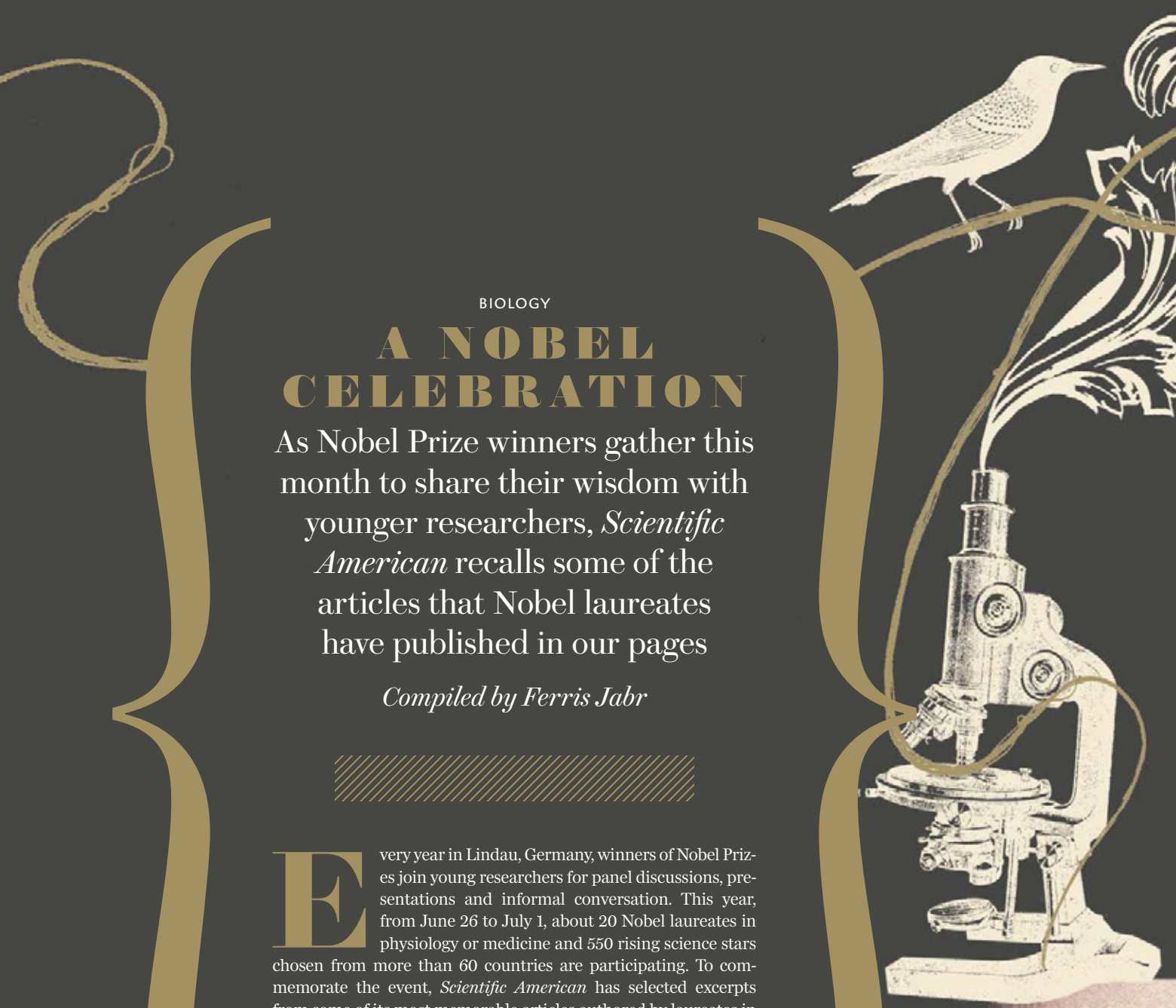
For an interactive map showing details of reactor sites, see ScientificAmerican.com/jun2011/piore

BIOLOGY

A NOBEL CELEBRATION

As Nobel Prize winners gather this month to share their wisdom with younger researchers, *Scientific American* recalls some of the articles that Nobel laureates have published in our pages

Compiled by Ferris Jabr



Every year in Lindau, Germany, winners of Nobel Prizes join young researchers for panel discussions, presentations and informal conversation. This year, from June 26 to July 1, about 20 Nobel laureates in physiology or medicine and 550 rising science stars chosen from more than 60 countries are participating. To commemorate the event, *Scientific American* has selected excerpts from some of its most memorable articles authored by laureates in the biological sciences. The passages trace overlapping arcs of scientific discovery and progress from the 1950s onward in cell biology, medicine, animal behavior and neuroscience. For ease of reading, we have not indicated deletions within the excerpts, many of which have been condensed significantly.

IN BRIEF

Nobel Prize winners in physiology or medicine are gathering in late June with hundreds of young scientists in Lindau, Germany.

To mark the event, *Scientific American* is publishing excerpts of biology-related articles that Nobelists have written for the magazine.

Stories focusing on cells address the origin and structure of key organic molecules and how complex cells came into being.

Other excerpts cover the roots of disease, why animals behave as they do, and how the brain operates and creates the mind.

Illustrations by Montse Bernal

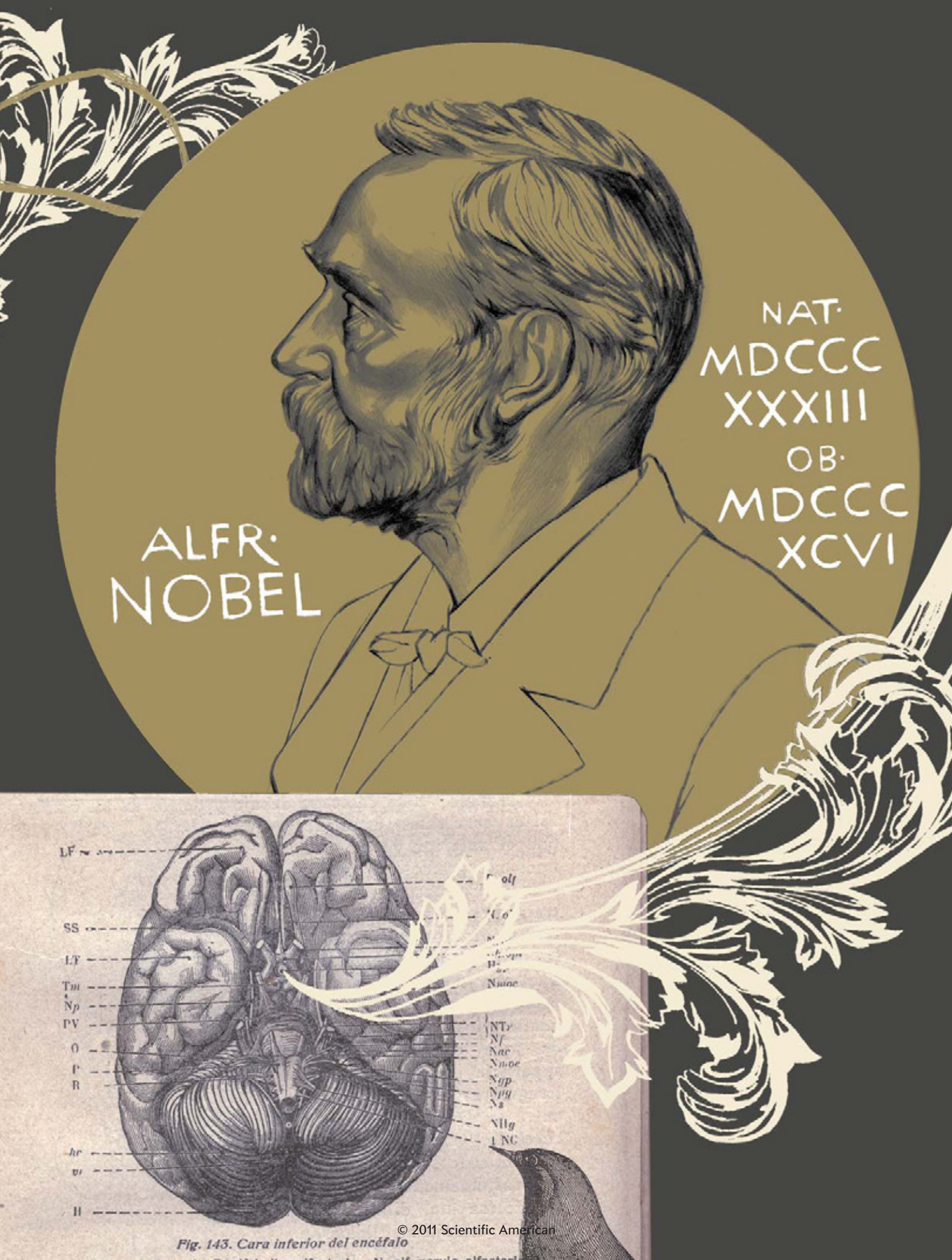


Fig. 143. Cara inferior del encéfalo

The Living Cell

The evolution and machinations of cells are endlessly fascinating—as is demonstrated in excerpts addressing how the molecules of life first formed, how DNA structure affects function and how complex cells came into being.

The Origin of Life

By George Wald (1967 Nobelist)

Published in August 1954

Organic molecules form a large and formidable array, endless in variety and of the most bewildering complexity. To understand how organisms originated we must first of all explain how such complicated molecules could come into being. To make an organism requires not only a tremendous variety of these substances, in adequate amounts and proper proportions, but also just the right arrangement of them. Structure here is as important as composition—and what a complication of structure! The most complex machine man has devised—say, an electronic brain—is child's play compared with the simplest of living organisms.

Recently Harold Urey, Nobel laureate in chemistry, has become interested in the degree to which electrical discharges in the upper atmosphere may promote the formation of organic compounds. One of his students, S. L. Miller, performed the simple experiment of circulating a mixture of water vapor, methane (CH_4), ammonia (NH_3) and hydrogen—all gases believed to have been present in the early atmosphere of the earth—continuously for a week over an electric spark. The circulation was maintained by boiling the water in one limb of the apparatus and condensing it in the other. At the end of the week the water was analyzed by the delicate method of paper chromatography. It was found to have acquired a mixture of amino acids! Glycine and alanine, the simplest amino acids and the most prevalent in proteins, were definitely identified in the solution, and there were indications it contained aspartic acid and two others. The yield was surprisingly high. The amazing result changes at a stroke our ideas of the probability of spontaneous formation of amino acids.

Recently several particularly striking examples have been reported of the spontaneous production of familiar types of biological structure by protein molecules. Cartilage and muscle offer some of the most intricate and regular patterns of structure to be found in organisms. A fiber from either tissue presents under the electron microscope a beautiful pattern of cross striations of various widths and densities, very regularly spaced. The proteins that form these structures can be coaxed into free solutions and stirred into a completely random orientation. Yet on precipitating, under proper conditions, the molecules realign with regard to one another to regenerate with extraordinary fidelity the original patterns of the tissues.

We have therefore a genuine basis for the view that the molecules of our oceanic broth will not only come together spontaneously to form aggregates but in doing so will spontaneously achieve various types and degrees of order.

BETTMANN/CORBIS (*Wald*)

The Structure of the Hereditary Material

By F.H.C. Crick (1962 Nobelist)

Published in October 1954

It is now known that DNA consists of a very long chain made up of alternate sugar and phosphate groups. The sugar is always desoxyribose. While the phosphate-sugar chain is perfectly regular, the molecule as a whole is not, because each sugar has a "base" attached to it. Four different types of base are commonly found: two of them are purines, called adenine and guanine, and two are pyrimidines, known as thymine and cytosine. So far as is known the order in which they follow one another along the chain is irregular, and probably varies from one piece of DNA to another. Although we know from the chemical formula of DNA that it is a chain, this does not in itself tell us the shape of the molecule, for the chain, having many single bonds around which it may rotate, might coil up in all sorts of shapes.

J. D. Watson and I, working in the Medical Research Council Unity in the Cavendish Laboratory at Cambridge, were convinced that we could get somewhere near the DNA structure by building scale models based on the x-ray patterns obtained by M.H.F Wilkins, Rosalind Franklin and their co-workers at King's College London. To get anywhere at all we had to make some assumptions. The most important one had to do with the fact that the crystallographic repeat did not coincide with the repetition of chemical units in the chain but came at much longer intervals. A possible explanation was that all the links in the chain were the same but the x-rays were seeing every tenth link, say, from the same angle and the others from different angles. What sort of chain might produce this pattern? The answer was easy: the chain might be coiled in a helix. The distance between crystallographic repeats would then correspond to the distance in the chain between one turn of the helix and the next.

This particular model contains a pair of DNA chains wound around a common axis. The two chains are linked together by their bases. A base on one chain is joined by very weak bonds to a base at the same level on the other chain, and all the bases are paired off in this way right along the structure. Paradoxically to make the structure as symmetrical as possible we had to have the two chains run in opposite directions; that is, the sequence of the atoms goes one way in one chain and the opposite way in the other.

Now we found that we could not arrange the bases any way we pleased; the four bases would fit into the structure only in certain pairs. In any pair there must always be one big one (purine) and one little one (pyrimidine). A pair of pyrimidines is too short to bridge the gap between the two chains, and a pair of purines is too big to fit into the space.

Adenine must always be pared with thymine and guanine with cytosine; it is impossible to fit the bases together in any other combination in our model. (This pairing is likely to be so fundamental for biology that I cannot help wondering whether some day an enthusiastic scientist will christen his newborn twins Adenine and Thymine!)

Now the exciting thing about a model of this type is that it immediately suggests how the DNA might produce an exact copy of itself. The model consists of two parts, each of which is the complement of the other. Thus, either chain may act as a sort of mold on which a complementary chain can be synthesized. The two chains of a DNA, let us say, unwind and separate. Each begins to build a new complement onto itself. When the process is completed, there are two pairs of chains where we had only one. Moreover, because of the specific pairing of the bases the sequence of the pairs of bases will have been duplicated exactly; in other words, the mold has not only assembled the building blocks but has put them together in just the right order.

GETTY IMAGES (*Crick*); COURTESY OF THE ROCKEFELLER UNIVERSITY (*de Duve*)

The Birth of Complex Cells

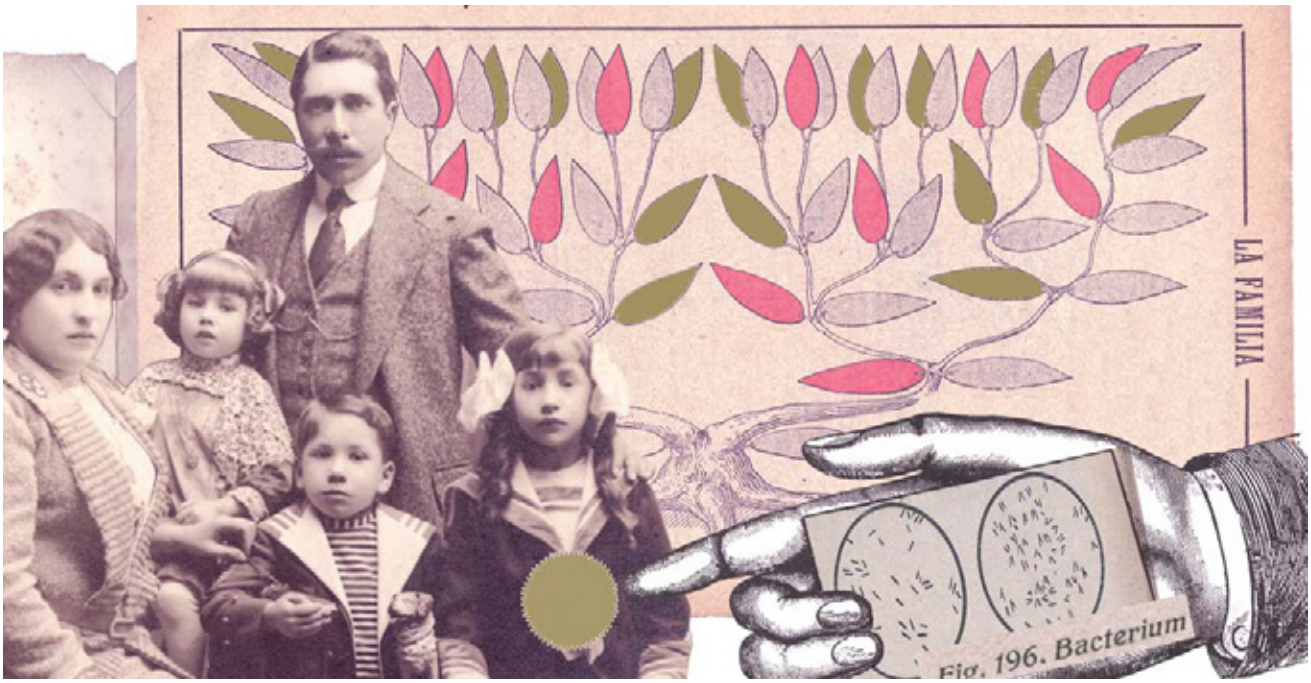
By Christian de Duve (1974 Nobelist)

Published in April 1996

About 3.7 billion years ago the first living organisms appeared on the earth. They were small, single-celled microbes not very different from some present-day bacteria. Prokaryotes turned out to be enormously successful. Thanks to their remarkable ability to evolve and adapt, they spawned a wide variety of species and invaded every habitat the world had to offer. The living mantle of our planet would still be made exclusively of prokaryotes but for an extraordinary development that gave rise to a very different kind of cell, called a eukaryote because it possesses a true nucleus. Today all multicellular organisms consist of eukaryotic cells. Eukaryotic cells most likely evolved from prokaryotic ancestors. But how?

Appreciation of this astonishing evolutionary journey requires a basic understanding of how the two fundamental cell types differ. Eukaryotic cells are much larger than prokaryotes (typically some 10,000 times in volume). In prokaryotes the entire genetic archive consists of a single chromosome made of a circular string of DNA that is in direct contact with the rest of the cell. In eukaryotes most DNA is contained in more highly structured chromosomes that are grouped within a well-defined central enclosure, the nucleus. Most eukaryotic cells further distinguish themselves from prokaryotes by having in their cytoplasm up to several thousand specialized structures, or organelles, about the size of a prokaryotic cell. The most important of such organelles are peroxisomes (which serve assorted metabolic functions), mitochondria (the power factories of cells) and, in algae and plant cells, plastids (the sites of photosynthesis).

Biologists have long suspected that mitochondria and plastids descend from bacteria that were adopted by some ancestral host cell as endosymbionts (a word derived from Greek roots that means "living together inside"). The most convincing evidence is the presence within these organelles of a vestigial—but still functional—genetic system. That system includes DNA-based genes, the means to replicate this DNA, and all the molecular tools needed to construct protein molecules from their DNA-encoded blueprints. Endosymbiont adoption is often presented as resulting from some kind of encounter—aggressive predation, peaceful invasion, mutually beneficial association or merger—between two typical prokaryotes. There is a more straightforward explanation—namely, that endosymbionts were originally taken up in the course of feeding by an unusually large host cell that had already acquired many properties now associated with eukaryotic cells. Many modern eukaryotic cells—white blood cells, for example—entrap prokaryotes. On a rare occasion, both captor and victim survive in a state of mutual tolerance that can turn into mutual assistance and, eventually, dependency. Mitochondria and plastids thus may have been a host cell's permanent guests.



Roots of Disease

Some Nobelists who have written for *Scientific American* have enlightened us about the microorganisms and molecules responsible for terrible illnesses.

Viruses

By F. M. Burnet (1960 Nobelist)

Published in May 1951

A virus can be defined as a microorganism, considerably smaller than most bacteria, which is capable of multiplication only within the living cells of a susceptible host. The practical control of a virus disease nearly always depends essentially on obtaining an understanding of the means by which the balance between the virus and the host is maintained in nature and how it can be modified in either direction by biological accident or by human design. In the approach to such an understanding two important related concepts have emerged—"subclinical infection" and "immunization."

A subclinical infection is one in which the infected person gives no sign of any ill effect. In a population attacked by an infectious disease, subclinical infections often greatly outnumber those severe enough to produce unmistakable symptoms of the disease. For example, when a child comes down with a paralyzing attack of poliomyelitis, a careful examination of the rest of the family will commonly reveal that all the other children have the virus in their intestines over a period of a week or two, but they either show no symptoms at all or have only a mild, nondescript illness. Fortunately even a subclinical infection produces heightened resistance or immunity to the virus for a period after the attack. This capacity of mild or subclinical infection to confer immunity is probably the greatest factor in maintaining a tolerable equilibrium between man and the common virus diseases. The trouble is that viruses are labile beings, liable to undergo mutation in various directions, and a virus that causes only mild infection may evolve into one far more deadly.

One cannot claim that there is full agreement about the nature of immunity to viruses, but it is possible to offer a simplified account which most virologists would accept. This interpretation is that all immunity to viruses is mediated through antibody. Antibodies can be described as modified blood-protein molecules capable of attaching themselves firmly to the specific virus or other invading organism that provoked their production by the body. If a sufficient number of antibody molecules can attach themselves to a virus particle, they have a blanketing effect which prevents the virus' attachment to the host cell and its multiplication within the cell. Antibody appears in the blood a few days after infection and reaches a peak in two to three weeks. The body continues to produce antibody at a slowly diminishing level long after recovery—in some diseases, such as measles and yellow fever, for the whole of life.

AP PHOTO (*Burnet*)

The Prion Diseases

By Stanley B. Prusiner (1997 Nobelist)

Published in January 1995

Fifteen years ago I evoked a good deal of skepticism when I proposed that the infectious agents causing certain degenerative disorders of the central nervous system in animals and, more rarely, in humans might consist of protein and nothing else. At the time, the notion was heretical. Dogma held that the conveyers of transmissible diseases required genetic material, composed of nucleic acid (DNA or RNA), to establish an infection in a host. Even viruses, among the simplest microbes, rely on such material to direct synthesis of the proteins needed for survival and replication. Later, many scientists were similarly dubious when my colleagues and I suggested that these "proteinaceous infectious particles"—or "prions," as I called the disease-causing agents—could underlie inherited, as well as communicable, diseases. Such dual behavior was then unknown to medical science. And we met resistance again when we concluded that prions (pronounced "PREE-eons") multiply in an incredible way; they convert normal protein molecules into dangerous ones simply by inducing the benign molecules to change their shape. Today, however, a wealth of experimental and clinical data has made a convincing case that we are correct on all three counts.

The known prion diseases, all fatal, are sometimes referred to as spongiform encephalopathies. They are so named because they frequently cause the brain to become riddled with holes. These ills, which can brew for years (or even for decades in humans), are widespread in animals. The most common form is scrapie, found in sheep and goats. Mad cow disease is the most worrisome. [The human prion diseases include among them Creutzfeldt-Jakob disease, a cause of dementia.]

In addition to showing that a protein can multiply and cause disease without help from nucleic acids, we have gained insight into how scrapie PrP ["prion protein"] propagates in cells. Many details remain to be worked out, but one aspect appears quite clear: the main difference between normal PrP and scrapie PrP is conformational. Evidently, the scrapie protein propagates itself by contacting normal PrP molecules and somehow causing them to unfold and flip from their usual conformation to the scrapie shape. This change initiates a cascade in which newly converted molecules change the shape of other normal PrP molecules, and so on.

The collected studies argue persuasively that the prion is an entirely new class of infectious pathogen and that prion diseases result from aberrations of protein conformation. Whether changes in protein shape are responsible for common neurodegenerative diseases, such as Alzheimer's, remains unknown, but it is a possibility that should not be ignored.

Telomeres, Telomerase and Cancer

By Carol W. Greider and Elizabeth H. Blackburn (2009 Nobelists)

Published in February 1996

During the past 15 years, investigations have led to identification of an extraordinary enzyme named telomerase that acts on telomeres [the tips of chromosomes] and is thought to be required for the maintenance of many human cancers. Cancers arise when a cell acquires multiple genetic mutations that together cause the cell to escape from normal controls on replication and migration. As the cell and its offspring multiply uncontrollably, they can invade and damage nearby tissue. Some parts may break away and travel to parts of the body where they do not belong, establishing new malignancies at distant sites.

The notion that telomerase might be important to the maintenance of human cancers was discussed as early as 1990. But the evidence did not become compelling until recently. Findings have led to an attractive but still hypothetical model for the normal and malignant activation of telomerase by the human body. According to this model, telomerase is made routinely by cells of the germ line in the developing embryo. Once the body is fully formed, however, telomerase is repressed in many somatic [nongerm] cells, and telomeres shorten as cells reproduce. When telomeres decline to a threshold level, a signal is emitted that prevents the cells from dividing further.

If, however, cancer-promoting genetic mutations block issuance of such safety signals or allow cells to ignore them, cells will continue to divide. They will also presumably continue to lose telomeric sequences and undergo chromosomal alterations that allow further, possibly carcinogenic mutations to arise. When telomeres are completely or almost completely lost, cells may reach a point at which they crash and die. But if the genetic derangements of the pre-crisis period lead to the manufacture of telomerase, cells will not fully lose their telomeres. The shortened telomeres will be rescued and maintained. In this way, the genetically disturbed cells will gain the immortality characteristic of cancer.

This scenario has generally been borne out by the evidence, although some advanced tumors lack telomerase, and some somatic cells—notably the white blood cells known as macrophages and lymphocytes—have recently been found to make the enzyme. Nevertheless, on balance, the collected evidence suggests that many tumor cells require telomerase in order to divide indefinitely.

The presence of telomerase in various human cancers and its absence in many normal cells mean the enzyme might serve as a good target for anticancer drugs. Agents able to hobble telomerase might kill tumor cells (by allowing telomeres to shrink and disappear) without disrupting the functioning of many normal cells. In contrast, most existing anticancer therapies disturb normal cells as well as malignant ones, and so are often quite toxic. Further, because telomerase occurs in numerous cancers, such agents might work against a broad array of tumors.

ULF SIRBORN *AP Photo (Prusiner)*; COURTESY OF JOHNS HOPKINS UNIVERSITY (*Greider*); ELISABETH FALL/FALLFOTO.COM (*Blackburn*)

The Animal's World

As some biologists developed the tools required to understand cellular behavior, others observed whole animals closely, making sense of their curious activities, including their mating rituals.

The Courtship of Animals

By N. Tinbergen (1973 Nobelist)

Published in November 1954

In contrast to such clearly motivated behavior as feeding or flight from predators, the courtship postures of animals are altogether puzzling, because it is difficult to see at first glance not only what circumstances cause them to occur but even what functions they serve. We may suppose that the male's display and activities stimulate the female to sexual cooperation, but even this elementary assumption has to be proved. And then we have to ask: Why does the female have to be stimulated in so elaborate a fashion, and what factors enter into the male's performance? Our work suggests that courtship serves not only to release sexual behavior in the partner but also to suppress contrary tendencies, that is, the tendencies to aggression or escape.

Let me give a brief sketch of what happens when gulls of the black-headed species form pairs at the beginning of the breeding season. An unmated male settles on

GODFREY ARGENT STUDIO (*Tinbergen*)

The Evolution of Behavior

By Konrad Z. Lorenz (1973 Nobelist)

Published in December 1958

Following the example of zoologists, who have long exploited the comparative method, students of animal behavior have now begun to ask a penetrating question. We all know how greatly the behavior of animals can vary, especially under the influence of the learning process. But is it not possible that beneath all the variations of individual behavior there lies an inner structure of inherited behavior which characterizes all the members of a given species, genus or larger taxonomic group—just as the skeleton of a primordial ancestor characterizes the form and structure of all mammals today?

Yes, it is possible! Let me give an example which, while seemingly trivial, has a bearing on this question. Anyone who has watched a dog scratch its jaw or a bird preen its head feathers can attest to the fact that they do so in the same way. The dog props itself on the tripod formed by its haunches and two forelegs and reaches a hindleg forward in front of its shoulder. Now the odd fact is that most birds (as well as virtually all mammals and reptiles) scratch with precisely the same motion! A bird also scratches with a hindlimb (that is, its claw), and in doing so it lowers its wing and reaches its claw forward in front of its shoulder.

One might think that it would be simpler for the bird to move its claw directly to its head without moving its wing, which lies folded out of the way on its back. I do not see how to explain this clumsy action unless we admit that it is inborn. Before the bird can scratch, it must reconstruct the old spatial relationship of the limbs of the four-legged common ancestor which it shares with mammals.

Comparative study of innate motor patterns represents an important part of the research program at the Max Planck Institute for Comparative Ethology. Our subjects are the various species of dabbling, or surface-feeding, ducks. By observing minute variations of behavior traits between species on the one hand and their hybrids on the other, we hope to arrive at a phylogenetics of behavior.

The first thing we wanted to know was how the courtship patterns of ducks become fixed. What happens when these ducks are crossbred? By deliberate breeding we have produced new combinations of motor patterns, often combining traits of both parents, sometimes suppressing the traits of one or the other parent and sometimes exhibiting traits not apparent in either. We have even reproduced some of the behavior-pattern combinations which occur in natural species other than the parents of the hybrid.

Thus, we have shown that the differences in innate motor patterns which distinguish species from one another can be duplicated by hybridization. This suggests that motor patterns are dependent on comparatively simple constellations of genetic factors.

Anyone who has watched a dog scratch its jaw or a bird preen its head feathers can attest that they do so in the same way.

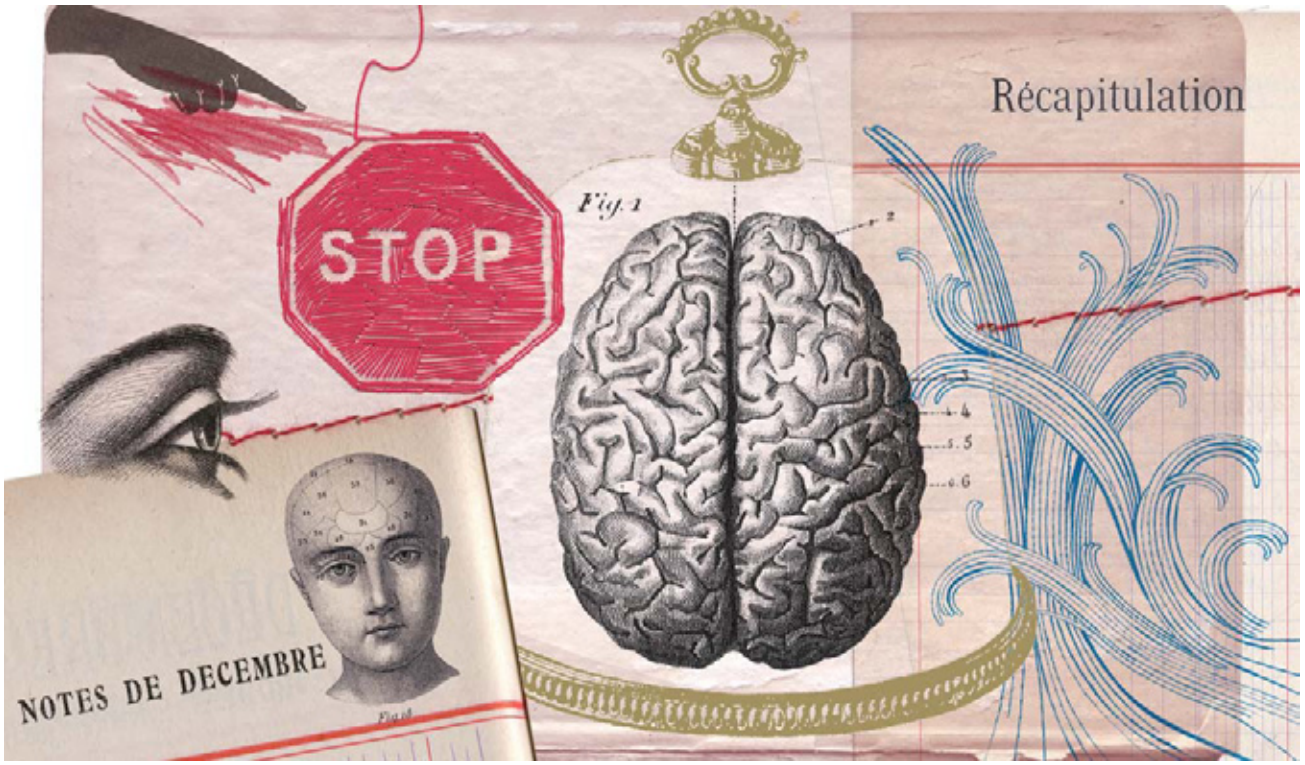
a mating territory. He reacts to any other gull that happens to come near by uttering a "long call" and adopting an oblique posture. This will scare away a male, but it attracts females, and sooner or later one alights near him. Once she has alighted, both he and she suddenly adopt the "forward posture." Sometimes they may perform a movement known as "choking." Finally, after one or a few seconds, the birds almost simultaneously adopt the "upright posture" and jerk their heads away from each other. Now most of these movements also take place in purely hostile clashes between neighboring males. They may utter the long call, adopt the forward posture and go through the choking and the upright posture.

The final gestures in the courtship sequence—the partners' turning of their heads away from each other, or "head-flagging"—is different from the others: it is not a threat posture. Sometimes during a fight between two birds we see the same head-flagging by a bird which is obviously losing the battle but for some reason cannot get away, either because it is cornered or because some other tendency makes it want to stay. This head-flagging has a peculiar effect on the attacker: as soon as the attacked bird turns its head away the attacker stops its assault or at least tones it down considerably. Head-flagging stops the attack because it is an "appeasement movement"—as if the victim were "turning the other cheek." We are therefore led to conclude that in their courtship these gulls begin by threatening each other and end by appeasing each other with a soothing gesture.

The black-headed gull is not an isolated case. We have learned that our courtship theory applies to many other birds (including various finches, tits, cormorants, gannets, ducks) and to animals of quite different groups, such as fish.

It is still an open question whether this gradual change in the motivational situation is mediated by endocrine changes, such as the growth of gonads. Future research will have to settle this. Our theory, as very briefly outlined here, is but a first step in the unraveling of the complicated causal relationships underlying the puzzling but fascinating phenomena of courtship.

AP PHOTO (*Lorenz*)

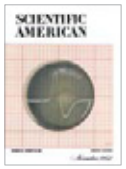


Inside Mind and Brain

The nervous system is dauntingly complex, but scientists over the years have hit on clever ways to figure out how it operates and how our wiring yields the mind.

The Nerve Impulse

By Bernhard Katz (1970 Nobelist)



Published in November 1952

Some of the foremost nerve physiologists have considered it worthwhile to study and analyze the properties of nerve fibers from the point of view of the cable engineer. The nerve fiber is in effect a chain of relay stations—a device with which the communications engineer is thoroughly familiar. Each point along the fiber receives an electric signal from the preceding point, boosts it to full strength and so enables it to travel a little farther. It is a peculiar combination of a cable (of very defective properties) with an automatic relay mechanism distributed all along the transmission line. Before the electric signal has had a chance to lose its strength, it stimulates the fiber, releases local energy resources and is renewed. The electric potential difference across one point of the fiber membrane serves to excite the region ahead, with the result that this region now contributes, at its own expense, a greatly amplified electric signal, capable of spreading to and exciting the next region. Experiments have fully confirmed this concept of how a nerve fiber transmits a signal.

When a current passes through the membrane, partially discharging the membrane surface and thus reducing the electric field, this makes the membrane more permeable to sodium. Positive sodium ions begin to flow inward and further reduce the negative charge on the inside. Thus, the electric field across the membrane is further reduced, the sodium permeability continues to rise, more sodium enters, and we have the elements of a self-reinforcing chain reaction. The flow of sodium into the fiber continues until the fiber interior has been charged up to such a high positive level that sodium ions are electrostatically repelled. This new equilibrium is precisely the reverse of the resting potassium potential. Now we can understand the basis of the all-or-none reaction of nerve cells: they generate no current until the "ignition point" is approached. Once this point is passed, the production of "sodium current" proceeds toward saturation and runs through a cycle of its own, no longer under the control of the original stimulus.

PHOTO RESEARCHERS, INC. (Katz)

Nerve Cells and Behavior

By Eric R. Kandel (2000 Nobelist)

Published in July 1970

Advances in the concepts and techniques for studying individual nerve cells and interconnected groups of cells have encouraged neural scientists to apply these methods to studying complete behavioral acts and modifications of behaviors produced by learning. This led to an interest in certain invertebrates, such as crayfish, leeches, various insects and snails, that have the great advantage that their nervous system is made up of relatively few nerve cells (perhaps 10,000 or 100,000 compared with the trillion or so in higher animals). In these animals one can begin to trace, at the level of individual cells, not only the sensory information coming into the nervous system and the motor actions coming out of it but also the total sequence of events that underlies a behavioral response.

One can begin to trace, at the level of cells, the events that underlie a behavioral response.

The most consistent progress has come from studies of habituation and dishabituation in the spinal cord of the cat and the abdominal ganglion of *Aplysia* [a giant marine snail that grows to about a foot in size].

Habituation is a decrease in a behavioral response that occurs when an initially novel stimulus is presented repeatedly. Once a response is habituated, two processes can lead to its restoration. One is spontaneous recovery, which occurs as a result of withholding the stimulus to which the animal has habituated. The other is dishabituation, which occurs as a result of changing the stimulus pattern, for example, by presenting a stronger stimulus to another pathway.

An *Aplysia* shows a defensive withdrawal response [to gentle stimulation]. The snail's gill, an external respiratory organ, is partially covered by the mantle shelf, which contains the thin residual shell. When either the mantle shelf or anal siphon, a fleshy continuation of the mantle shelf, is gently touched, the siphon contracts and the gill withdraws into the cavity under the mantle shelf.

We can now propose a simplified circuit diagram to illustrate the locus and mechanism of the various plastic changes that accompany habituation and dishabituation of the gill-withdrawal reflex. Repetitive stimulation of sensory receptors leads to habituation by producing a plastic change at the synapse between the sensory neuron and the motor neuron. Stimulation of the head leads to dishabituation by producing heterosynaptic facilitation at the same synapse.

It would seem that cellular approaches directed toward working out the wiring diagram of behavioral responses can now be applied to more complex learning processes.

The Problem of Consciousness

By Francis Crick (1962 Nobelist) and Christof Koch

Published in September 1992

Some psychologists feel that any satisfactory theory [of consciousness] should try to explain as many aspects as possible. We thought it wiser to begin with the particular aspect of consciousness that is likely to yield most easily. We selected the mammalian visual system. We have postulated that when we clearly see something, there must be neurons actively firing that stand for what we see.

How can we discover the neurons whose firing symbolizes a particular percept? William T. Newsome and his colleagues at Stanford University have done a series of brilliant experiments on neurons in cortical area MT of the macaque's brain. By studying a neuron in area MT, we may discover that it responds best to very specific visual features having to do with motion. A neuron, for instance, might fire strongly in response to the movement of a bar in a particular place in the visual field, but only when the bar is oriented at a certain angle, moving in one of the two directions perpendicular to its length within a certain range of speed. Such experiments do not, however, show decisively that the firing of such neurons is the exact neural correlate of the percept. The correlate could be only a subset of the neurons being activated or the firing of neurons in another part of the visual hierarchy that are strongly influenced by the neurons activated in area MT.

The key issue is how the brain forms its global representations from visual signals. If attention is crucial for visual awareness, the brain could form representations by attending to just one object at a time, rapidly moving from one to the next. For example, neurons representing all the different aspects of the attended object could all fire together very rapidly for a short period, possibly in rapid bursts. This fast, simultaneous firing might not only excite neurons that symbolized the implications of that object but also temporarily strengthen the relevant synapses so that this particular [firing pattern] could be quickly recalled—a form of short-term memory.

MORE TO EXPLORE

Nobel Laureate Meetings at Lindau: www.lindau-nobel.org

SCIENTIFIC AMERICAN ONLINE

More excerpts and online coverage, including videos, of the Lindau meeting at ScientificAmerican.com/jun2011/lindau

Ferris Jabr is a science writer based in Massachusetts.

JET BUDELMAN *Redux Pictures (Kandel)*; GETTY IMAGES (*Crick*)

TECHNOLOGY

INSIDE THE MEAT LAB

A handful of scientists aim to satisfy the world's growing appetite for steak without wrecking the planet. The first step: grab a petri dish

By Jeffrey Bartholet

IN BRIEF

Meat grown in a laboratory could provide high-protein food sources free of the environmental and ethical concerns that accompany large-scale livestock operations. **Yet progress** has been slow, in no small part due to the difficulty scientists have securing funding for their research. **One promising strategy** involves growing embryonic stem cells from livestock in a culture, then coaxing them to transform into muscle cells. **Even if research is successful,** some people question whether the public would ever develop a taste for meat engineered in the lab.

Photograph by Kevin Van Aelst

Jeffrey Bartholet is a veteran foreign correspondent and former Washington bureau chief for *Newsweek* magazine.

IT IS NOT UNUSUAL FOR VISIONARIES TO BE IMPASSIONED, IF NOT FANATICAL, and Willem van Eelen is no exception. At 87, van Eelen can look back on an extraordinary life. He was born in Indonesia when it was under Dutch control, the son of a doctor who ran a leper colony. As a teenager, he fought the Japanese in World War II and spent several years in prisoner-of-war camps. The Japanese guards used prisoners as slave labor and starved them. "If one of the stray dogs was stupid enough to go over the wire, the prisoners would jump on it, tear it apart and eat it raw," van Eelen recalls. "If you looked at my stomach then, you saw my spine. I was already dead." The experience triggered a lifelong obsession with food, nutrition and the science of survival.

One obsession led to another. After the Allies liberated Indonesia, van Eelen studied medicine at the University of Amsterdam. A professor showed the students how he had been able to get a piece of muscle tissue to grow in the laboratory. This demonstration inspired van Eelen to consider the possibility of growing edible meat without having to raise or slaughter animals. Imagine, he thought, protein-rich food that could be grown like crops, no matter what the climate or other environmental conditions, without killing any living creatures.

If anything, the idea is more potent now. The world population was just more than two billion in 1940, and global warming was not a concern. Today the planet is home to three times as many people. According to a 2006 report by the Food and Agriculture Organization, the livestock business accounts for about 18 percent of all anthropogenic greenhouse gas emissions—an even larger contribution than the global transportation sector. The organization expects worldwide meat consumption to nearly double between 2002 and 2050.

Under normal conditions, 10 cells could grow into 50,000 metric tons of meat in just two months. One such cell line would be sufficient to feed the world.

Meat grown in bioreactors—instead of raised on farms—could help alleviate planetary stress. Hanna Tuomisto, a Ph.D. candidate at the University of Oxford, co-authored a study last year on the potential environmental impacts of cultured meat. The study found that such production, if scientists grew the muscle cells in a culture of cyanobacteria hydrolysate (a bacterium cultivated in ponds), would involve "approximately 35 to 60 percent lower energy use, 80 to 95 percent lower greenhouse gas emissions and 98 percent lower land use compared to conventionally produced meat products in Europe."

As it is, 30 percent of the earth's ice-free land is used for grazing livestock and growing animal feed. If cultured meat were to become viable and widely consumed, much of that land could be used for other purposes, including new forests that would pull carbon out of the air. Meat would no longer have to be shipped around the globe, because production sites could be located close to consumers. Some proponents imagine small urban meat labs selling their products at street markets that cater to locavores.

THE ONLY CHOICE LEFT

EVEN WINSTON CHURCHILL thought in vitro meat was a good idea. "Fifty years hence, we shall escape the absurdity of growing a whole chicken in order to eat the breast or wing by growing these parts separately under suitable medium," he predicted in a 1932 book, *Thoughts and Adventures*. For most of the 20th century, however, few took the idea seriously. Van Eelen did not let it go. He worked all kinds of jobs—selling newspapers, driving a taxi, making dollhouses. He established an organization to help underprivileged kids and owned art galleries and cafes. He wrote proposals for in vitro meat production and eventually plowed much of his earnings into applying for patents. Together with two partners, he won a Dutch patent in 1999, then other European patents and, eventually, two U.S. patents. In 2005 he and others finally convinced the Dutch Ministry of Economic Affairs to pledge €2 million to support in vitro meat research in the Netherlands—the largest government grant for such research to date.

By that time, an American scientist had already succeeded in growing a piece of fish filet in a lab. Using a small grant from NASA, which was interested in developing food sources for deep-space voyages, Morris Benjaminson removed skeletal muscle from a common goldfish and grew it outside the fish's body. Then an associate briefly marinated the explants in olive oil, chopped garlic, lemon and pepper, covered them in bread crumbs and deep-fried them. "A panel of female colleagues gave it a visual and sniff test," says Benjaminson, now an emeritus professor at Touro College in Bay Shore, N.Y. "It looked and smelled pretty much the same as any fish you could buy at the supermarket." But NASA, apparently convinced there were easier ways to pro-

vide protein to astronauts on long deep-space voyages, declined to further fund Benjaminson's research.

The Dutch money was used by van Eelen and H. P. Haagsman, a scientist at Utrecht University, to fund a consortium that would aim to show that stem cells could be taken from farm animals, cultured and induced to become skeletal muscle cells. The team included a representative from meat company Meester Stegeman BV, then part of Sara Lee Corporation in Europe, and top scientists at three Dutch universities. Each university studied different aspects of in vitro meat production. Scientists at the University of Amsterdam focused on producing efficient growth media; a group at Utrecht worked on isolating stem cells, making them proliferate and coaxing them into muscle cells; and those at Eindhoven University of Technology attempted to "train" the muscle cells to grow larger.

The scientists made some progress. They were able to grow small, thin strips of muscle tissue in the lab—stuff that looked like bits of scallop and had the chewy texture of calamari—but several obstacles remained to commercial-scale production. "We gained knowledge; we knew a lot more, but we still didn't have [something that tasted like] a T-bone steak that came from a petri dish," says Peter Verstrate, who represented Meester Stegeman in the consortium and now works as a consultant. In time, the Dutch money ran out.

Van Eelen now fumes that one scientist involved was "stupid" and others just milked him and the Dutch government for money. "I don't know what they did in four years—talking, talking, talking—every year taking more of the money," he says. For their part, the scientists say that van Eelen never understood the scale of the challenge. "He had a naive idea that you could put muscle cells in a petri dish and they would just grow, and if you put money into a project, you'd have meat in a couple of years," says Bernard Roelen, a cell biologist who worked on the project at Utrecht.

Van Eelen was not the only one who imagined a revolution. In 2005 an article in the *New York Times* concluded that "in a few years' time there may be a lab-grown meat ready to market as sausages or patties." A couple of months before the story appeared, researchers had published the first peer-reviewed article on cultured meat in the journal *Tissue Engineering*. The authors included Jason G. Matheny, co-founder of the lab-produced meat advocacy group New Harvest. He understands the challenges better than most. "Tissue engineering is really hard and extremely expensive right now," he says. "To enjoy market adoption, we mainly need to solve the technical problems that increase the cost of engineered meat." That will take money, he notes, and few governments or organizations have been willing to commit necessary funding.

To the scientists involved, that failure seems shortsighted. "I think [in vitro meat] will be the only choice left," says Mark J. Post, head of the physiology department at Maastricht University. "I'm very bold about this. I don't see any way you could still rely on old-fashioned livestock in the coming decades."

ASSEMBLY REQUIRED

IN THEORY, an in vitro meat factory would work something like this: First, technicians would isolate embryonic or adult stem cells from a pig, cow, chicken or other animal. Then they would grow those cells in bioreactors, using a culture derived from plants. The stem cells would divide and redivide for months on end. Technicians would next instruct the cells to differentiate into muscle (rather than, say, bone or brain cells). Finally, the muscle cells would need to be "bulked up" in a fashion similar to the way in which animals build their strength by exercising.

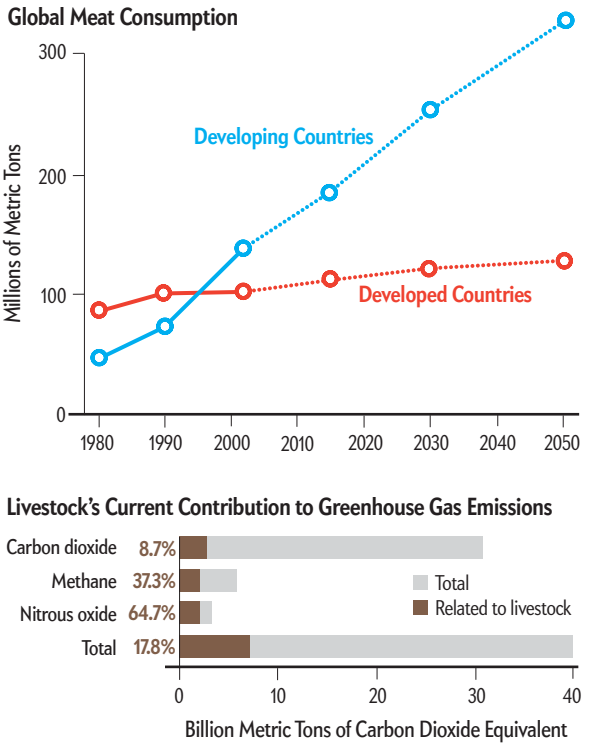
For now there are challenges at every stage of this process. One difficulty is developing stem cell lines that can proliferate for long periods without suddenly deciding they want to differentiate on their own. Another challenge is to be sure that when stem cells are prompted to differentiate, the overwhelming majority of them turn into muscle as instructed. "If 10 cells differentiate, you want at least seven or eight to turn into muscle cells, not three or four," Roelen says. "We can achieve 50 percent now."

The Utrecht scientists tried to extract and develop embryonic stem cell lines from pigs. Such cells would, in normal conditions, be able to duplicate every day for long periods, meaning 10 cells could grow into a staggering amount of potential meat in just two months—more than 50,000 metric tons. "Culturing embryonic stem cells would be ideal for this purpose since these cells have an (almost) infinite self-renewal capacity," according to a 2009 report by the Utrecht team. "In theory, one such cell line would be sufficient to literally feed the world."

GLOBAL TRENDS

Meaty Problems

The rich world already eats a lot of meat; the developing world is catching up. One reason is that as more people move to cities, improved infrastructure means that meat can be kept cold throughout its journey from the slaughterhouse to the kitchen. Yet as demand for meat increases, so will the environmental consequences. Livestock farming already accounts for 17.8 percent of all anthropogenic greenhouse gas emissions.

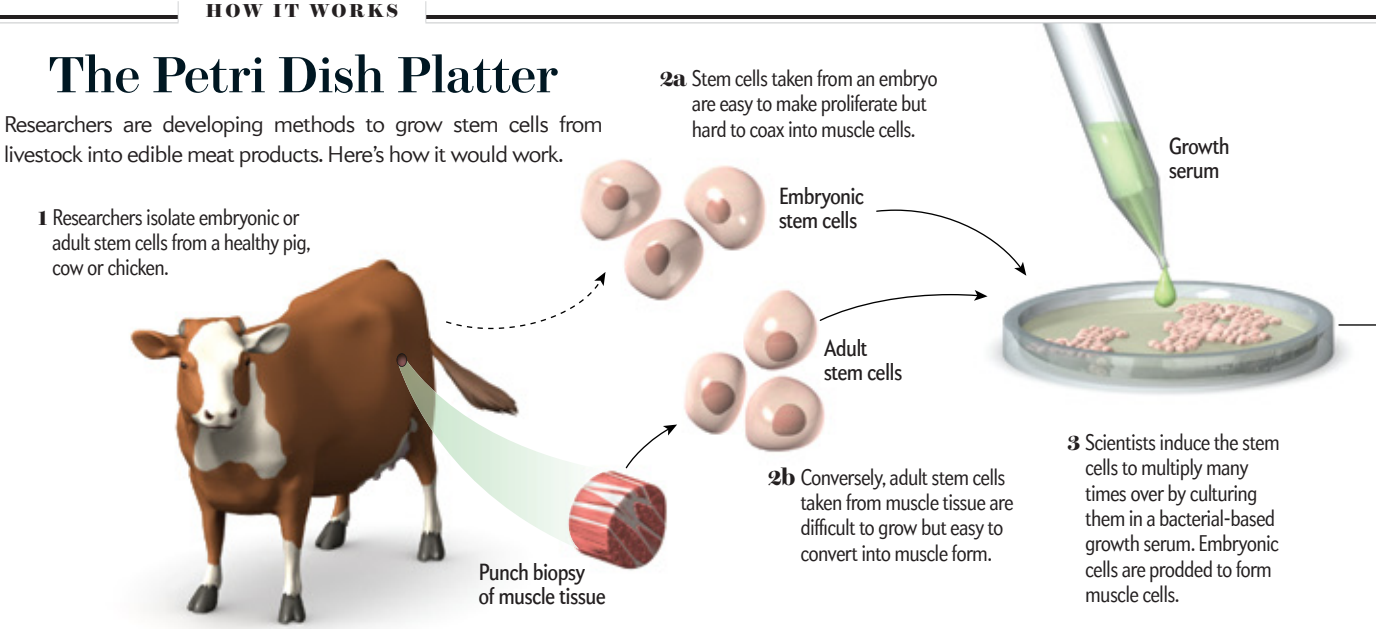


SOURCES: "LIVESTOCK PRODUCTION: RECENT TRENDS, FUTURE PROSPECTS," BY PHILIP K. THORNTON, IN *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B*, VOL. 365; 2010 (*consumption graph*); "LIVESTOCK'S LONG SHADOW," REPORT OF THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2006 (*emissions graph*)

Graphics by Jen Christiansen

The Petri Dish Platter

Researchers are developing methods to grow stem cells from livestock into edible meat products. Here's how it would work.



Until now, however, such cell lines have been developed only from mice, rats, rhesus monkeys and humans. Embryonic cells from farm animals have had a tendency to differentiate quickly—and of their own accord—into specialized cells. In the report, Utrecht team's porcine cells often veered toward "a neural lineage"—brains, not bacon.

The Utrecht group also worked with adult stem cells, which have the advantage of being largely preprogrammed. These cells exist within skeletal muscle (as well as other parts of the body) with a specific mission: to do repair work when tissue is injured or dies off. So if you are making in vitro meat and want stem cells that will almost surely turn into muscle tissue, adult stem cells from skeletal muscle tissue should work very well. Until now, however, scientists have not been able to get these cells to proliferate as readily as they can embryonic cells.

Cost is another barrier. The culture used to grow stem cells of any kind is very expensive. With currently available media, it might cost $50,000 to produce a pound of meat, according to Roelen, and the most efficient nutrient bath is derived from fetal calf or horse serum taken from slaughtered animals. In recent years scientists have developed their own recipes for "chemically defined media" that include no animal products. By using recombinant-DNA technology, they have also been able to get plant cells to produce animal proteins that could be used to grow the meat. But both these types of media are, for now, prohibitively expensive. An algae-based medium may eventually work best because algae can produce the proteins and amino acids necessary to sustain cell life, but that, too, is costly—at least for now.

Once the researchers get a big supply of muscle cells, they will need to keep them alive and bulk them up. It is possible now to engineer a thin strip of tissue, but if it gets thicker than a few cell layers, parts of it start to die off. The cells need a constant flow of fresh nutrients to stay alive. In the body, these nutrients are delivered by the bloodstream, which also removes waste. Post is working on how to develop a three-dimensional system that delivers such nutrients.

He is also exploring bulking up the muscle cells. "If you take your cast off after a bone break, it scares you: the muscles are gone," he says. "But within a couple of weeks they're back. We need to replicate that process." The body achieves this in several ways, including exercise. In a lab setting, scientists can stimulate the tissue with electrical pulses. But that is costly and inefficient, bulking up the cells by only about 10 percent. Another method is simply to provide anchor points: once the cells are able to attach to different anchors, they develop tension on their own. Post has made anchors available by providing a scaffold of sugar polymers, which degrades over time. But at this stage, he says, "We're not looking at Schwarzenegger muscle cells."

He has one more method in mind, one he thinks might work best. But it is also more complex. The body naturally stimulates muscle growth with tiny micropulses of chemicals such as acetylcholine. These chemicals are cheap, which is part of what makes this approach appealing. "The trick is to do it in very, very short pulses," Post says. The hurdles to that are technological, not scientific.

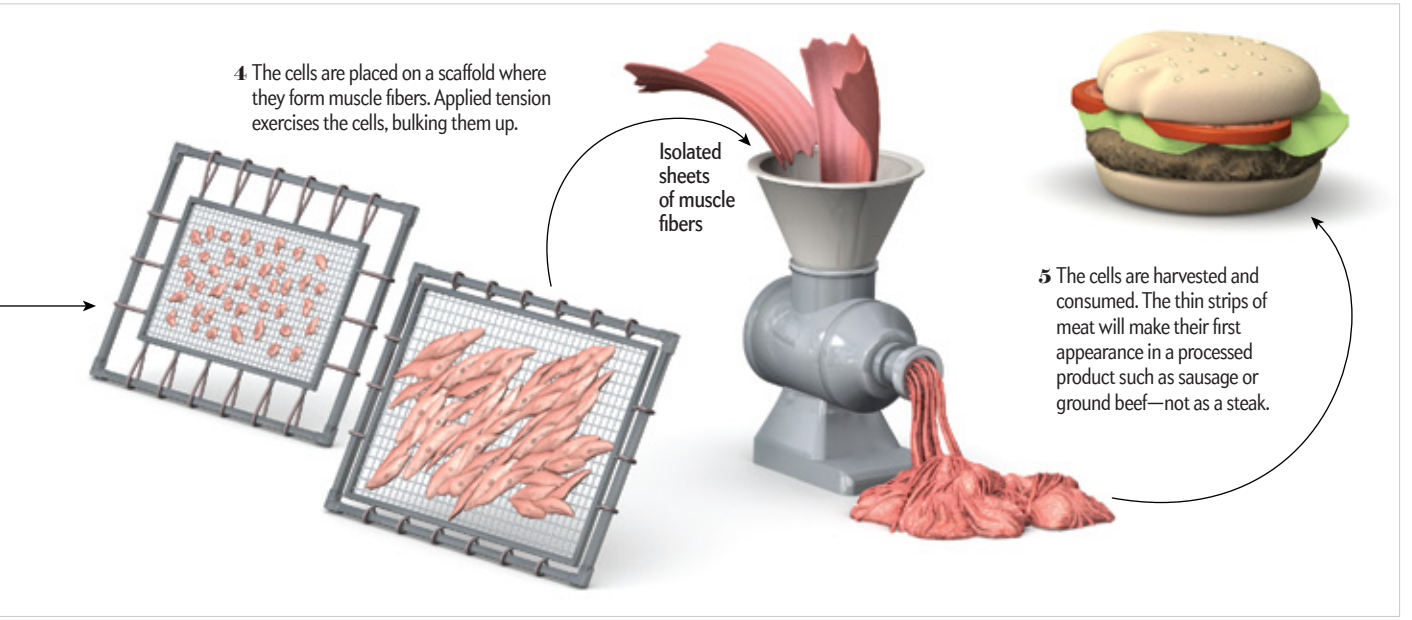
Breakthroughs in all these areas will take money, of course. In 2008 People for the Ethical Treatment of Animals (PETA) offered $1 million to the first person or persons who could grow commercially viable chicken in a lab by 2012. But that was mainly a publicity stunt and no help to scientists who need money to get research done now. More seriously, the Dutch government recently pledged roughly €800,000 toward a new four-year project that would continue the stem cell research at Utrecht—and also initiate a study on the social and moral questions related to in vitro meat.

THE ICK FACTOR

SOME SEE SOCIAL ACCEPTANCE as the biggest barrier of all to producing in vitro meat on a commercial scale. "I've mentioned cultured meat to scientists, and they all think, 'great idea,'" says Oxford's Tuomisto. "When I talk to nonscientists, they are more afraid of it. It sounds scary. Yet it's basically the same stuff: muscle cells. It's just produced differently."

Cor van der Weele of Wageningen University is heading up

Illustration by Emily Cooper



the philosophical aspects of the new Dutch study (for example, is cultured meat a moral imperative or morally repugnant, or some combination of the two?). She has been intrigued by the emotional reactions that some people have toward the idea. "We call it the 'yuck response,'" she says. "People initially think that it might be something contaminated or disgusting."

But that perception can change quickly, van der Weele observes. She notes that people often associate cultured meat with two other ideas: genetically modified foods—which are often seen, particularly in Europe, as a dangerous corporate scheme to dominate or control the food supply—and negative perceptions of the meat industry in general, with its factory farms, disease and mistreatment of animals. Once people realize that cultured meat is not genetically modified and could be a clean, animal-friendly alternative to factory farms, she says, "the scared, very negative response is often very fleeting."

Such observations are only anecdotal, of course. The study will assess popular responses to in vitro meat in detail—comparing reactions across different regions and cultures—and will determine ways to frame the issue that might enhance consumer interest. Proponents imagine a day when governments will levy special environmental taxes on meat produced from livestock or when consumers will be able to opt for in vitro meat that is labeled "cruelty-free."

"I don't think you want to know about the hygienic conditions in the majority of slaughterhouses in the U.S. or the efficiency of euthanasia," says Post, who spent six years at Harvard University and Dartmouth College before returning home to the Netherlands in 2002. Another outbreak of disease—like mad cow or bird flu—could make cultured meat seem all the more appetizing. "We are far from what we eat," Roelen says. "When we're eating a hamburger, we don't think, 'I'm eating a dead cow.' And when people are already so far from what they eat, it's not too hard to see them accepting cultured meat."

Post has a bold scheme to attract new funding: he aims to create an in vitro sausage just to demonstrate that it is possible. He estimates that it will cost €300,000 and take six months of work by two doctoral students using three incubators. "We'll take two or three biopsies of a pig—say, 10,000 stem cells," Post says. "After 20 population doublings, we'll have 10 billion cells." The students will use 3,000 petri dishes to produce many tiny bits of porcine muscle tissue, which then will be packed into a casing with some spices and other nonmeat ingredients to give it taste and texture. In the end, scientists will be able to display the sausage next to the living pig from which it was grown.

"It's basically a stunt to generate more funds," Post says. "We're trying to prove to the world we can make a product out of this." But will it taste like a sausage? "I think so," Roelen says. "Most of the taste in a chicken nugget or a sausage is artificially made. Salt and all kinds of other things are added to give it taste."

Van Eelen, who regards himself as "the godfather of in vitro meat," is not a fan of the sausage proposal. He is a diehard idealist and thinks it is important to launch the in vitro revolution with meat that looks, smells and tastes just like anything you would buy off the farm. Van Eelen probably also realizes that time is running out to realize a dream that he has pursued nearly his entire life. "Every time you talk to him, he's speaking about someone else he's found who will be the top scientist who will solve his problems," Roelen says. "I can understand his point of view. But I can't change the laws of the universe." SA

MORE TO EXPLORE

Production of Animal Proteins by Cell Systems. H. P. Haagsman, K. J. Hellingwerf and B.A.J. Roelen. University of Utrecht, October 2009.

Livestock Production: Recent Trends, Future Prospects. Philip K. Thornton in *Philosophical Transactions of the Royal Society B,* Vol. 365, No. 1554, pages 2853–2867; September 27, 2010.

Food: A Taste of Things to Come? Nicola Jones in *Nature,* Vol. 468, pages 752–753; 2010.

Animal-Free Meat Biofabrication. B. F. Bhat and Z. Bhat in *American Journal of Food Technology,* Vol. 6, No. 6, pages 441–459; 2011.

New Harvest: **www.new-harvest.org**

SCIENTIFIC AMERICAN ONLINE

Listen to an interview about the future of cultured meat at ScientificAmerican.com/jun2011/meat

MICROBIOLOGY

The Smartest Bacteria on Earth

One species of soil microbe makes unusually wise communal decisions

By Anna Kuchment, staff editor

ESHEL BEN-JACOB IS INTERESTED NOT ONLY IN THE genomes of the bacteria he studies but also in their personalities. He compares many to Hollywood celebrities. "On the one hand, we admire them, but on the other hand, we think that they are stupid," says Ben-Jacob, a professor of physics at Tel Aviv University in Israel. In December, though, he and his colleagues published a paper in the journal *BMC Genomics* reporting that a species of soil bacteria he discovered in the mid-1990s, *Paenibacillus vortex*, is surprisingly smart by microbial standards.

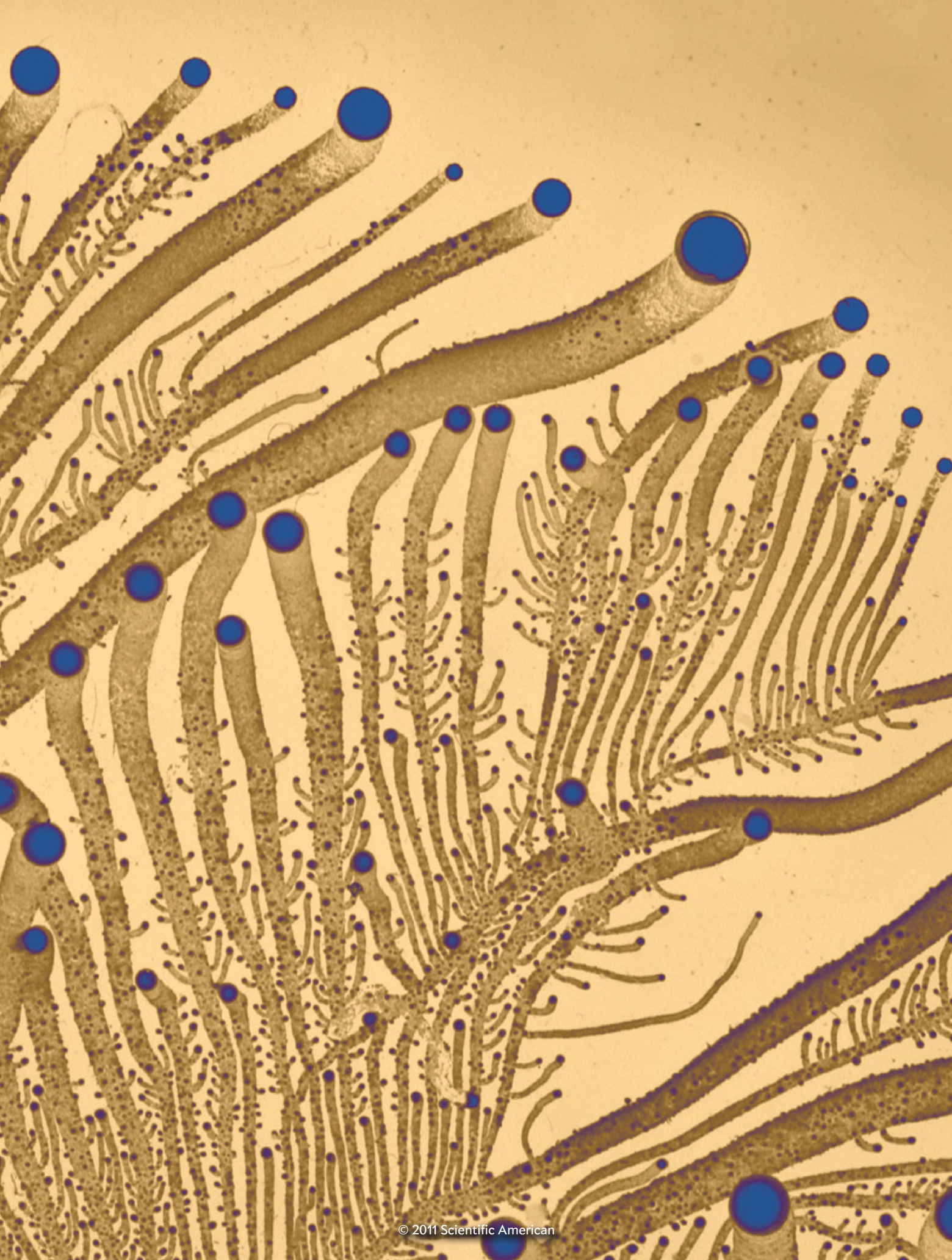
The team identified this relative intelligence by comparing the *P. vortex* genome with that of 502 different bacterial species whose genomes were known and, based on that comparison, calculating what Ben-Jacob calls the bugs' "social IQ score." The researchers counted genes associated with social function, such as those allowing bacteria to communicate and process environmental information and to synthesize chemicals that are useful when competing with other organisms. *P. vortex* and two other *Paenibacillus* strains have more of those genes than any of the other 499 bacteria Ben-Jacob studied, including pathogenic bacteria such as *Escherichia coli,* indicating a capacity for "exceptionally brilliant social skills."

This social sophistication is manifested in the elaborate colonies that *P. vortex* can form, such as the one in the accompanying micrograph, which grew over several days in a petri dish. The colony, about eight centimeters in diameter, contains 100 times more bacteria than the number of people on earth. The blue dots are dense groups of bacteria called vortices that swarm collectively around a common center to better pave the way on hard surfaces and protect themselves from hazards. As the cells replicate, each vortex expands in size and moves outward as a unit, leaving behind a trail of older, nonreplicating cells, which form branches that maintain communication across the colony.

"Acting jointly, these tiny organisms can sense the environment, process information, solve problems and make decisions so as to thrive in harsh environments," Ben-Jacob says. Never underestimate a single-celled star. SA

SCIENTIFIC AMERICAN ONLINE
More images and readings at ScientificAmerican.com/jun2011/bacteria

COURTESY OF ESHEL BEN-JACOB, INA BRAINIS AND KINERET BEN-KNAAN *Tel Aviv University*



HEALTH

The Devil's Cancer

A contagious tumor threatens to wipe out the famous Tasmanian devil. Could similarly "catching" cancers arise in humans, too?

By Menna E. Jones and Hamish McCallum

Endangered: Devils make formidable foes, but the cancer may be too much for them.

Menna E. Jones is an Australian Research Council Future Fellow at the University of Tasmania. Her research on Tasmanian devils, facial tumor disease and the effects of the loss of this top predator on biodiversity underpins conservation management programs.

Hamish McCallum, who has studied the ecology of wildlife for many years, is head of the School of Environment at Griffith University in Queensland, Australia. Before moving to Griffith, he was senior scientist at the Save the Tasmanian Devil Program.

LOVE BITES ON THE NECK OF THE YOUNG FEMALE TASmanian devil in my lap tell me she has recently had a sexual encounter. They also indicate something ominous: she might well be dead before she can raise her first litter of pups.

I (Jones) am sitting on the ground holding a devil that I trapped in Freycinet National Park on the eastern coast of Tasmania—a wild jewel of an island to the south of the mainland of Australia. It was here, in 2001, that I first witnessed a hideous disease that causes large, festering tumors on the face of these marsupials, impairing feeding and routinely killing them within six months of infection. Today the Freycinet population has almost disappeared—a reflection of what is happening across most of the animal's range. First detected in 1996, up in the northeastern corner of the island, the cancer—now known to be contagious—has reduced devil populations across Tasmania by up to 95 percent, pushing the species, which lives only on this island, to the edge of extinction.

Fortunately, most cancers in the world are not "catching": you can sit beside someone on a bus without fear of contracting a tumor. Some malignancies do stem from contagious viruses or bacteria. Human papillomavirus, for instance, can cause cervical cancer. But it does so by predisposing cells in infected individuals to become malignant, not by spreading tumor cells directly from one person to another. In the case of the devil's disease, the cancer cells themselves are the infectious agents.

The rapid devastation of devil populations has spurred recent research into how their cancer managed to become contagious and what might be done to stop it. Anyone who has heard about the plight of the devils naturally wonders if such tumors could someday also become common in humans. Investigators are pondering this question as well. The short answer seems to be that the odds are in our favor for now, but we are behaving in ways that could potentially reverse the equation.

THE DEVIL'S CURSE

ASIDE FROM THE DEVIL'S AFFLICTION, just one other transmissible cancer is known in the wild: canine transmissible venereal tumor, which is estimated to have evolved about 10,000 years ago. This disease is spread in dogs by the transfer of cancer cells during sexual intercourse. Contagious cancers have also been generated by laboratory manipulations of animals. And tumors can occasionally be transferred from one person to another by organ transplantation or from mother to fetus. As a rule, though, cancers begin and end in a single host, because despite their considerable ability to wreck havoc in the body, they encounter a number of barriers that usually prevent them from hopping between individuals. Contagious cancer arose in Tasmanian devils because of an unlucky confluence of factors.

Typical, noncontagious cancers arise after some cells undergo genetic changes enabling them to divide uncontrollably and invade tissues. As tumors grow, they become complex communities of malignant and nonmalignant cells. At some point, the masses may outgrow their blood and nutrient supply and so, like wild animals and plants, come under pressure to disperse tumor cells from their "birthplace" and thereby perpetuate the cancer. Some cells may then break off, travel through the blood or lymph, and set up home in a distant site within the same body—that is, they metastasize. Often it is metastatic tumors, rather than the primary one, that kill a victim, destroying the tumors in the process. This fate puts malignancies under strong pressure to perpetuate themselves in a different way: by spreading to others.

Yet they are usually thwarted at every turn. Notably, for cells to get from one host to another, the trip has to be rapid. Cells are not adapted for survival in the outside world; they tend to dry up and die within minutes of leaving the body. To be transmitted, cancer cells need their original host to behave in ways that will place them directly in contact with the living tissue of a new host.

Once in that new host, invading tumor cells also need to evade

IN BRIEF

In less than 20 years a contagious cancer, known as devil facial tumor disease, has arisen and pushed the marsupial called the Tasmanian devil to the brink of extinction.

The cancer became "catching" in part because the devils bite one another a lot. When they do that, cells from the tumor, which grows on the face and in the mouth and sheds cells readily, get deposited into wounds on the bitten animals and take root there.

In addition, most devils are very similar genetically, so their immune systems do not recognize the deposited cancer cells as foreign and do not destroy them.

The authors describe conditions under which a human cancer could also become contagious, although such an occurrence does not seem imminent.

GETTY IMAGES (*preceding pages*)

immune recognition. The immune systems of higher animals have a number of mechanisms for detecting and destroying foreign cells. Immune system warriors, for instance, hunt down and eliminate cells that look different from the body's own. Cells from a different organism display protein fragments on their surface unique to that organism, akin to flags that say, "I'm foreign," and the immune defenses pounce when they detect those flags. The flags are encoded by a variety of genes, including the highly variable major histocompatibility complex genes. Indeed, some biologists think that the major histocompatibility genes, which evolved in early vertebrate animals, became so diverse primarily because they ensure that cancers do not become transmissible.

Sadly for the devils, they lack these blockades to transmissibility. The tumor now tormenting them—officially called devil facial tumor disease—typically forms near or in the mouth, and the animals frequently bite one another, both during sex and combat and often on the face. Hence, their behavior readily delivers malignant cells from one individual to another, either through bites by teeth coated with cells shed from a nearby tumor or through direct contact between a facial tumor and wounds on a partner. The dog venereal tumor similarly spreads through direct contact but, in this instance, as a result of abrasive genital contact during copulation. Both the devil and the dog cancers also become friable with age and size, facilitating the infectious spread by allowing cells to readily peel off from the original mass.

Further, if genetic diversity in a population becomes depleted—if most individuals possess highly similar versions of genes that once occurred in multiple, more divergent forms in the group—the immune system of one individual will have trouble distinguishing cells from a different individual as foreign and will thus attempt no attack at all or will, at best, mount a weak immune response. Tasmanian devils have low genetic diversity, especially in their major histocompatibility complex genes—probably resulting from a catastrophic reduction in populations sometime in the past and possibly from past disease challenges that spared only a group of animals that had a very similar genetic makeup. The dog cancer, too, is thought to have evolved in a small, genetically restricted and inbred population, either in an isolated group of wolves or in a population that lived around the time of domestication.

(The conditions promoting contagion in the devils and in dogs also explain why cancers sometimes travel from mother to fetus in humans or from organ donors to recipients. In both cases, tumor cells pass quickly from the original host to the next one. Also, fetuses have immature immune systems, and transplant recipients take medications that suppress immunity to protect the new organ from rejection.)

Genetic analyses have revealed that the tumors of afflicted devils descend from cancer cells that originated in a single, long-dead devil; notably the growths share a telling loss of certain chromosomes and chromosomal segments that are not missing in other cells of the victims. Because the originator of the tumor is long gone, no one will ever know for certain what caused the initial mutations that allowed the devil's cancer to become transmissible. The cancer might have arisen, though, from mutations that occurred in cells in or near the face as a result of repeated injury and chronic inflammation, an etiology known as wound carcinogenesis. Elizabeth P. Murchison of the Wellcome Trust Sanger Institute in England provided added specificity in 2010; in a paper published in *Science,* she reported that the devil tumor originated in Schwann cells, which ensheath neurons outside the central nervous system.

The mix of factors that led the devil facial tumor disease and the canine transmissible cancer to become contagious might suggest that cancers become infectious only rarely in nature because the required conditions—intimate contact permitting transfer of live cells, together with low genetic diversity—hardly ever coincide in nature. Yet other observations suggest contagious cancers might be more common than is generally believed. All birds and mammals, for instance, fight and copulate, and many populations are highly inbred. It is possible, then, that infectious cancers arise more often than is recognized but usually do not persist in the world for long—say, because they kill off infected host populations, and thus themselves, quickly.

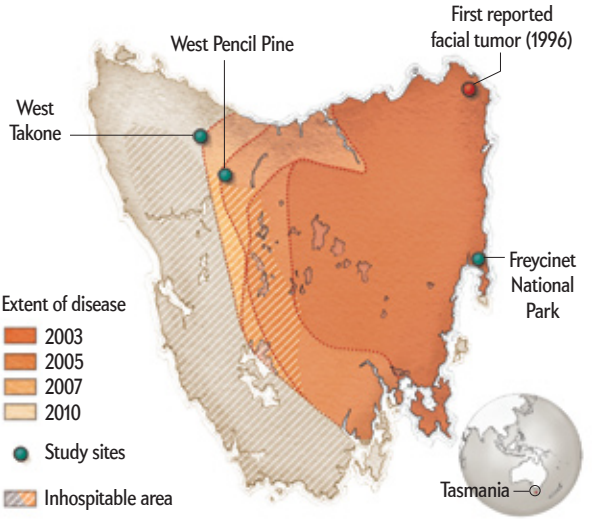
The dog cancer does not fit that pattern but hints at another way contagious cancers could exist without being known to us. Today the canine tumors manage to "hide" from the immune system initially, but eventually the system "sees" the malignancies and destroys them, leaving the animals immune to future infection. Other contagious cancers that also do not kill their

THE DEVIL'S PLIGHT

A Fast-Spreading Scourge

COURTESY OF RODRIGO HAMEDE *University of Tasmania*

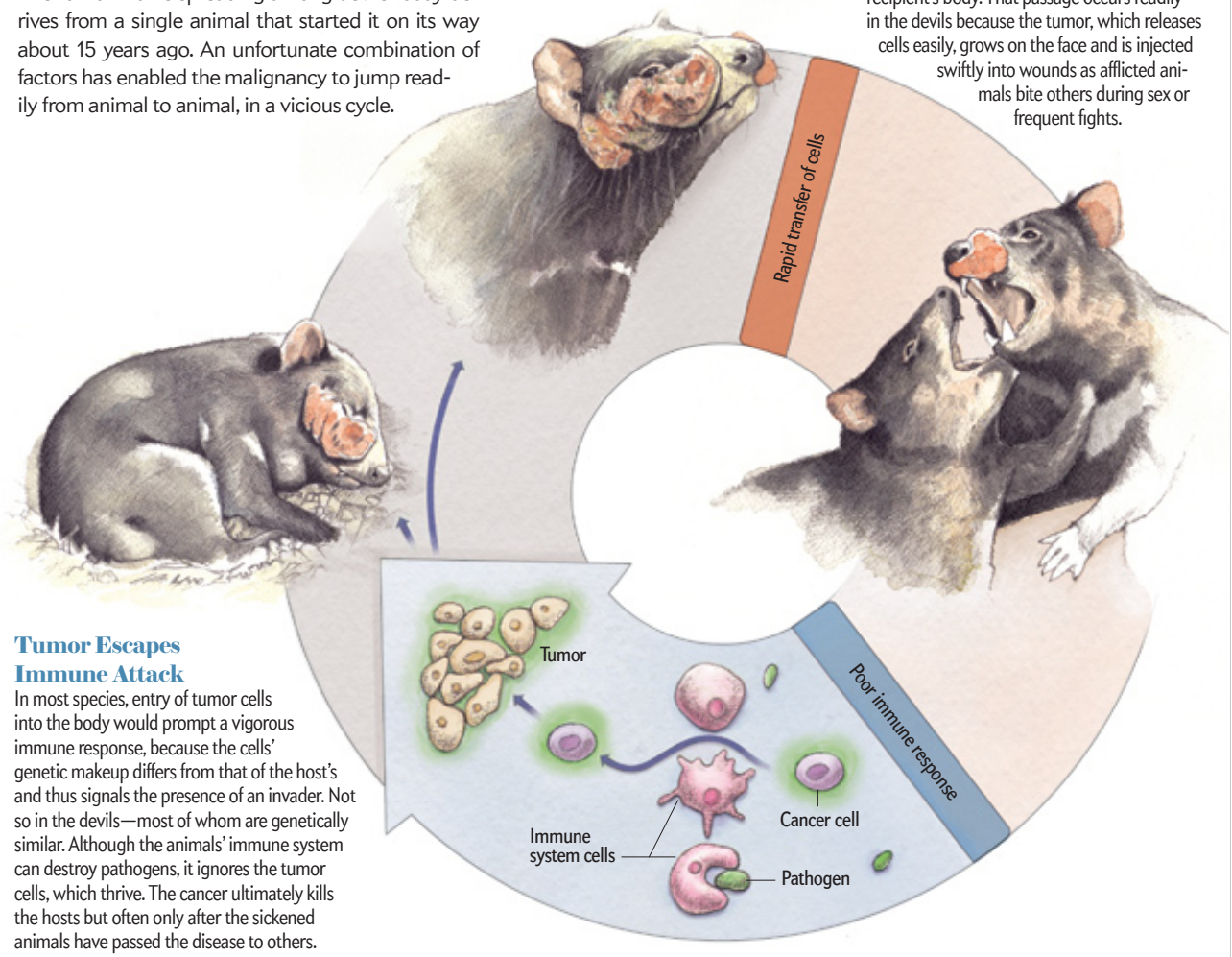
Since first being discovered in 1996 in northeastern Tasmania, devil facial tumor disease (*photograph*) has traveled rapidly (*map*), reducing some devil populations, such as that in Freycinet National Park, by as much as 95 percent. Twenty years earlier the animals thrived across most of the island, except in the southwest, where the terrain is not particularly hospitable (*hatched area in map*). Devils in the far northwest vary genetically from those elsewhere and are somewhat resistant to the cancer. The authors and their colleagues have set up study sites there, hoping to gain new insights into how devil numbers might be increased.



Map by Mike Sudal

How Cancer Becomes "Catching"

The tumor that is spreading among devils today derives from a single animal that started it on its way about 15 years ago. An unfortunate combination of factors has enabled the malignancy to jump readily from animal to animal, in a vicious cycle.



Cancer Cells Transfer Easily

Out in the air, cells die rapidly. So tumor cells can transfer from one individual to another only if they can be injected directly into a recipient's body. That passage occurs readily in the devils because the tumor, which releases cells easily, grows on the face and is injected swiftly into wounds as afflicted animals bite others during sex or frequent fights.

Tumor Escapes Immune Attack

In most species, entry of tumor cells into the body would prompt a vigorous immune response, because the cells' genetic makeup differs from that of the host's and thus signals the presence of an invader. Not so in the devils—most of whom are genetically similar. Although the animals' immune system can destroy pathogens, it ignores the tumor cells, which thrive. The cancer ultimately kills the hosts but often only after the sickened animals have passed the disease to others.

hosts could be out there. Only detailed genetic work, such as has been done with the dog and devil tumors, will clearly identify whether a wildlife cancer is in fact infectious.

WHAT LIES AHEAD

HOSTS AND PATHOGENS USUALLY CO-EVOLVE over time in nature—with the host developing adaptations that control the pathogen, the pathogen taking countermeasures and both persisting in the end. We wondered, therefore, if we might see signs of this evolutionary dance between the contagious cancer and its devil hosts and thus find some glimmer of hope for the animals. We did.

The devils are under intense evolutionary pressure to develop any kind of trait that could improve survival or increase reproduction. And in the years since the devil cancer emerged, it has indeed induced a response in its host: devils are resorting to teenage sex. In the past, females began reproducing at two years old and raised about three litters in a lifetime of five to six years; the disease has cut the litter number to one for many of the animals. Juvenile females that grow fast enough in the first few months after weaning can raise a litter a year earlier than is usual if they have their joeys before winter sets in; this early procreation gives them a chance to nurture at least one, and perhaps two, litters before succumbing to the cancer. Given enough time, such behavior could help maintain species numbers.

With our Ph.D. student Rodrigo Hamede, we are seeking other signs of evolution in animals living in the somewhat isolated northwestern region of Tasmania. The northwestern devil population harbors many genes that differ from the versions found further east, and the group seems better able to resist the disease. As the tumor encounters different genotypes for the first time, it is not causing any population decline. Disease prevalence remains low, and infected devils there survive with the cancer much longer than is the case in eastern Tasmania. We return to several sites in the northwest a number of times a year to ob-

Illustration by Mike Sudal

serve disease trends and to collect tissue and blood samples, which our collaborators, Katherine Belov of the University of Sydney and Greg Woods of the Menzies Research Institute Tasmania, help us to analyze. By looking at genes and immune responses, Belov and Woods, respectively, are trying to discern whether any particular combinations of genetic variants make the animals' immune systems particularly good at fighting the cancer. If we can find resilient devil genotypes, we may be able to help spread good genes through wild populations—for instance, by establishing the resistant animals in other parts of Tasmania—and speed up recovery of the species.

We are also seeing evolutionary changes in the tumor itself. Anne-Maree Pearse, a geneticist at the Save the Tasmanian Devil Program—an initiative supported by the Australian and Tasmanian governments—has found that a number of strains have arisen. That variety may or may not be good news. On one hand, some strains could evolve to become less virulent. But on the other hand, different strains may evolve to overcome any resistance that develops in the devil population.

The history of the dog cancer's evolution offers grounds for some optimism. As is true for many diseases, the canine transmissible tumor probably started off as highly virulent, like the devil's, and then co-evolved over time with its host canines to decrease virulence, thus increasing the overall success of the tumor: that is, the reduced virulence enabled hosts to live longer with the disease and to spread it to more animals. That pattern would explain how the dog cancer became the generally nonlethal infection it is today.

Contagious tumors not only evolve, they probably also manipulate their hosts, much as parasites manipulate the behavior of their hosts to increase transmission. The canine tumors induce the female dog to produce chemicals that increase sexual receptivity, thus improving the odds of the cancer being passed on to males. Strains of the devil tumor that induce aggression in their hosts could conceivably be selected for, which would increase transmission rates. But it is also possible that low aggression would be selected for because milder animals would be less likely to fight and become infected. We watch the evolutionary dance between the devil and its cancer with close interest.

We hope that, given the will and sufficient resources, the devil can be saved from extinction, allowing it to fulfill its historic role as a top predator in many parts of its range. Devil loss in those areas is expected to precipitate cascading changes in the ecosystems—such as increases in predation by introduced cats and foxes—that could lead to the extinction of various other species. The same pattern has already led to the extinction of several small marsupials on mainland Australia; Tasmania is now their last refuge. Whether efforts to prevent devil extinction can succeed will depend on what we learn in northwestern Tasmania.

IS INFECTIOUS CANCER A RISK TO HUMANS?

GIVEN THAT HUMANS HAVE GREAT GENETIC DIVERSITY and can avoid behaving in ways that would foster tumor transmission, it might seem safe to assume that our species can readily avoid the fate of the Tasmanian devils. Indeed, even if a person were bitten by an infected devil or by a dog with the canine transmissible tumor, the person's genetic makeup, being so different from that of the animals, would probably ensure a strong immune response able to detect and kill the invading cells; the bitten individual would not get sick or start spreading the disease to others.

There are grounds for concern, nonetheless. Contagious cancers could, in theory, arise in a group of great apes (such as chimpanzees, gorillas or orangutans) having low genetic diversity because of population declines. If these animals were hunted by human populations with many members having impaired immunity, the close contact might enable tumor cells to transfer to humans and then spread. Such conditions exist where humans with a high HIV prevalence hunt endangered apes. Although this scenario is possible, we suspect that cross-species transmission is not the most likely way that a contagious cancer would arise in humans. We hold this view in part because no known cases of cross-species transmission of the dog cancer have occurred in nature—although the disease has been experimentally transferred to closely and distantly related canids in the laboratory.

Still, burgeoning human populations are changing the world in unprecedented ways. HIV has infected millions of people, suppressing their immune systems and leading to the emergence of many once rare cancers. This situation is conducive to the evolution of a contagious cancer. The possibility of an infectious cancer arising in immunosuppressed humans and subsequently evolving the ability to infect the general population is very real. That exact pattern occurred in dogs: the canine transmissible cancer, after probably evolving in an inbred, genetically invariant population, is now able to infect genetically variable dog and wolf populations. That the dog cancer is usually not lethal these days is not terribly reassuring. As we noted earlier, most likely the disease went through a period of being lethal to many of its hosts, as HIV is today, before populations of individuals naturally able to control the cancer expanded and came to predominate.

The devil cancer provides biologists with a unique opportunity to learn about contagious cancers. It also serves to remind us, in the most brutal manner, of the consequences of human activities on our planet. We are releasing copious amounts of carcinogens into the environment, and we are destroying the wild habitats of the world, causing losses of both species and genetic diversity. Global trade and habitat destruction are bringing humans and wildlife into contact with pathogens they have never previously encountered. As a consequence, we can expect to see an increase in new kinds of cancer in wildlife, both contagious and induced by viruses and other pathogens. It is not inconceivable that these malignancies could jump species—even to humans. SA

MORE TO EXPLORE

To Lose Both Would Look Like Carelessness: Tasmanian Devil Facial Tumour Disease. Hamish McCallum and Menna Jones in *PLoS Biology,* Vol. 4, No. 10, pages 1671–1674; October 17, 2006.

Conservation Management of Tasmanian Devils in the Context of an Emerging, Extinction-Threatening Disease: Devil Facial Tumor Disease. Menna E. Jones et al. in *EcoHealth,* Vol. 4, No. 3, pages 326–337; September 2007.

Life-History Change in Disease-Ravaged Tasmanian Devil Populations. Menna E. Jones et al. in *Proceedings of the National Academy of Sciences USA,* Vol. 105, No. 29, pages 10023–10027; July 22, 2008.

Transmission Dynamics of Tasmanian Devil Facial Tumor Disease May Lead to Disease-Induced Extinction. H. McCallum et al. in *Ecology,* Vol. 90, No. 12, pages 3379–3392; December 2009.

Evidence That Disease-Induced Population Decline Changes Genetic Structure and Alters Dispersal Patterns in the Tasmanian Devil. Shelly Lachish et al. in *Heredity,* Vol. 106, No. 1, pages 172–182; January 2011.

Save the Tasmanian Devil Program (an initiative of the Australian and Tasmanian governments): www.tassiedevil.com.au/tasdevil.nsf

SCIENTIFIC AMERICAN ONLINE

See a slide show and videos of devils at ScientificAmerican.com/jun2011/cancer

IN BRIEF

The history books say that Roald Amundsen beat Robert F. Scott in a race to the South Pole in 1911. Less widely known is that Scott had big scientific ambitions for his trip, which he largely fulfilled.

Scott's team made several side trips to search for fossils and other scientific evidence, despite competition from Amundsen.

One of Scott's most significant finds was fossils of an ancient plant, *Glossopteris,* that proved to be important evidence in support of Darwin's theory of evolution.

SIDE TRIP
One of Scott's 32 expedition members sleds past a massive ice structure named Castle Berg, off the shore of Ross Island, Antarctica.

CORBIS

Edward J. Larson, professor of history and law at Pepperdine University, is author of nine books on the history of science, including the Pulitzer Prize–winning *Summer for the Gods,* on the Scopes trial. His latest, *An Empire of Ice: Scott, Shackleton and the Heroic Age of Antarctic Science,* comes out this month (Yale University Press).

HISTORY OF SCIENCE

Greater Glory

In the race to the South Pole, explorer Robert F. Scott refused to sacrifice his ambitious science agenda

By Edward J. Larson

ONE HUNDRED YEARS AGO, IN JUNE 1911, ROBERT FALCON SCOTT and 32 explorers—most of them British scientists, naval officers or seafarers—were huddled in the darkness of the Antarctic winter, when the sun never rises above the horizon and up to eight feet of ice seals the surrounding sea. Winter temperatures on Ross Island, the southernmost piece of exposed land reached by Scott's ship, can plunge below –50 degrees Fahrenheit. Blizzards rise up often. Lacking wireless communication and totally cut off from the outside world, the explorers waited for the longer, warmer days of spring, in October, when some of them would set out to cross nearly 900 miles of ice shelf, mountains and the Polar Plateau to arrive at a spot of no particular interest to anybody except for its location at the bottom of the earth.

Two British expeditions had tried to reach the South Pole before. Scott led one himself from 1901 to 1904, and Ernest Shackleton led another from 1907 to 1909. They had fallen short. This time, though, Scott was brimming with confidence. Drawing on those earlier experiences, he had methodically planned this expedition not merely to be the first to reach the South Pole but also to advance an ambitious scientific agenda. He had already put in place several teams that would fan out across the Ross Sea basin, collecting fossils, data and other things of scientific importance. With the spring, his own team planned to make its way slowly southward, plant the Union Jack at the pole early in the Antarctic summer, and head back laden with the glory of both polar conquest and scientific discovery.

The long winter months gave Scott plenty of time to mull over a momentous decision that he had made four months earlier, shortly before winter closed in on the explorers. In February 1911 a small band of Scott's men were trying to reach the virtually unknown King Edward VII Land on the Ross Ice Shelf's eastern side and ran into another group encamped on the shelf's sea edge, about 350 miles away. These nine men hailed from Norway, and their leader was Roald Amundsen, an expert Arctic skier and dogsledder who in 1905 had been the first to traverse the Northwest Passage above Canada. Amundsen was supposed to be heading for the North Pole, more than 12,000 miles away, but he had secretly shifted his goal to the southern pole in what appeared to Scott to be an effort to catch the British explorers off guard. Amundsen's men traveled light—no scientific ambitions for them. With sled dogs and skis, they planned to make a dash to the pole from a base already 60 miles closer than Scott's base on Ross Island. What started for Scott as a deliberate march to the pole had suddenly turned into a race.

The news caused something of a crisis in Scott's camp. Some team members suggested jettisoning the science and focusing on the race. If it came down to a choice between science and the pole, they said, better to go for the pole. Scott, however, thought differently. Scott's first expedition to Antarctica had yielded a wealth of geologic and biological specimens, meteorological and magnetic data, and oceanographic and glaciological findings. He saw science as an important part of the new expedition.

Not having anticipated competition, Scott had to choose between staking everything on the pole and persevering with his plan. He persevered. "The proper, as well as the wiser, course for us is to proceed exactly as though this had not happened," Scott wrote in his diary about Amundsen's challenge. He doubted that Amundsen's sled dogs could manage a sprint of hundreds of miles over unknown terrain, but if they did, Scott could not hope to beat them anyway. From the standpoint of history, we can be grateful that he did not abandon research for the pole, because his trip yielded important contributions to science. But this faithfulness to science cost Scott and his team dearly.

SCIENTIFIC DIVERSIONS

SCIENCE WAS SOMETHING of a tradition in the Royal Navy—and Scott was, after all, an officer. All three British Antarctic expeditions of the early 1900s had taken along physicists, geologists and biologists. Since evolution was one of the central issues of the day, the scientists had kept an eye out for a key piece of fossil evidence: Paleozoic Era flora called *Glossopteris*. Critics of Darwin's theory of evolution had pointed to the seemingly abrupt appearance of this distinct, broad-leaved flora in the fossil record of Africa, Australia and South America to defend creationist explanations for life. In response, Darwin had hypothesized the existence of a south polar landmass, somehow connected to the other southern continents, where *Glossopteris* had evolved. Scott's first expedition had found seams of coal, proving that plants once flourished in Antarctica, and Shackleton's expedition found plant fossils but no *Glossopteris*. Scott hoped to settle the matter.

Scott's polar plan called for multiple support parties falling back in stages, leaving a small team to haul one sled to the pole on foot. This approach, Scott thought, would provide a margin of safety and perhaps allow for research and mapping along the way. And throughout his time on Antarctica, he would dispatch several teams of explorers whose sole purpose was to gather scientific evidence. Although Scott could have had these groups abandon their arduous missions and focus on the polar trip, he chose not to. During the time of the polar trek, various officers and scientists would remain at the main base to keep meteorological and magnetic records, while sailors and scientists onboard Scott's ship would conduct oceanographic research in the Southern Ocean. None of this changed because of Amundsen.

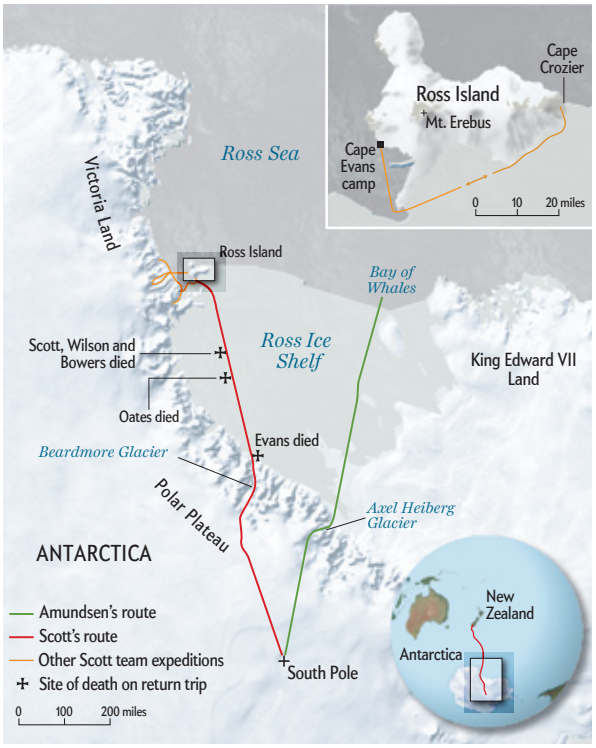
The first of the groups set out from base camp in January 1911, without knowing about Amundsen's location. Scott dispatched 10 men in two separate parties to explore the mountains and glaciers of the Antarctic mainland. Even after the larger of the two parties discovered Amundsen's base, it returned to the field on another scientific mission—to study rock outcroppings, glaciers and bays along Victoria Land's northern coast. This team spent the winter of 1911 there, as planned, unable to contribute to the polar effort. After an unexpected second winter in the field, the party returned to Scott's base in November 1912 with an array of fossils, including a striking tree imprint, but no *Glossopteris*.

The smaller party, which included geologists T. Griffith Tay-

LOCATOR

More Than a Race

Robert F. Scott's path to the South Pole (*red*) differed from that of Roald Amundsen (*green*), who arrived first. Before Scott set off from Cape Evans, the main base, his men spent months doing geologic and other research on and beyond Ross Island, such as at Cape Crozier and Victoria Land. Science was so important to Scott that, on the ultimately fatal return trek from the pole, he and his comrades—Edgar Evans, Lawrence Oates, H. R. Bowers and Edward A. Wilson—collected 35 pounds of fossils and rocks.



Map by XNR Productions

OPPOSITE PAGE: SCOTT POLAR RESEARCH INSTITUTE, UNIVERSITY OF CAMBRIDGE

SCIENTIFIC SNAPSHOTS *Top row, left to right:* Scott, at his base, writes in his journal of work and adventure; Scott, Bowers, George C. Simpson and Evans head out to explore Victoria Land's mountain range. *Middle row:* An emperor penguin rests; Bowers, Wilson and Apsley Cherry-Garrard prepare to go to Cape Crozier to collect emperor eggs; biologist Edward W. Nelson examines equipment for collecting marine specimens. *Bottom row:* Simpson makes observations at a weather station on Cape Evans; geologist Frank Debenham grinds stone samples.

lor and Frank Debenham, explored the dry valleys, exposed peaks and enormous glaciers of Victoria Land's midcoastal region during February and March 1911. They spent the winter months from April to October 1911 at the main base, examining their findings, which included many fossils (but still no *Glossopteris*). Taylor and Debenham then left for an even longer research trip in early November 1911, just after Scott departed for the pole. They took with them Scott's best Nordic skier, Tryggve Gran, and petty officer Robert Forde, an extraordinarily strong sledder, to help with the rough terrain. Assigning Gran and Forde to the scientific party rather than his own group showed Scott's commitment to science. It paid off: Taylor and Debenham were able to explore a vast area of previously unknown mountains and glaciers, where they found a remarkable set of Paleozoic Era fossils (but, alas, no *Glossopteris*).

PURSUING PENGUINS

THE MOST SEVERE DIVERSION from the polar effort, though, came from a promise Scott made to Edward A. Wilson, in return for agreeing to undertake the trip. Wilson had served with distinction as a zoologist on Scott's first Antarctic expedition, which found an emperor penguin egg rookery on Ross Island's Cape Crozier, where Wilson discovered that birds of this supposedly ancient species laid and hatched their eggs in winter. Scott promised Wilson that he could go back to the rookery in midwinter to see if emperor embryos showed vestiges of reptilian teeth. Wilson hoped to prove that birds evolved from reptiles.

The journey would take Wilson, assistant zoologist Apsley Cherry-Garrard and H. R. "Birdie" Bowers—among Scott's best men—away from the base during a period of planning and preparation for the polar journey and subject them to the unknown hazards of sledding in the dark Antarctic winter. Wilson and his party set off on June 27, 1911, for a 70-mile trek across the Ross Ice Shelf. They dragged 757 pounds of scientific equipment, cold-weather gear and supplies on two nine-foot sleds linked end to end and to the men by harnesses.

The party traveled around Ross Island to the south, where the temperature frequently dipped below –70 degrees F. The heavy surface caused by extreme cold forced the men to relay the sleds—one mile gained for three miles walked. After three weeks of brutal hauling, the men finally reached a moraine overlooking Cape Crozier. There they built a stone hut in which they hoped to examine embryos before the eggs froze solid. Using one sled for a ceiling beam, they stretched canvas over the top of four rock walls, caulked cracks with snow and assembled a blubber stove for heat. Then, using the midday twilight that dimly illuminated the ice for a few hours each day, the men struggled through a maze of massive ice hummocks and crevasses to the rookery. They arrived just as the twilight failed. "We had within our grasp material which might prove of the utmost importance to science," Cherry-Garrard lamented. "We were turning theories into facts with every observation we made—and we had but a moment to give." They grabbed six eggs and bolted for the hut with the expectation of returning later.

A severe storm rolled in overnight. The hut's canvas roof rose and fell with the gale-force winds until, at about noon on the third day, it exploded outward in shreds, leaving the men cowering in their sleeping bags under drifting snow. When the storm finally subsided a day later, Wilson abandoned the effort. "We had to own ourselves defeated by the Cape Crozier weather and by the darkness," he wrote. The few eggs they had collected were lost or frozen, rendering them useless for research.

The men were exhausted on the return trip. The temperature again plunged toward –70 degrees F, and the sleeping bags were now worthless for warmth. No one slept much at night; Bowers and Cherry-Garrard became so tired that they dozed while sledding. At one point, Bowers dropped into a deep crevasse and hung by his sledding harness until rescued. Cherry-Garrard's jaws chattered so much that his teeth shattered. When they arrived at camp in August, each 17-pound bag had accumulated up to 27 pounds of ice from melted snow and sweat. "They looked more weather-worn than anyone I have yet seen," Scott said. "Their faces were scarred and wrinkled, their eyes dull, their hands whitened and creased with the constant exposure to damp and cold."

Bowers bounced back quickly and took again to the field. In September 1911, for his final outing before the polar journey, Scott took Bowers and Edgar Evans on a two-week, 175-mile trip to check on stakes that another team had planted in glaciers to measure their movement. The trek over mountains was taxing. The team hauled a heavy sled in –40 degrees F and in one 24-hour period had to march 35 miles. "It is not quite clear why they are going," Debenham noted at the time. The most plausible reason was science. Scott had written earlier in his diary, "It is a really satisfactory state of affairs all around. If the [polar] journey comes off, nothing, not even priority at the Pole, can prevent the Expedition ranking as one of the most important that ever entered the Polar regions." Science would make it so.

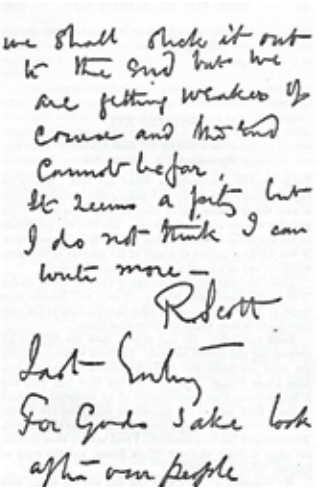
THE POLAR JOURNEY BEGINS

BAD WEATHER AND DELAYS caused by some of the expedition's side efforts held up the start of Scott's polar journey. By the time he finally set off on November 1, 1911, he was already 12 days behind Amundsen.

"I don't know what to think of Amundsen's chances," Scott wrote shortly before departing. "I decided at a very early date to act exactly as I should have done had he not existed. Any attempt to race must have wrecked my plan." Scott's push for the pole was designed for safety, not speed. It used several supporting teams, one with tractors pulling sleds over the initial ice shelf and others with dogs and ponies that might reach or even ascend the mountains at Beardmore Glacier. Each would place supplies in depots for the polar party's return trip and then fall back in stages until only one group was left to haul a single sled across the nearly 10,000-foot-high Polar Plateau to the pole itself. The process was cumbersome because the entourage could go only as fast as its slowest part. That turned out to be the ponies, which labored in soft snow up to their haunches and required fodder for food and special protection from the winds when resting.

On January 3, 1912, the last supporting team turned back from the plateau. The final polar party—consisting of Scott, Wilson, Bowers, Evans and British army captain Lawrence "Titus" Oates—faced nothing but a 150-mile expanse of ice, which offered scant prospect for doing any scientific research beyond taking regular meteorological readings and observing the windswept surface.

Amundsen and his men, meanwhile, were moving swiftly. With his dogs pulling well, the party reached the pole on December 14, after two months of sledding. Their journey back went even quicker. The surface was firm, and the route was mostly downhill. "We always had the wind at our backs, with



DISAPPOINTMENT AND DEATH
Scott, Wilson, Evans and Oates were photographed at the pole by Bowers after they found a flag left by Amundsen. Scott wrote his last journal entry (*above*) on March 29, 1912, probably shortly before he died.

sunshine and warmth the whole time," Amundsen wrote. Rations steadily increased for men and dogs as they passed their evenly spaced supply depots. They returned in just five weeks. Amundsen had gained weight.

On January 17, 1912, Scott arrived at the pole and found the Norwegian flag. "Great God," he wrote, "this is an awful place."

THE MARCH BACK

THE WORST WAS YET TO COME. The weather turned bitterly cold, and the snow assumed the texture of sand. Day after day, the sledders' diaries were filled with the same complaint: all pull, no glide, with the sled runners sometimes sinking so deep into the granular surface that the crossbars plowed through the coarse snow. The food held out, but there was not enough to supply the calories needed for trekking in such conditions.

The men grew weaker. Evans gashed his hand, and the wound became infected. Oates suffered from severe frostbite. Though not diagnosed, everyone showed signs of scurvy. Nevertheless, they took time out to make geologic observations. Descending Beardmore Glacier, they steered toward the moraine beneath Mount Buckley. "The moraine was obviously so interesting that … I decided to camp and spend the rest of the day geologising," Scott wrote after lunch on February 8. "We found ourselves under perpendicular cliffs of Beacon sandstone, weathering rapidly and carrying veritable coal seams. From the last, Wilson, with his sharp eyes, has picked several plant impressions, the last a piece of coal with beautifully traced leaves in layers."

The plants looked like *Glossopteris*. With Bower's help, Wilson took away 35 pounds of fossils and rock samples.

Evans and Oates died first. After floundering down the glacier for a week, Evans became increasingly disoriented, lost consciousness and passed away on February 17. Oates's frostbite worsened to the point where he could not keep up, yet he refused to hold the others back. Instead he left the tent during a snowstorm on March 16. "I am just going outside and may be some time," he reportedly said. He never returned.

The others marched their last on March 19. They had left behind everything except the barest essentials and, at Wilson's request, diaries, field notes and geologic specimens. These they carried to their final camp, only 11 miles shy of a critical supply depot, where a blizzard pinned them down for eight days. They ran out of food and fuel. They died together, with Wilson and Bowers in an attitude of sleep and Scott between them, his sleeping bag half open and an arm flung across Wilson.

A search party found them the following spring, frozen, along with their writings and specimens. Wilson, it turned out, had been correct about the fossils: they were indeed the long-sought *Glossopteris*. "The 35 lbs. of specimens brought back by the Polar Party from Mt. Buckley," wrote Debenham, "are of the character best suited to settle a long-standing controversy between geologists as to the nature of the former union between Antarctica and Australasia." A relentless researcher with a religious zeal, Wilson would have been satisfied. Darwin was right, and he had helped prove it. SA

MORE TO EXPLORE

The Last Place on Earth: Scott and Amundsen's Race to the South Pole. Roland Huntford. Modern Library, 1999.
The Coldest March. Susan Solomon. Yale University Press, 2001.
The Worst Journey in the World. Apsley Cherry-Garrard. Penguin, 2006.
www.gutenberg.org/ebooks/14363
Scott of the Antarctic. David Crane. Vintage, 2007.
Robert Falcon Scott Journals: Captain Scott's Last Expedition. Reissued edition. Edited by Max Jones. Oxford University Press, 2008.
Scott Polar Research Institute: www.spri.cam.ac.uk

SCIENTIFIC AMERICAN ONLINE
Listen to an interview with the author and recordings of Scott's polar trip journal at ScientificAmerican.com/jun2011/south-pole

SCOTT POLAR RESEARCH INSTITUTE, UNIVERSITY OF CAMBRIDGE (*left*); GETTY IMAGES (*right*)

GLOBAL WARMING

"I Stick to the Science"

Why Richard A. Muller wouldn't tell House climate skeptics what they wanted to hear

Interview by Michael D. Lemonick

IN BRIEF

WHO
RICHARD A. MULLER

VOCATION/AVOCATION
Physicist who has become involved in climate change research

WHERE
Lawrence Berkeley National Laboratory

RESEARCH FOCUS
Astrophysics and geophysics

BIG PICTURE
Muller enraged climate skeptics after testifying before Congress that he embraced the mainstream view that Earth is warming as climate models project.

RICHARD A. MULLER HAS NEVER BEEN COMFORTABLE WITH CONVENTIONAL scientific wisdom. In the 1980s, when his mentor Luis Alvarez came up with the then outrageous idea that a giant comet or asteroid impact wiped out the dinosaurs, the University of California, Berkeley, physicist went him one better, suggesting that the meteorite had been hurled our way by a dim companion star to the sun, which Muller dubbed Nemesis. In the 1990s he posited that ice ages are triggered by space debris encountered because of cyclical changes in the location of Earth's orbit.

More recently, Muller called Al Gore's *An Inconvenient Truth* a pack of half-truths and asserted that measurements of global temperature rises are deeply flawed, insisting that many of those who warn of climate change have sold the public a bill of goods. Although he is convinced that climate change is real, potentially dangerous and probably caused in part by humans, he has taken climate scientists to task for ignoring criticisms by outsiders, including meteorologist Anthony Watts of the Watts Up with That? blog and statistician Steve McIntyre of the Climate Audit blog. Along with several colleagues, Muller started the Berkeley Earth Surface Temperature (BEST) project to rectify what he saw as the flaws in existing measurements of global warming.

Muller's views on climate have made him a darling of skeptics—and newly elected Republicans in the House of Representatives, who invited him to testify to the Committee on Science, Space and Technology about his preliminary results. Muller, however, surprised the skeptics, the committee's leadership and himself by declaring on March 31 that so far, at least, BEST was confirming what the mainstream had been say-

Photograph by Timothy Archibald

ing all along: Earth is warming in line with the projections of climate models.

That testimony immediately turned Muller from hero to villain in some skeptics' eyes and delighted environmentalists. (The Web site Grist declared: "Science bites climate skeptics in the ass on the House floor.") Muller will be finished with the final study any day now, and if it confirms those early results, as expected, he could be permanently relegated to the skeptics' doghouse. In an interview with SCIENTIFIC AMERICAN shortly after his testimony, Muller made it clear that this did not bother him even a little bit.

SCIENTIFIC AMERICAN: As a physicist by training, what got you interested in climate change as a topic?

MULLER: I became interested in the relationship between astronomy, Earth history and geology. A theory called the Milankovitch theory related astronomical causes to the ice ages. But there's been a nonscientific interest in that relationship for a long time—that's astrology, right? People believe the future is in the stars. And because of that, I think the field got very little attention. I spent 10 years in that field, culminating in a technical book called *Ice Ages and Astronomical Causes* [Springer, 2000]. It's very detailed, technical, mathematical. When I would give presentations on this subject, of course, half the questions had to do with global warming. So I began preparing myself to answer those questions by studying the issue of global warming. And all the tools I had developed and all the methods I had learned were appropriate for this new field.

The reason I really took on the field seriously had to do with my recognition that so much of the public discourse was ignoring the science, that the issue was enormously important. There were recommendations that even the poor nations of the world spend substantial fractions of their gross domestic product on addressing global warming. It was affecting major U.S. energy policy. And yet the science didn't seem settled. So it struck me as perhaps the most important issue in the world that a physical scientist can address.

How did the BEST project come about?

A colleague of mine drew my attention to some of the issues that were raised by Anthony Watts, who was showing that many of the stations that recorded temperature were poorly sited, that they were close to building and heat sources. I also separately learned of work done by Steve McIntyre up in Canada, who looked at the "hockey stick" data [the data behind a 1999 graph showing temperatures remaining more or less steady for 1,000 years, then rising sharply in the 20th century, like the blade of a hockey stick].

I reviewed the paper that the hockey stick was based on, and I became very uncomfortable. I felt that the paper didn't support the chart enough.

"Before my testimony, there were news articles in prominent newspapers already claiming that I had a bias, that I had an agenda. I don't know where they got this from."

A few years later, McIntyre came out and, indeed, showed that the hockey-stick chart was in fact incorrect. It had been affected by a very serious bug in the way scientists calculated their principal components. So I was glad that I had done that.

There were other issues, too. There were three major groups analyzing temperature, and issues began to be raised. One of them was: Why had they used only a small fraction of the available temperature stations? We looked into this and realized that they did it because their methods of statistical analysis really were fine with a small number of stations, and they worked better when they had long, continuous records. So they were selecting stations that had such records.

This raised a legitimate question: Is there an inherent bias when you choose stations that have long, continuous records? There's a possibility that could happen because if you have a station that's been around for 100 years, it may have started out as being rural and then later was inside of a city, and that could have given it an anomalous warming. We see this in stations in Tokyo, for example. It's called the urban heat-island effect.

The three groups claim that it was not a problem. And maybe they were right. We found it very hard to evaluate that and decided that with modern computers, we could design a system that could actually use all of the data that would address the known problems, such as the urban heat island, in a different way. Not necessarily a better way but in a different way.

This is how scientists do things. We can't always claim that our methods are better than what came before, but we can do things differently and see if we come to the same answer. If we come to a different answer, then that raises the issue of why. And then we can address that issue. But doing things in a different way is a real benefit to a field like this.

Did the mainstream temperature-analysis groups think so, too?

We contacted the other groups who were doing this, and I would say that there was universal agreement that doing things in yet a different way could help. Jim Hansen [of the NASA Goddard Institute for Space Studies], for example, really welcomed our effort because he believed, based on his own care with the subject, that the answer we were going to get would be the same as his group has gotten. That's very nice—that kind of confidence comes about only in people who have done careful work.

Anthony Watts, whom some climate scientists consider a denier, not just a skeptic, has denounced you for going public before the final results are in. Why did you go public?

The idea that you don't show anybody, including your colleagues, results until they are peer-reviewed is something new in science. And it's brought about because of media attention. I don't think that's good.

Now, the problem becomes even more difficult when someone like me is asked

to testify before Congress. I didn't volunteer. I came close to turning it down. And I discussed it with my colleagues, and for the most part they said, "Look, this is the government. This is important. If you don't give them your honest opinion, your honest thoughts on what you know, they're going to pass legislation that doesn't take into account the current status of the science."

Given the favorable things you've said about climate science critics such as Watts and McIntyre, do you think you were called to testify because Committee Chair Ralph M. Hall thought you'd come down against the mainstream consensus?

Before my testimony, there were news articles in prominent newspapers already claiming that I had a bias, that I had an agenda. I don't know where they got this from. Well, I can guess. I think they were predicting what I was going to say in the hopes of discounting it when it came out.

I'm not even going to guess at the Republican committee chair's motivations. Having testified before Congress, I have a sense that most members of Congress are serious, that they are thoughtful, that if they have a point of view that disagrees with what you call the mainstream, it's because there have been legitimate skeptics who have raised real issues that have not necessarily been answered.

I don't care whether I'm speaking to a Republican or a Democrat; science is nonpartisan. And I believe that my refuge is sticking to the science. I have no agenda. I have no political reasons for saying one thing or the other. I stick to the science. I think that's what I'm good at. And if I say something that's surprising, that's good. That adds to the discussion.

You've also said more than once that nothing we do in the U.S. to reduce emissions will make any difference because emissions from coal burned by India and China are growing so rapidly.

In fact, if we cut back and China continues to grow and India continues to grow, our cutting back will not achieve any real good. The hope is that we'll set an example that China and India will follow. But the way it's presented by many people, for political purposes because it sounds more compelling, is that we are responsible for terrible global warming, and we have to cut back regardless of what other people do. And that is not looking at the numbers.

Do you consider yourself a climate skeptic?

No—not in the way that the term is used. I consider myself properly skeptical in the way every scientist would be. But people use the term "skeptic," and unfortunately, they mix it in with the term "denier." Now, there are climate deniers. I won't name them, but people know who they are. These are people who pay no attention to the science but just cherry-pick the data that were incorrectly presented and say there's no there there.

I include among the skeptics people such as Watts and McIntyre, who are doing, in my opinion, a great service to the community by asking questions that are legitimate, doing a great deal of work in and out—that is something that is part of the scientific process.

But you've certainly been critical of people one might call climate "advocates," right?

I've been quoted as saying that both Gore and [*New York Times* columnist Thomas L.] Friedman are exaggerators. These are people who are so deeply concerned with the dangers of global warming that they cherry-pick the data, too, and they're not really paying attention to the science, which is not surprising. They're not scientists.

But that's not science. With science, you have to look at all the data and draw a balanced conclusion. And I believe they're doing it because they are so deeply concerned, and they have accomplished some real good in alerting the American public to an issue that it needs to know about. But not being scientists, they feel they don't have to show the disagreeing data, they don't have to show the discordant data. To the general public, Gore is a scientist. The danger is that when you do it to exaggeration, eventually people will discover you've exaggerated, and then people react.

React how?

I have a sense that part of the reason why climate change is getting less attention in the U.S. these days is because the public is reacting to the prior exaggerations. The public is the jury and hears it on both sides. And when people hear such different results, they get very confused. And right now I believe the public is in a state of confusion because people have learned that some of the issues raised by legitimate skeptics are valid.

Do you think that the IPCC, a major arbiter of climate science, is a legitimate institution?

The IPCC [Intergovernmental Panel on Climate Change] has some very legitimate science in it. The problem is the aspects of the IPCC that have gotten the most public attention are the places where they are grossly exaggerated. So when people say the IPCC is still basically right, the public view of the IPCC is not in the temperature measurements and the computer models; the public view is in the exaggeration, such as the melting of the Himalayas.

The results you described to Congress in March were "preliminary," based on only a couple of percent of the total data. When you're done with the entire data set, will you go before Congress again?

If I'm asked to testify before Congress, I'll have a problem. Congress will ask me to testify. I almost guarantee it. So what do we do? Hey, scientific community, give me advice on this. What do you do when your country asks you for your best state of knowledge of the world's climate change? SA

Michael D. Lemonick *is senior science writer at Climate Central, a nonprofit, nonpartisan climate science and journalism organization.*

MORE TO EXPLORE

The Instant Physicist: An Illustrated Guide. Richard A. Muller. W. W. Norton, 2010.

Richard A. Muller's Web site: http://muller.lbl.gov

SCIENTIFIC AMERICAN ONLINE

A transcript of Muller's testimony at the House hearing is at ScientificAmerican.com/jun2011/muller-hearing

Among Giants: A Life with Whales

by Charles "Flip" Nicklin, with Karen M. Kostyal. University of Chicago Press, 2011 ($40)

For more than 30 years Flip Nicklin has been photographing the world's whales—from humpbacks in Hawaii to narwhals in the Northwest Passage to sperm whales in Sri Lanka. Equal parts coffee-table book and memoir, the gorgeous volume transports readers to the underwater realm of these most mysterious mammals.

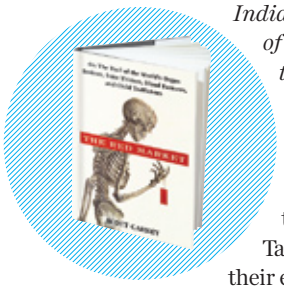
Gray whale

EXCERPT

The Red Market: On the Trail of the World's Organ Brokers, Bone Thieves, Blood Farmers and Child Traffickers

by Scott Carney. HarperCollins, 2011 ($25.99)

Investigative journalist *Scott Carney takes readers on an eye-opening tour of the global trade in human body parts—the so-called red market. Here he describes the plight of the residents of Tsunami Nagar, a refugee camp in India's Tamil Nadu province for survivors of the 2004 tsunami that devastated coastal villages in Indonesia, India and Sri Lanka. The villagers are so poor that many have sold one of their kidneys for cash only to end up receiving less money than they were promised, as well as woefully inadequate follow-up care.*



"For [Maria Selvam, the village's most respected man] and thousands of other poor Tamilians who never got their equal share of India's rising fortunes, selling organs sometimes feels like their only option in hard times.

"'In other parts of India people say that they are going to Malaysia or the United States with a glimmer of hope in their eyes. In Tsunami Nagar people speak that way about selling their kidneys,' he tells me.

"Tsunami Nagar is far from unique. The ample supply of available organs in the third world and excruciating long waiting lists in the first world make organ brokering a profitable occupation. Not only has demand for kidneys risen steadily in the last forty years, but poor people around the world often view their organs as a critical social safety net.

"Since the inception of antirejection drugs like cyclosporine, international cabals of doctors and corruptible ethics boards have slowly transformed slums in Egypt, South Africa, Brazil, and the Philippines into veritable organ farms. The dirty secret of the organ business is that there is no shortage of willing sellers.

"For someone living on less than a dollar a day, $800 is almost an unthinkably large sum of money. The payment offers an undue incentive, coercion that pits abject poverty against a global capitalist enterprise."

ALSO NOTABLE

How the Hippies Saved Physics: Science, Counterculture, and the Quantum Revival, by David Kaiser. W. W. Norton, 2011 ($26.95)

The Science of Evil: On Empathy and the Origins of Cruelty, by Simon Baron-Cohen. Basic Books, 2011 ($25.99)

Adventures in the Orgasmatron: How the Sexual Revolution Came to America, by Christopher Turner. Farrar, Straus and Giroux, 2011 ($35)

The Order of Days: The Mayan World and the Truth about 2012, by David Stuart. Harmony, 2011 ($24)

The Mathematics of Life, by Ian Stewart. Basic Books, 2011 ($27.50)

Epigenetics: The Ultimate Mystery of Inheritance, by Richard C. Francis. W. W. Norton, 2011 ($25.95)

Listed: Dispatches from America's Endangered Species Act, by Joe Roman. Harvard University Press, 2011 ($27.95)

Unnatural Selection: Choosing Boys over Girls, and the Consequences of a World Full of Men, by Mara Hvistendahl. PublicAffairs, 2011 ($26.99)

Measure of the Earth: The Enlightenment Expedition That Reshaped Our World, by Larrie D. Ferreiro. Basic Books, 2011 ($26.99)

The Animal Connection: A New Perspective on What Makes Us Human, by Pat Shipman. W. W. Norton, 2011 ($26.95)

COMMENT AT ScientificAmerican.com/jun2011

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His next book is *The Believing Brain*. Follow him on Twitter @michaelshermer

The Myth of the Evil Aliens

Why Stephen Hawking is wrong about the danger of extraterrestrial intelligences

With the Allen Telescope Array run by the SETI Institute in northern California, the time is coming when we will encounter an extraterrestrial intelligence (ETI). Contact will probably come sooner rather than later because of Moore's Law (proposed by Intel's co-founder Gordon E. Moore), which posits a doubling of computing power every one to two years. It turns out that this exponential growth curve applies to most technologies, including the search for ETI (SETI): according to astronomer and SETI founder Frank Drake, our searches today are 100 trillion times more powerful than 50 years ago, with no end to the improvements in sight. If E.T. is out there, we will make contact. What will happen when we do, and how should we respond?

Such questions, once the province of science fiction, are now being seriously considered in the oldest and one of the most prestigious scientific journals in the world—*Philosophical Transactions of the Royal Society A*—which devoted 17 scholarly articles to "The Detection of Extra-Terrestrial Life and the Consequences for Science and Society" in its February issue. The myth, for example, that society will collapse into fear or break out in pandemonium—or that scientists and politicians will engage in a conspiratorial cover-up—is belied by numerous responses. Two such examples were witnessed in December 2010, when NASA held a very public press conference to announce a possible new life-form based on arsenic, and in 1996, when scientists proclaimed that a Martian rock contained fossil evidence of ancient life on the Red Planet and President Bill Clinton made a statement on the topic. Budget-hungry space agencies such as NASA and private fund-raising organizations such as the SETI Institute will shout to the high heavens about anything extraterrestrial they find, from microbes to Martians. But should we shout back to the aliens?

According to Stephen Hawking, we should keep our mouths shut. "We only have to look at ourselves to see how intelligent life might develop into something we wouldn't want to meet," he explained in his 2010 Discovery Channel documentary series. "I imagine they might exist in massive ships, having used up all the resources from their home planet. Such advanced aliens would perhaps become nomads, looking to conquer and colonize whatever planets they can reach." Given the history of encounters between earthly civilizations in which the more advanced enslave or destroy the less developed, Hawking concluded: "If aliens ever visit us, I think the outcome would be much as when Christopher Columbus first landed in America, which didn't turn out very well for the Native Americans."

I am skeptical. Although we can only represent the subject of an N of 1 trial, and our species does have an unenviable track record of first contact between civilizations, the data trends for the past half millennium are encouraging: colonialism is dead, slavery is dying, the percentage of populations that perish in wars has decreased, crime and violence are down, civil liberties are up, and, as we are witnessing in Egypt and other Arab countries, the desire for representative democracies is spreading, along with education, science and technology. These trends have made our civilization more inclusive and less exploitative. If we extrapolate that 500-year trend out for 5,000 or 500,000 years, we get a sense of what an ETI might be like.

In fact, any civilization capable of extensive space travel will have moved far beyond exploitative colonialism and unsustainable energy sources. Enslaving the natives and harvesting their resources may be profitable in the short term for terrestrial civilizations, but such a strategy would be unsustainable for the tens of thousands of years needed for interstellar space travel.

In this sense, thinking about extraterrestrial civilizations forces us to consider the nature and progress of our terrestrial civilization and offers hope that, when we do make contact, it will mean that at least one other intelligence managed to reach the level where harnessing new technologies displaces controlling fellow beings and where exploring space trumps conquering land. *Ad astra!*

COMMENT ON THIS ARTICLE ONLINE
ScientificAmerican.com/jun2011

Illustration by Invisible Creature

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column since he was a man trapped in the body of a slightly younger man. He also hosts the *Scientific American* podcast Science Talk.

Dining and Dancing

A few easy fixes for long-standing culinary and terpsichorean problems

Inventions exist today that would have boggled the mind just a generation ago. I play Scrabble daily with people all over the country on a smartphone that I carry in my pocket. This device is remarkably versatile and powerful. Why, just yesterday it edited a note I was writing so that a particularly objectionable word choice was corrected to the much more acceptable "duchess," despite the fact that the two words had only the second and third letters in common.

Even with magical gizmos becoming ubiquitous, a few really useful inventions have yet to be realized. Forget flying cars and the carnage they would wreak. I'm talking about stuff we really need. For example, the sequentially ripening banana bunch.

When you buy a bunch of bananas, why must they all ripen to perfection on the same day? One should be ready on Monday, the next one on Tuesday, and so on. This idea is not beyond the bounds of scientific ingenuity. Agricultural scientists could breed bananas with varying peel thicknesses so that each banana would ripen at a different rate. Pharmaceutical scientists faced with a similar challenge came up with time-release cold medications, proving that it can be done!

Another solution would have the benefit of employing the millions of discarded vinyl record turntables, victims of the development of devices such as the one in my pocket, that lie unused in shag-carpeted rec rooms around America. Banana bunches could be set on the turntables and exposed to a nozzle issuing a small, constant stream of the gas ethylene, which promotes ripening. A robotic arm would change the turntable speed from 33 revolutions per minute to 45 rpm (plus the 78 and even 16 rpm speeds if the turntable is sufficiently ancient) at regular intervals to ensure different gas exposure times for different bananas. Each banana in the bunch should thus ripen at a unique rate. Simple and effective.

Fine-tuning bananas' ripening might also decrease peel friction, thus increasing their pratfall potential. Which brings to mind an idea about shoes. How often have you seen women enter a dance club dressed to the nines, wearing shoes that probably cost twice as much as the price of the rest of the items in their wardrobe combined? A few hours later the same women exit the club carrying their expensive shoes like tiny, aerated handbags. These poor young ladies have been forced into fashion extremis because the physical challenges involved in club dancing make the feet swell to enormous proportions. The solution: expandable shoes.

COMMENT ON THIS ARTICLE ONLINE
ScientificAmerican.com/jun2011

One aspect of foot swelling is easily accommodated by elastic bands on the sides of the shoe uppers—such elastics already grace laceless loafers favored by business travelers forced to strip to their socks at every airport security portal. But the true challenge for the dance shoe, much like that of the spiritual being seeking enlightenment, is the expansion of the sole.

The answer can be found in dining-room tables throughout this great land. A table for four becomes a table for six or eight via the insertion of leaves between the two separable halves of the table in its smallest configuration. Talented footwear engineers could design shoes that are similarly pulled apart at the base to allow for the insertion of sole leaves. A few leaf insertions, and the dancers' feet can swell and look swell, too.

Back to agronomy. It is high past time we had an easy-open coconut. Prying apart a coconut today requires an entire Sears Craftsman tool set, as noted previously in this space, in my February 2010 column called "Greenhouse Bananas"—hey, I like bananas and coconuts. Genetic engineers can surely thin the hide of the coconut so that consumers could crack it like an egg. Of course, the coconut shell-lacking could not survive the long fall from a conventional tree. So the hand-operated coconut would necessitate the concurrent development of the ultrashort palm tree. Because a breakthrough can be valuable even if it doesn't make a huge impact. SA

Illustration by Matt Collins

June 1961

Optical Maser

"All conventional light sources are essentially noise generators that are unsuited for anything more than the crudest signaling purposes. It is only within the last year, with the advent of the optical maser, that it has been possible to attain precise control of the generation of light waves. Although optical masers are still very new, they have already provided enormously intense and sharply directed beams of light. These beams are much more monochromatic than those from other light sources; at their best optical masers rival the very finest electronic oscillators as a source of a single frequency. The development of optical masers is moving so rapidly that they should soon be ready for a wide variety of applications. —Arthur L. Schawlow"

This device is today called a laser. Schawlow was a co-winner of the 1981 Nobel Prize in Physics.

Virus Genes

"Less than a decade ago there was no reason to doubt that virus genetics and cell genetics were two different subjects and could be kept cleanly apart. Now we see that the distinction between viral and nonviral genetics is extremely difficult to draw, to the point where even the meaning of such a distinction may be questionable. As a matter of fact there appear to be all kinds of intermediates between the 'normal' genetic structure of a bacterium and that of typical bacterial viruses. Recent findings in our laboratory have shown that phenomena that once seemed unrelated may share a deep identity. —François Jacob, André Lwoff and Jacques Monod"

Jacob shared the 1965 Nobel Prize for medicine.

June 1911

Science of the Unfit

"Ever since the late Sir Francis Galton gave us his science of Eugenics, which in its most literal sense means 'good breeding,' the scientific students of mankind, the directors of insane asylums and hospitals, and criminologists the world over, have been compiling statistics to show not only the danger of permitting the marriage of criminals, lunatics, and the physically unfit, but the effect upon mankind. Fortunately Eugenic associations here and abroad have done much to clear away the popular prejudices inevitably encountered in such educational work and to prepare the ground for legislative action."

Full article is available at www.ScientificAmerican.com/jun2011/eugenics

Iron road: engineering the railroads for the free flow of goods and people across a continent, 1911

A Nation of Railroads

"The first of the transcontinental railroads across the western deserts and mountains [*see illustration*] were built rather more for military and governmental reasons than through any hope of their immediately earning a sufficient amount to make the enormous investment in their construction profitable. Since private owners of capital were not inclined to be philanthropic, the government had to hold out inducements to them to invest their money by giving them land grants and making them loans of five of the seven major roads. These days, competition between these seven roads, both for freight and passenger business, is very keen."

Global Blanket

"Svante Arrhenius has advanced an ingenious theory to account for the glacial periods which have marked several stages of geological history. According to the experiments of Langley, the carbon dioxide and the water vapor, which the atmosphere contains, are more opaque to the heat rays of great wave lengths which are emitted by the earth, than to the waves of various lengths which emanate from the sun. Arrhenius infers that any increase in the proportion of carbon dioxide and water vapor in the atmosphere will increase the protection of the earth against cooling and will consequently raise the temperature of its surface. The theory assumes that the earth's atmosphere was poor in carbon dioxide and water vapor during the earth's cool glacial periods, and rich in these gases during hot periods."

June 1861

War and King Cotton

"We recently published an article on cotton and the war setting forth the conviction that if the struggle should be a prolonged one, it would put an end to the pre-eminence of the cotton States in the supply of this important staple. For this assertion one or two of our subscribers in the cotton States are denouncing us as enemies to the South. It will ultimately appear, when the events now transpiring have reached their practical solution, that those who have 'precipitated the South into revolution' will have done more to uproot their institutions than all the noisy abolitionists to be found in the country. We firmly believe that the permanent interests of the cotton States are secure only in the Union."

SCIENTIFIC AMERICAN, VOL. CIV, NO. 24, JUNE 17, 1911

Up in Flames

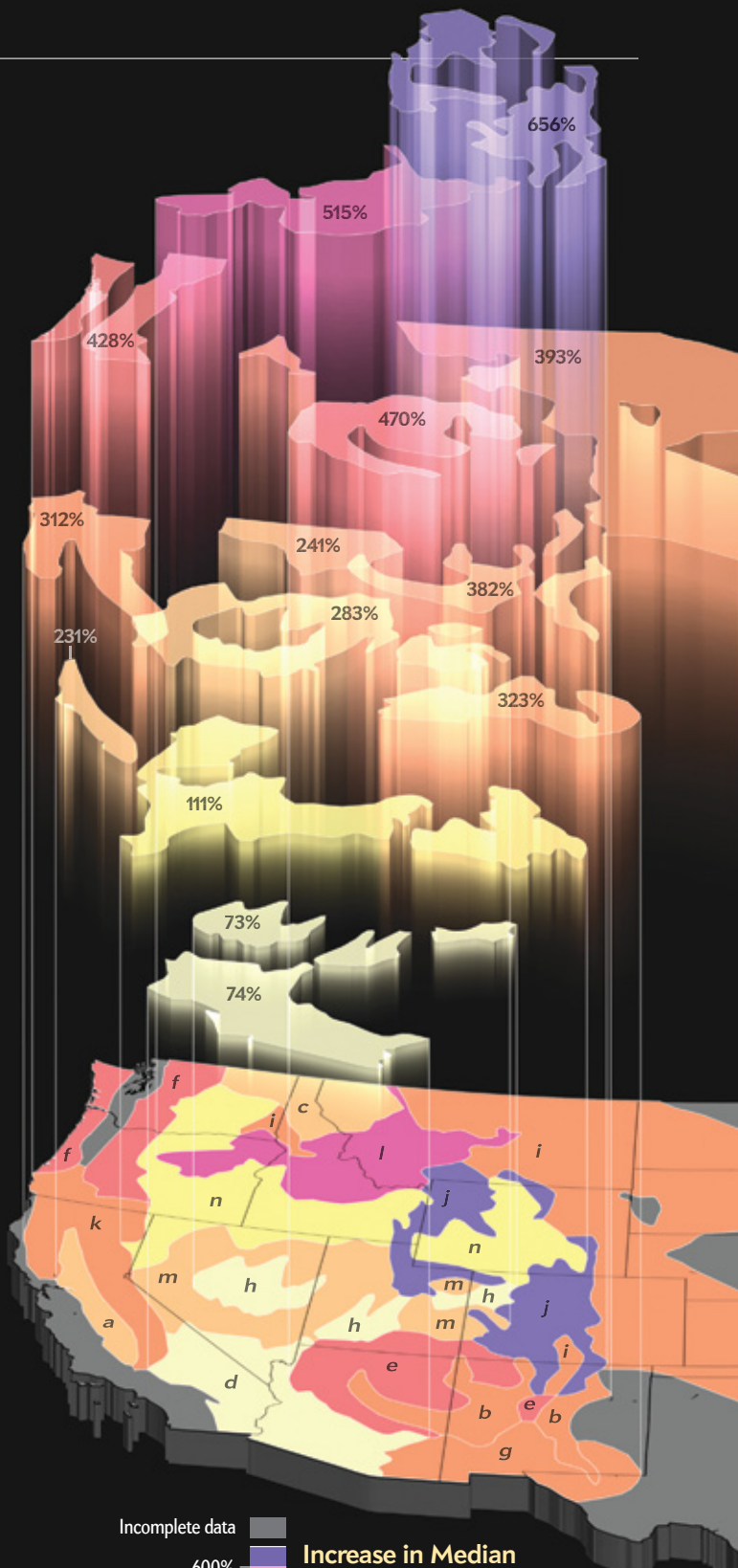
Global warming could scorch the western U.S.

"If climate change drives temperature up a degree or two," goes the common dismissal, "how bad could that be?"

Here's an example: Higher temperatures draw moisture out of live and dead trees and brush, making them more flammable. The heat also can alter precipitation, as well as shift spring thaw earlier, lengthening the fire season. A one degree Celsius climb in average global temperature could cause the median area burned annually by wildfires in parts of the American West to increase up to sixfold. "A one-degree rise could occur well before 2050," notes Jeremy Littell, a climate and fire researcher at the University of Washington, who created the projections with the U.S. Forest Service and other institutions.

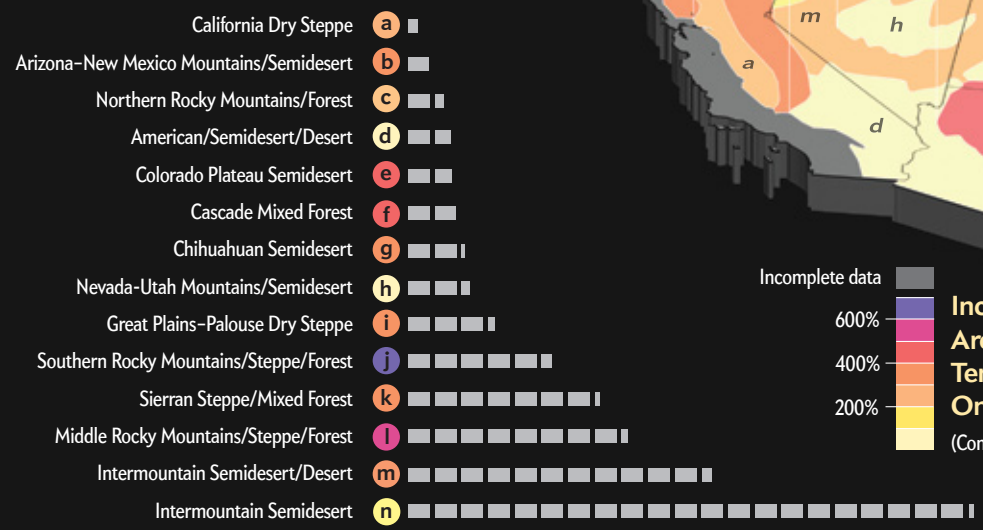
Scientists in Canada have reached similar conclusions about their western region. The U.S. prediction applies to area burned during median fire years; extreme fire years would consume still more area. Unfortunately, as temperature goes up, Littell predicts, "what were historically big fire years may become more frequent." *—Mark Fischetti*

SCIENTIFIC AMERICAN ONLINE
More fire data at ScientificAmerican.com/jun2011/graphic-science



Area Burned in Ecoregion Each Year

(1980–2000 mean) = 100,000 hectares



SOURCES: UNIVERSITY OF WASHINGTON; U.S. FOREST SERVICE

Graphic by Bryan Christie

INTRODUCING

Origins and Endings

Scientific American's new Special Edition for iPad™

Take a journey from the origins of the universe to the end of time. Explore interactive feature articles, expanded information graphics, videos, audio interviews and slide shows. **Download today!**

SA

Available on the App Store

Humans win!

This February, the IBM computer Watson and former champions Ken Jennings and Brad Rutter competed on the TV quiz show *Jeopardy!*

And the winner was—resoundingly—humankind.

Watson's advances in deep analytics—and its ability to interpret natural language (like the complex, contextual, punning language on *Jeopardy!*)—will now be directed toward the world's most enticing challenges.

Natural language is the language of our lives and, increasingly, of our businesses. Watson's ability to discover insights in this very human data has the potential to transform industry and society. Already, we are exploring ways to apply Watson's skills to the rich, varied language of healthcare, finance, law and academia.

We are also at work developing a "Watson cloud"—to help people and organizations understand data and answer questions they couldn't answer before.

During the four years IBM scientists prepared Watson for *Jeopardy!*, they came to appreciate more fully the speed, flexibility and sweep of the human mind. And now, they have created a tool that will extend human potential and address many of our most pressing concerns.

We believe the technology underlying Watson will help make our lives, our work and our societies smarter. Win-win-win. Let's build a smarter planet.

Learn more at **ibmwatson.com**

IBM