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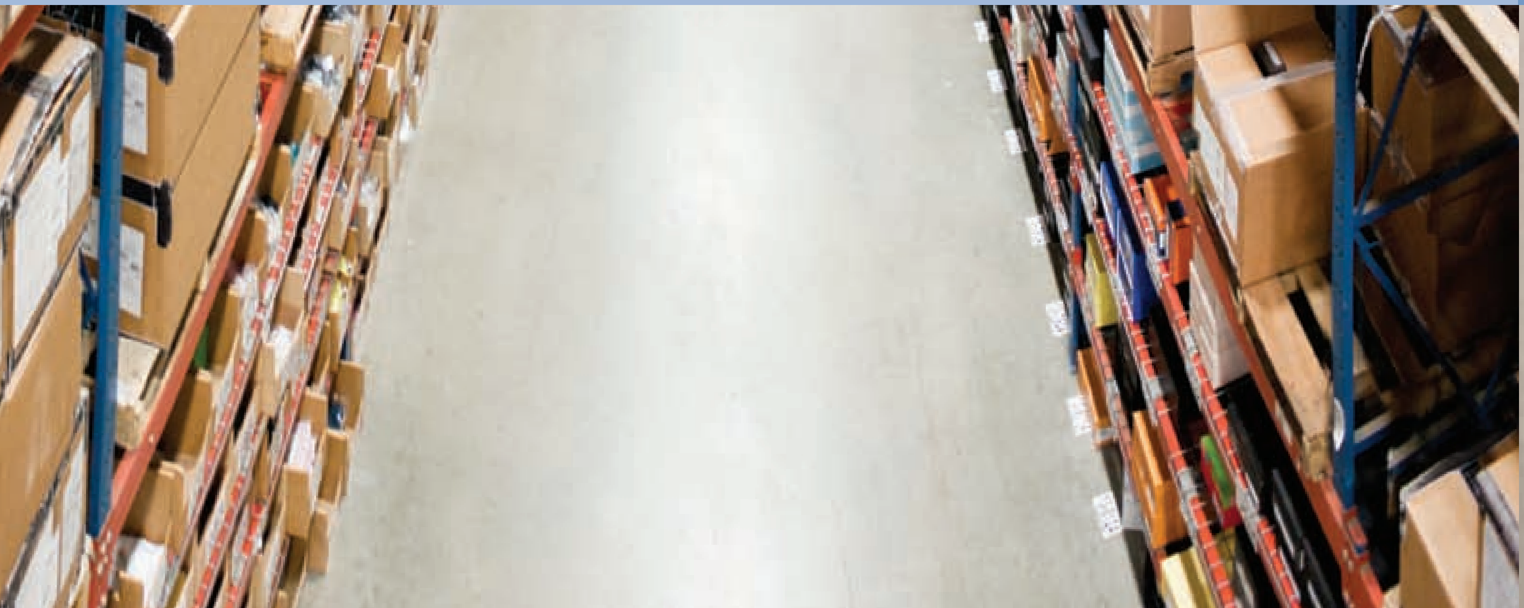
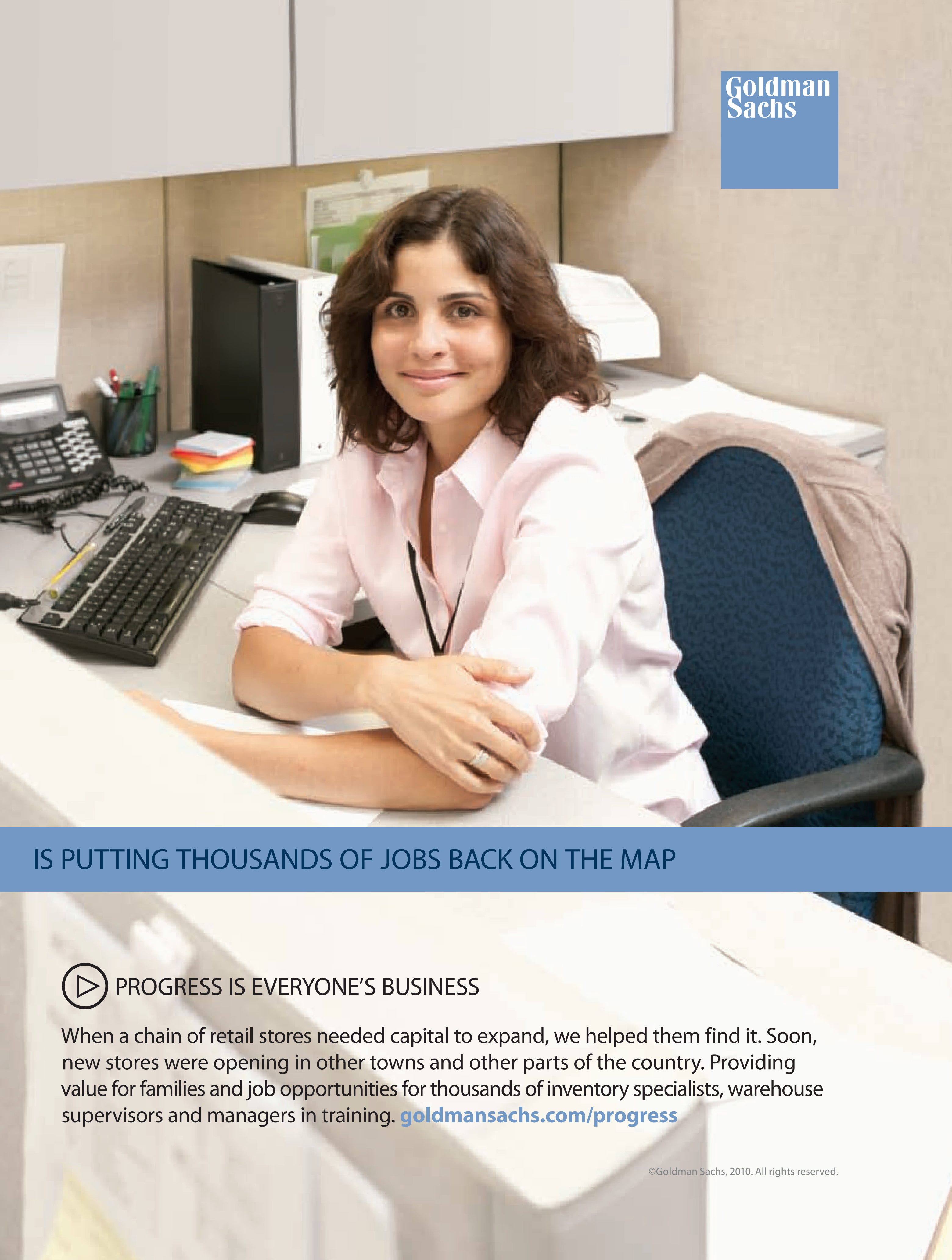
The Real Sexual Revolution

HOW A STRATEGY TO HELP A REGIONAL STORE GO NATIONAL

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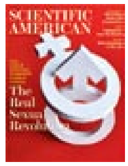
SCIENTIFIC AMERICAN

January 2011 Volume 304, Number 1

ON THE COVER



Fish fossils indicate that copulation in backboned animals originated more than 25 million years earlier than previously thought and hint that it was a driving force in our evolution, helping to establish the anatomical foundation for legs, reproductive organs and perhaps even jaws in the lineage of creatures that ultimately led to humans. Illustration by Owen Gildersleeve.

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FEATURES

Photography by Grant Delin


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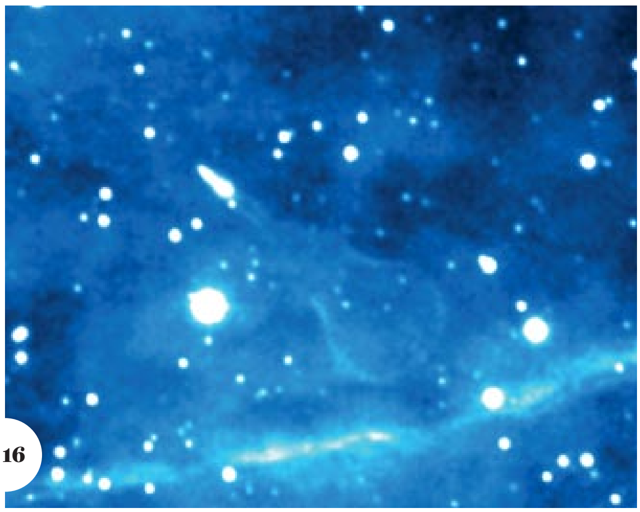
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SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

The Top 10 Science Stories of 2010
An unprecedented oil spill in the Gulf of Mexico and a dramatic change of course for NASA are just two of the stories that dominated headlines last year.
Go to www.ScientificAmerican.com/jan2011

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Mariette DiChristina is editor in chief of *Scientific American*.

Casting a Wide Net

The English language offers some entertaining euphemisms, and one I've always found amusing is used by parents like me, who will say they need to talk to the kids about the "birds and the bees." Science, as usual, adds a new perspective: fishes were around a long time before the birds and bees got busy. Now recently discovered fossils show that internal fertilization arrived millions of years before previously thought and in a more primitive species of fish than expected.

In what is today an Australian cattle ranch, biologist John A. Long and his team examined fossils of sea creatures from the Devonian era. They discovered the earliest evidence of an animal that had sex and gave birth the way we do: a 375-million-year-old embryo inside an ancient fish called *Materpiscis*. The fossils give us new clues about how our own reproductive system arose and how different parts of anatomy evolved over time. As Long writes in his feature article and this issue's cover story, "Dawn of the Deed" (*page 34*): "Sex, it seems, really did change everything." That's no fish tale.

Social science: Magician and skeptic James Randi addresses the New York Academy of Sciences.

Long and his colleagues had to go to Australia to make their finds, but the Internet lets us share the joy of science discovery and learning globally. A new program that provides this capability is the Google Online Science Fair, which will be formally announced in mid-January. The fair will accept submissions from students around the world in three age categories, covering kids from middle through high school. I will be among the judges of the fair projects and will travel to the event to meet the winners in July 2011. *Scientific American* is partnering on the project as part of our ongoing educational efforts.

Perhaps you will view the information about the online science fair by using your smart phone or an electronic tablet. And if you do, you might also look for *Scientific American* on the iPhone, iPad and other devices soon. The magazine and its editors are also on Facebook and Twitter. In addition, we're taking science to the people in person. In the past few months we have held *Scientific American* events at the California Academy of Sciences in San Francisco, at the 92nd Street Y TriBeCa in New York City—and most recently at the New York Academy of Sciences (*photograph above*).

The heart of what we do at *Scientific American* will always be the expert-informed, authoritative editorial that we provide, and we hope that exploring these new venues and formats will help bring science to the lay public more broadly. The world at large could certainly use more science. SA

COURTESY OF MARIA CRUZ-LORD

Illustration by Nick Higgins

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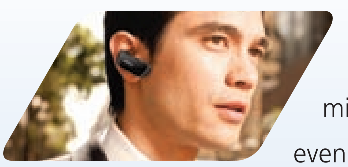

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September 2010

“The dead-donor rule is medically counterproductive and is merely a sop to the most skittish.”

K. A. BORISKIN *BELLINGHAM, MASS.*

END OF LIFE

I agree with Robert D. Truog—quoted in Robin Marantz Henig’s “When Does Life Belong to the Living?”—that the dead-donor rule, which says that organs can be taken only from donors who have already been declared dead, is eyewash and should be scrapped. The rule is horrible and medically counterproductive and is merely a sop to the most skittish, and probably least informed, members of society. And Arthur L. Caplan’s caution in “What Comes Next” about having to consider these people notwithstanding—constantly looking over one’s shoulder, asking what Jim Public would say about any given rule or action—is excessive, potentially to the point of paralysis.

If I thought it would carry any weight, I would be more than willing to sign a waiver of the rule right now, when I am presumably of sound mind, and reaffirm it whenever necessary. Further, I would be willing to sign whatever was necessary to exclude family members from any end-of-life and dead-donor decisions. I have seen such family decisions made that ended up merely being destructive, potentially denying someone perfectly good organs. I do not want to be in that situation, as donor or receiver getting a rotting organ. Understandably the receiver has no control over the situation, but denying the donor the right to make the decision is an outrage.

K. A. Boriskin
Bellingham, Mass.

END OF DEATH

Of course, it would be wonderful if—as Thomas Kirkwood writes in “Why Can’t We Live Forever?”—we could “identify novel drugs able to combat age-related diseases in completely new ways and thereby shorten the period of chronic illness experienced at the end of life.”

But we should not lose sight of the fact that many sick old people want to prolong their lives even if they cannot be cured. Health is better than illness, but illness is not necessarily worse than death. Ask Stephen Hawking.

Felicia Nimue Ackerman
Department of Philosophy
Brown University

END OF TRASH

Christopher Mims’s “Landfills” [“Good Riddance”] really missed the mark when it wished the end of landfills. Modern, state-of-the-art landfills are carefully regulated facilities, managed to reduce air pollution, control leachate and minimize odors. They are also an important source of clean, renewable energy. Landfill operators are increasingly turning to technology that captures methane emissions and converts them into clean fuel.

More than 500 of these landfill-gas-to-energy projects are operating across 46 states, generating enough energy to supply more than 1.6 million homes and businesses, including major companies such as Honeywell and Dell. The U.S. Environmental Protection Agency estimates that the use of landfill-gas-to-energy projects reduces greenhouse gas emissions by the equivalent of taking 16 million passenger cars off the road.

Solid-waste companies fully support zero-waste initiatives and are working closely with local governments, manufacturers, consumers and other partners to achieve this goal. But the volume of trash that Americans continue to generate means we must rely on traditional means of disposal for some time.

Fortunately, today’s solid-waste industry is ready to meet this challenge with science-based solutions, including waste-based energy, more efficient and sophisticated recycling facilities, and modern landfill technology.

Bruce J. Parker
President and CEO
National Solid Wastes Management Association

END OF COLUMNS

How sad to have to say good-bye to Jeffrey D. Sachs and Lawrence M. Krauss, whose final columns [Sustainable Developments and Critical Mass, respectively] appeared in the September issue. They will be missed. Their columns were each written with knowledge, wisdom and insight, of the kind that one normally does not encounter in day-to-day living. We can be grateful, however, for what they do for humanity and for the words they wrote during their time with *Scientific American*. I have to believe that they have left us all wiser and more hopeful for the future.

William Kremer
Watsonville, Calif.

END OF TIME

I think it is instructive that in a discussion of how time would not exist if there were no natural clocks [“Could Time End?”], George Musser refers to the fact that the Compton wavelength of particles would not have existed before 10 picoseconds after the big bang—and hence there could have been no possibility of time before that. If so, how could he assert that the era was 10 picoseconds long? Why not 10 billion years?

Tom Alrich
Evanston, Ill.

MUSSER REPLIES: This is an excellent question. It is what I was trying to get across in my remark that “If the early universe had no sense of scale, how was it able to expand, thin out and cool down?” How can we meaningfully say that structures became possible only at 10 picoseconds if we can’t define a picosecond?

Roger Penrose's answer is that spatial and temporal scales, though individually ambiguous, remain linked, so that we are still able to meaningfully describe cosmic evolution.

As I near 50 years of age and consider my own end, I find that the more certainty those who speak with "conviction"—be it Stephen Hawking and his existential Godless universe, or Christopher Hitchens, or Richard Dawkins—proclaim to have, the less convinced I am. I need no God, nor do I need a cosmologist to espouse theories that cannot be proven in my lifetime (or in any lifetime).

While they seek to explain how the universe works, the quest for the answer to "Why are we here?" may never be answered, from which I take solace. Why are we here? Because we *are* here. 'Nuff said. It is more interesting and comforting to know that for now, we are; we exist; we argue over ridiculous beliefs. This tapestry needs no explanation, to which I simply say, "Be grateful that you and I have had the opportunity to experience its wonder."

W. Scott Fentress
Brookfield, Conn.

ERRATA

In "How Much Is Left?" Michael Moyer wrote that indium is a silvery metal that sits next to platinum on the periodic table and shares many of its properties. This is untrue: iridium, not indium, is the metal located next to platinum.

In Zeeya Merali's "Rummaging for a Final Theory" [News Scan], the Lie group that Murray Gell-Mann used to map particles was wrongly identified as SO(3). Gell-Mann used the group SU(3).

In the August 2010 issue, we credited the snail egg images on page 71 to Robert Sutton of the University of Plymouth. Instead the images were by Robert Ellis of the University of Plymouth.

CLARIFICATION

Moyer's "How Much Is Left?" shows a graph of oil production peaking at less than 80 million barrels per day in 2014. Total oil production was more than 85 million barrels per day already in 2009, but the graph referred exclusively to conventional oil from major producers.

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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/jan2011

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A Political Wish List

As a new Congress takes office, Washington will face urgent issues in science, health and the environment. Here are a few good places to start

Grain silos

Throughout U.S. history there have been leaders, both Republicans and Democrats, who have supported the advancement of science and the protection of health and the environment and who have taken care to inform their policy decisions with the best scientific advice. After the midterm elections in November, it looked as though this tradition might take a backseat in the new Congress. For example, Representative-elect Jon Runyan, Republican of New Jersey, said in the aftermath of the election that to balance the federal budget one could cut "all the money we spend on frivolous research projects … studying mating tendencies of fruit flies, stuff like that—is that really necessary?"

It is. The study of disease (for which fruit flies are essential tools), and scientific research in general, boosts economic growth, creates jobs and often ends up saving taxpayers money, as do improving infrastructure, supporting small farmers and promoting green energy. These are issues on which both parties could and should find common ground. Here is what we think should be top priorities of Congress and the Obama administration during the next two years.

Farm subsidies. The nation's agricultural policy is due for an update in 2012. This gives Congress an opportunity both to cut spending and to help the environment. Federal subsidies now mostly reward large farms for planting monocultures of corn, soybeans, wheat and rice. Much of that food goes to factory farms, where tightly packed animals provide a breeding ground for infectious diseases and produce vast quantities of waste that poses an environmental hazard. The current system devours fossil fuels, depletes the soil and pollutes waterways. It also makes high-sugar foods and beef artificially cheap, contributing to the obesity and diabetes epidemic. Through a transition in the way subsidies are allocated, the government should encourage a progressive return to sustainable, integrated farming, which alternates commodity crops with legumes and with grass for pasture.

Climate change. Opponents of proposals to cap carbon emissions argue that such measures would be a drag on the economy. But action on climate change is simple prudence. Doing nothing carries risks that outweigh the cost of phasing out emissions. Politicians should accept that calculation because the science that supports it is strong. They should also consider adopting sensible, market-friendly climate and energy measures. Options include the bipartisan "cap and dividend" bill proposed by Senator Susan M. Collins of Maine and Senator Maria Cantwell of Washington State—a revenue-neutral approach that would auction carbon permits and return the proceeds to taxpayers—and a low-carbon-electricity standard, which would give states more options for generating clean power.

Smoking. In 2004 the U.S. signed the World Health Organization's Framework Convention on Tobacco Control, which encourages measures to reduce smoking. Seven years later the U.S. Senate has yet to ratify that document. It should. Despite a recent move to require more graphic warning labels, the U.S. is still one of only a handful of nations that are not required to adopt anti-smoking programs or counter the increased marketing of tobacco products in the developing world. Also, as Brianna Rego describes in this issue [see "Radioactive Smoke," on page 78], the Food and Drug Administration now has the authority to regulate tobacco and could begin to use it by making cigarettes free of highly toxic substances such as the radioactive isotope polonium 210.

Protecting the Internet. The monopoly power of Internet providers, reinforced by a regulatory quirk, is putting the democratizing and liberating effects of new media at risk. Nine years ago the Federal Communications Commission classified broadband Internet access as an "information service" rather than a "telecommunications service"—in effect, ruling that broadband was more akin to a single information source rather than an essential conduit through which the 21st century communicates. As a consequence, the agency lacks the authority to prevent Internet providers from screening what information we can or cannot access online. The FCC should reverse this decision and ensure the Internet stays free and open. SA

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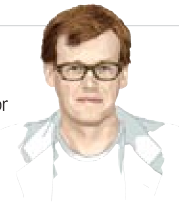
LESTER LEFKOWITZ *Getty Images*

Commentary on science in the news from the experts

David G. Victor is director of the Laboratory on International Law and Regulation at the University of California, San Diego. He is author of *Global Warming Gridlock*, to be published by Cambridge University Press in February.



Diplomacy's Meltdown

When it comes to climate change, developing nations aren't the laggards

Bad news on climate diplomacy continues to pile up. A spate of studies has shown over the past year that even if countries honored the pledges they made in the Copenhagen Accord in December 2009, warming would still blow past the agreed limit of two degrees. Most other elements of the accord, which was designed to keep momentum until a formal climate treaty could be reached, are under shadow as well. Plans by rich nations to add $100 billion of new money in the next decade to help developing countries cut emissions are evaporating. And diplomatic talks on a formal treaty are moving backward.

SETH RESNICK *Getty Images*

Why is diplomacy stalled? The conventional wisdom holds that developing countries are the main villains. Few will agree to sign binding and verifiable commitments to control emissions. The reality, however, is different. China, India, Brazil and other developing countries are actually the leaders in the effort to curb emissions. But most of what they are doing is not visible, because it is rooted in local concerns, such as urban air pollution, rather than fear of global warming.

China, the world's biggest emitter, is making the world's biggest effort to check growth in its pollution. Last year marks the end of a five-year massive program to boost the country's energy efficiency, and plans are in place for another major push over the next five years. China is building more nuclear plants (zero-emissions) and ultrasupercritical coal plants, which are much more efficient than conventional plants and thus less polluting, than the rest of the world combined. China is much more in the news for its big push on renewable power, but its investment in advanced coal and nuclear power will have a much bigger impact on warming emissions. Across the Chinese economy, efficiency has become a watchword. It even factors into how the Chinese Communist Party promotes its officials.

India is in the midst of a similar push. Most new coal-fired power plants are more efficient than the older technologies that used to be standard equipment. A program to build commercial nuclear power is gathering steam, thanks in part to a deal brokered by the U.S. to give India access to Western technology and fuel. India, China and many other countries are poised to rely more heavily on natural gas, which has less than half the warming emissions of coal. And India is embarking on one of the world's most ambitious solar energy programs.

Developing nations are also making progress on curbing deforestation, which accounts for perhaps one seventh of all greenhouse gas emissions. Brazil, owner of the planet's largest tropical forests, has radically improved enforcement of its forest laws—contributing to the lowest rate of deforestation in that country in two decades. Indonesia is crafting policies—in part with external help from Norway and other wealthy countries—to cut its total emissions, mainly by slowing deforestation.

The sum of these efforts in developing countries will reduce growth in warming emissions by billions of metric tons of warming gases per year over the coming decade. That dwarfs the total cuts by Westerns nations to comply with the Kyoto Protocol, which amounted to, at most, a few hundred million tons. Developing countries have most of the leverage for further cuts. They now account for half the emissions of warming gases—and rising.

Developing countries have resisted enshrining their programs into binding international law because most of these initiatives are rooted in national goals, such as controlling local pollution and increasing the value of forests, which makes them skittish about foreign commitment and monitoring. Breaking the gridlock on global warming, which will make it easier for these countries to do even more in the future, will require less intrusive approaches, such as flexible commitments and peer review.

The initiatives under way in developing countries will not be enough, of course. Strict treaties with deep cuts in emissions, monitoring and penalties will be required for all nations. But that is a long way off, and the current track is making it harder to build the credibility and trust that will be needed. The rich countries focus on bold goals—such as stopping warming at two degrees or giving away $100 billion in financial support—with no relation to what they can really implement. That makes developing countries unsure which commitments are genuine. Smaller initiatives aligned with what countries can really honor would be a smarter way forward. SA

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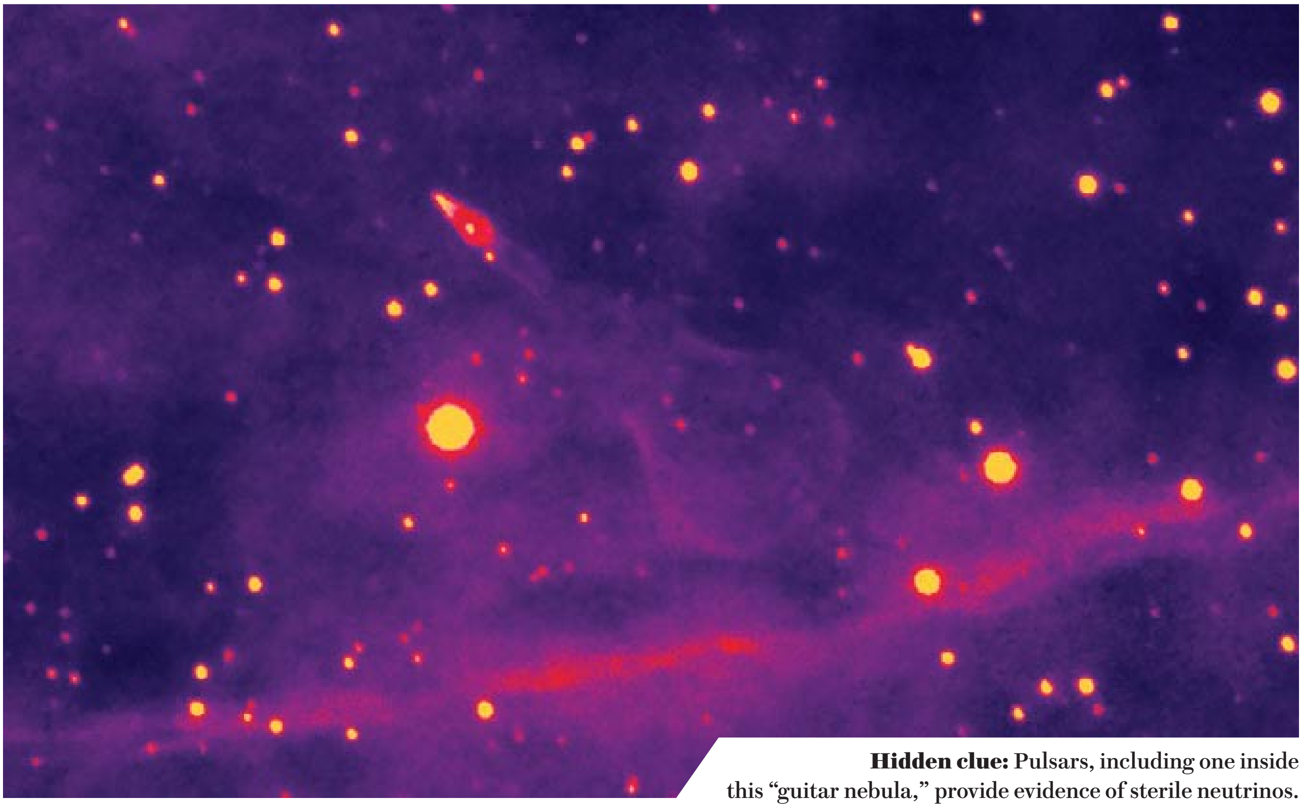

Hidden clue: Pulsars, including one inside this "guitar nebula," provide evidence of sterile neutrinos.

ASTRONOMY

A Whole Lot of Nothing

A flurry of evidence for a new subatomic particle could help explain the mystery of dark matter

Neutrinos are the most famously shy of particles, zipping through just about everything—your body, Earth, detectors specifically designed to catch them—with nary a peep. But compared with their heretofore hypothetical cousin the sterile neutrino, ordinary neutrinos are veritable firecrackers. Sterile neutrinos don't even interact with ordinary matter via the weak force, the ephemeral hook that connects neutrinos to the everyday world. Recently, however, new experiments have revealed tantalizing evidence that sterile neutrinos are not only real but common. Some of them could even be the stuff of the mysterious dark matter astronomers have puzzled over for decades.

Physicists aren't quite ready to make such dramatic pronouncements, but the results "will be extremely important—if they turn out to be correct," says Alexander Kusenko of the University of California, Los Angeles.

How did scientists go about looking for particles that are virtually undetectable? Kusenko and Michael Loewenstein of the NASA Goddard Space Flight Center reasoned that if sterile neutrinos really are dark matter, they would occasionally decay into ordinary matter, producing a lighter neutrino and an x-ray photon, and it would make sense to search for these x-rays wherever dark matter is found. Using the Chandra x-ray telescope, they observed a nearby dwarf galaxy thought to be rich in dark matter and found an intriguing bump of x-rays at just the right wavelength.

Another piece of evidence comes from supernovae. If sterile neutrinos really do exist, supernovae would shoot them out in a tight stream along magnetic field lines, and the recoil from this blast would kick the pulsars out through the cosmos. It turns out astronomers observe precisely that: pulsars whizzing through the universe at speeds of thousands of kilometers a second.

Astronomers don't have to rely on the skies for evidence of sterile neutrinos, though. Scientists at Fermi National Accelerator Laboratory recently verified a 16-year-old experiment that sought the first evidence of these particles. The Fermilab scientists fired ordinary neutrinos through Earth at a detector half a kilometer away. They found that in flight, many of these neutrinos changed their identities in just the way they should if sterile neutrinos do in fact exist.

The next step is to confirm the results. Loewenstein and Kusenko recently repeated their experiment on another space-based x-ray telescope, the XMM-Newton, and Fermilab scientists are also setting up another run. The shyest elementary particles may not be able to evade their seekers for long.

—Michael Moyer

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COURTESY OF SHAMI CHATTERJEE AND JAMES M. CORDES *Cornell University*

ONCOLOGY

How Old Is Your Cancer?

Pancreatic tumors can germinate for a decade before turning deadly, raising hopes for early detection

A patient who receives a diagnosis of pancreatic cancer has only a 5 percent chance of surviving for five years, a harrowing prognosis that scientists have long struggled to understand. Part of the problem, new research suggests, is that the disease is not typically diagnosed until 15 years after the first cancer-causing mutations appear, by which point the cancer has spread and become highly aggressive. The findings indicate that there may be plenty of time for doctors to intervene before pancreatic cancer becomes lethal—an exciting prospect given recent advances in diagnosing the disease early, when it can be successfully removed with surgery and chemotherapy.

Pancreatic cancer cells

In research published recently in *Nature* (*Scientific American* is part of Nature Publishing Group), scientists at Johns Hopkins University sequenced the genomes of seven people who had died of late-stage pancreatic cancer. Their tumor cells contained different types of mutations that the scientists traced back in evolutionary time using mathematical models to build a kind of "family mutational tree." The models suggested that cancer cells appear 10 years after the first cancer-causing mutation arises and that another five years pass before the cancer cells spread and become deadly. The findings question "the pervasive belief that pancreatic cancer is so aggressive and grows so quickly that screening cannot be effectively used," says study co-author and Johns Hopkins pathologist and oncologist Christine A. Iacobuzio-Donahue.

In the past two years scientists have brought screening techniques for pancreatic cancer closer to reality. In February 2010 researchers at the University of California, Los Angeles, compared RNA found in the saliva of 60 treatable pancreatic cancer patients with the saliva of 30 cancer-free individuals and identified four RNAs that together could correctly identify the cancer 90 percent of the time. And in March 2009 Northwestern University researchers publishing in the journal *Disease Markers* developed an optical technology that recognizes various stages of pancreatic cancer cells with 95 percent sensitivity. The technique uses light scattering to detect changes in the cells of the duodenum, part of the small intestine adjacent to the pancreas, which can be viewed using minimally invasive endoscopy.

These technologies are not yet available commercially, but early detection using optical tests and blood or saliva analyses should "advance measurably in the next decade," says David Tuveson, an oncologist at the Cambridge Research Institute in England. Until then, he notes, doctors should consider using current techniques such as CT and MRI scans to screen patients who are at high risk because of family history of the disease. "Recall that our Supreme Court Justice Ruth Bader Ginsburg had a small pancreatic cancer diagnosed in January 2009 when she was undergoing a CT scan," Tuveson says. One month later doctors removed it successfully and discharged her with a clean bill of health.

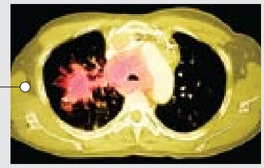
—Melinda Wenner Moyer

QUOTABLE

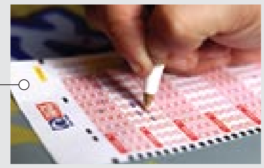
"To me, this whole thing looks like a snow globe that you've simply just shaken."

—Peter H. Schultz, a Brown University astronomer describing Comet Hartley 2, which a NASA spacecraft photographed spewing ice chunks through carbon dioxide jets near its surface.

Genius

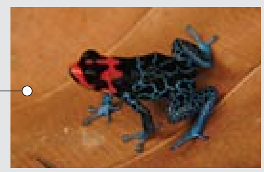


A major study shows spiral CT scans can lower lung cancer mortality rate.

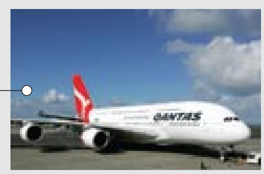


An Israeli lottery drawing produces two identical six-digit winning numbers twice in three weeks, a four trillion-to-one probability.

Conjoined twins from Canada, who share a thalamus, may each be able to see and feel what the other is experiencing. An intriguing case or media hype?



The good news: 1,200 species were discovered in the Amazon region over the past decade. The bad news: their rain-forest habitats are being systematically destroyed to make room for farming.



Problems with Rolls Royce engines in Airbus superjumbo jets cause groundings, increasing passenger anxiety. High-speed rail, anyone?

Cholera breaks out in Haiti after January 2010 earthquake. Could better planning have prevented this?

Folly

—George Hackett

STEVE GSCHMEISSNER *Photo Researchers, Inc.* (*cancer cell*); SCOTT CAMAZINE *Photo Researchers, Inc.* (*CT scan*); ABIR SULTAN *Corbis* (*lottery*); COURTESY OF EVAN TWOMEY (*frog*); TIM HALES *Getty Images* (*plane*)

DO THE MATH

Animal Instincts

Are creatures better than us at computation?

A number of recent news stories have had a similar kind of message: animals viscerally understand certain mathematical operations better than humans do. Such stories are always interesting in a Sunday-newspaper sort of way, but do the abilities of animals to calculate really exceed those of humans? It may help to examine some of these claims.

In the infamous Monty Hall Problem, named after the television game show, human subjects seem to pale next to pigeons in mathematical reasoning. A guest on the show has to choose among three doors, behind one of which is a prize. The guest states his choice, and the host opens one of the two remaining closed doors, always being careful that it is one behind which there is no prize. Should the guest switch to the remaining closed door? Most people choose to stay with their original choice, which is wrong—switching would increase their chance of winning from $1/3$ to $2/3$. (There is a $1/3$ chance that the guest's original pick was correct, and that does not change.) Even after playing the game many times, which would afford ample opportunity to observe that switching doubles the chances of winning, most people in a recent study switched only $2/3$ of the time. Pigeons did better. After a few tries, the birds learn to switch every time.

They learn, but do they calculate or understand? Not at all. Good empiricists, the pigeons simply follow the evidence. People, on the other hand, overanalyze and get confused.

Bees who seem to find the shortest path connecting many flowers in a meadow provide another example of what appears to be animal perspicacity. Even if the path they follow is optimal (and the only way to find out is to measure all possible paths), they cannot be said to have come up with a general algorithm, a task so complex that it belongs in a class of virtually unsolvable problems called NP-hard. Their path may often be a good approximation of the shortest path, but there is no good reason to think that they will always produce such an approximation, much less the optimal solution for all placements of an indefinite number of flowers.

Similar hyperbole arises in articles about dogs' alleged ability to do calculus and spiders' knowledge of geodesics (not to mention octopuses' knowledge of soccer). Alas, although all these results (except for the last) are of real scientific interest, they are almost always mischaracterized as instances of understanding. By insinuating that animals' innate instincts are superior to humans' feeble attempts to mathematize, some of the journalistic accounts betray an anti-intellectual bias. "What good are our dry algorithms, our probability, calculus and geometry," they seem to ask, "when pigeons, bees, dogs and spiders can do the math without thinking?" *—John Allen Paulos*

Paulos is a professor of mathematics at Temple University.

MARKUS BOTZEK *Corbis*


WHAT THE NEW CAR
HAS BEEN WAITING FOR.
Introducing the WattStation™
It seems like we've been waiting a long time for the electric car, but maybe the electric car was waiting for this. Introducing the WattStation from GE. Learn more about electric vehicle charging at: ecomagination.com/wattstation.
imagination at work
ecomagination™

NEUROMEDICINE

Breaching the Brain Barrier

Tiny bubbles may help lifesaving drugs cross a crucial boundary

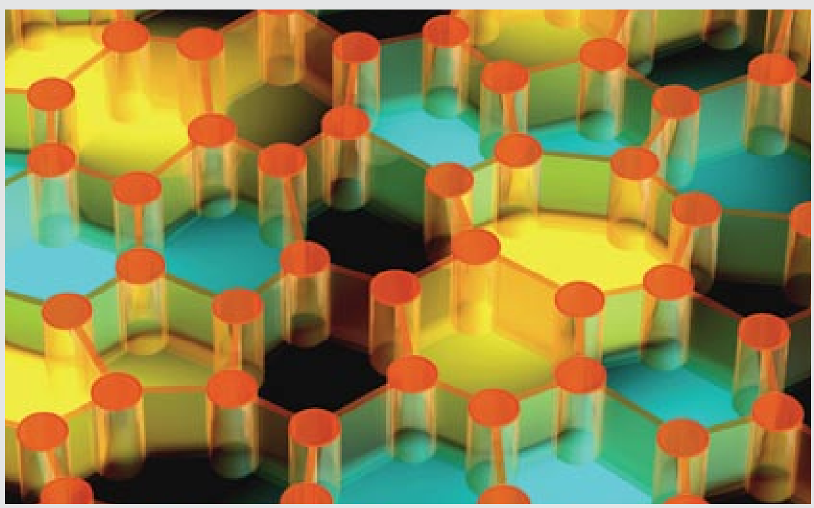
The blood-brain barrier, a dense layer of tightly packed cells that line brain capillaries like a regiment of infantrymen, has always been the bane of neuromedicine. True, this line of defense protects the brain from all manner of potentially harmful chemicals. But it keeps most medications out, too. Scientists have spent decades searching for ways to breach the barrier just long enough for Alzheimer's, Parkinson's or antitumor drugs to slip through. Now, researchers say, they are finally onto something.

The new method employs microbubbles—small, preformed bubbles made up of a simple gas surrounded by a rigid lipid cell. Scientists at Harvard, the Massachusetts Institute of Technology, Columbia and other institutions are developing ways of injecting the bubbles into the bloodstream and guiding them by ultrasound to the blood-brain barrier. The bubbles then pry open the barrier at specific points targeted by the ultrasound beam. Once the barrier is breached, scientists inject drug-coated, magnetically charged nanoparticles into the patient and utilize MRI beams to guide them to the precise spot where they are most needed. So far rodent studies have shown as much as a 20 percent increase in the amount of antitumor or Alzheimer's medication that reaches the brain when ultrasound and microbubbles are used.

Microbubbles are only the latest and most promising in a string of recent projects aimed at solving the blood-brain barrier problem. These include running a catheter into the brain capillaries and designing a whole suite of drugs that would trick the brain into letting them cross. "Microbubbles are less invasive and more cost-effective than other things we've come up with," says Nathan McDannold, who is a radiologist and researcher at Brigham and Women's Hospital in Boston.

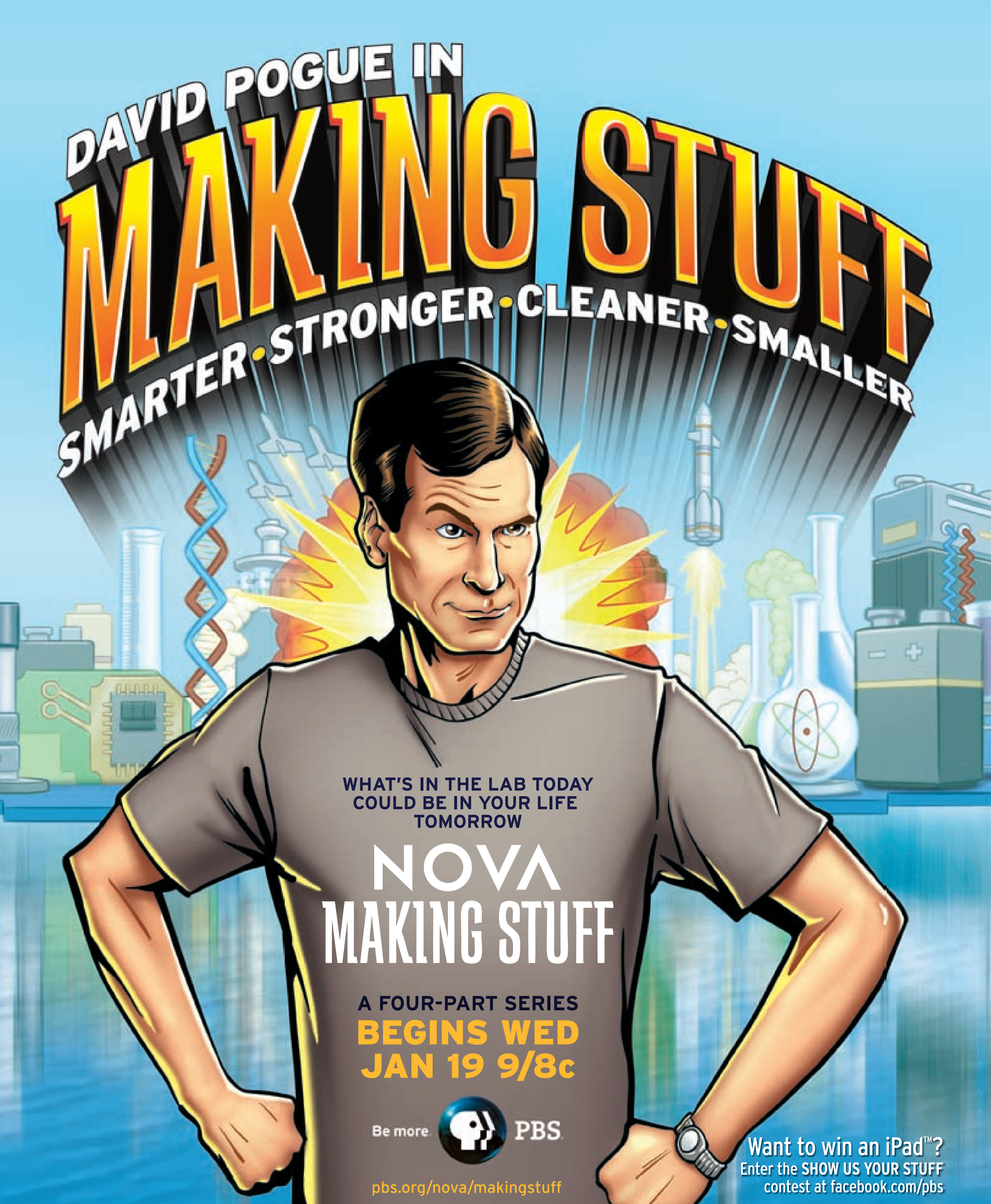
Scientists need to iron out some kinks, however. The main problem is how to increase the intensity of ultrasound to a level that will work in humans without causing tissue damage. McDannold believes that researchers are making rapid progress on all fronts. "It's not quite ready for humans yet," he says. "But we are getting there, quickly." *—Jeneen Interlandi*

WHAT IS IT?



Order from chaos: *The Art of Science exhibit at Princeton University recently displayed a new design for a material that will help researchers develop smaller circuits for compact photonic devices, which use light instead of electrons to transmit information. To bend and guide light in photonic devices, engineers often create regular nanometer-scale patterns of holes called photonic crystals. But photonic crystals' regular patterns bend light differently depending on the angle, whereas the new materials, thanks to their random structure, would allow engineers to bend it at any angle without losing information. This computer-generated image, created by Paul J. Steinhardt and his colleagues at Princeton, shows networks of cylinders and walls (orange), which would be carved out of a layer of silicon.* —Ann Chin

COURTESY OF MARIAN FLORESCU, PAUL J. STEINHARDT AND SALVATORE TORQUATO AND PRINCETON UNIVERSITY ART OF SCIENCE COMPETITION


DAVID POGUE IN
MAKING STUFF
SMARTER • STRONGER • CLEANER • SMALLER
WHAT'S IN THE LAB TODAY COULD BE IN YOUR LIFE TOMORROW
NOVA
MAKING STUFF
A FOUR-PART SERIES
BEGINS WED JAN 19 9/8c
Be more PBS
pbs.org/nova/makingstuff
Want to win an iPad™?
Enter the SHOW US YOUR STUFF contest at facebook.com/pbs

WILDLIFE

Will It Float?

Two scientists and a computer weigh in on a long-standing mystery about giraffes

If you dropped a giraffe into a deep pool of water, would it float, or would it sink? If it could float, would it swim briskly and confidently to the nearest bit of land, or would it flail around helplessly and drown?

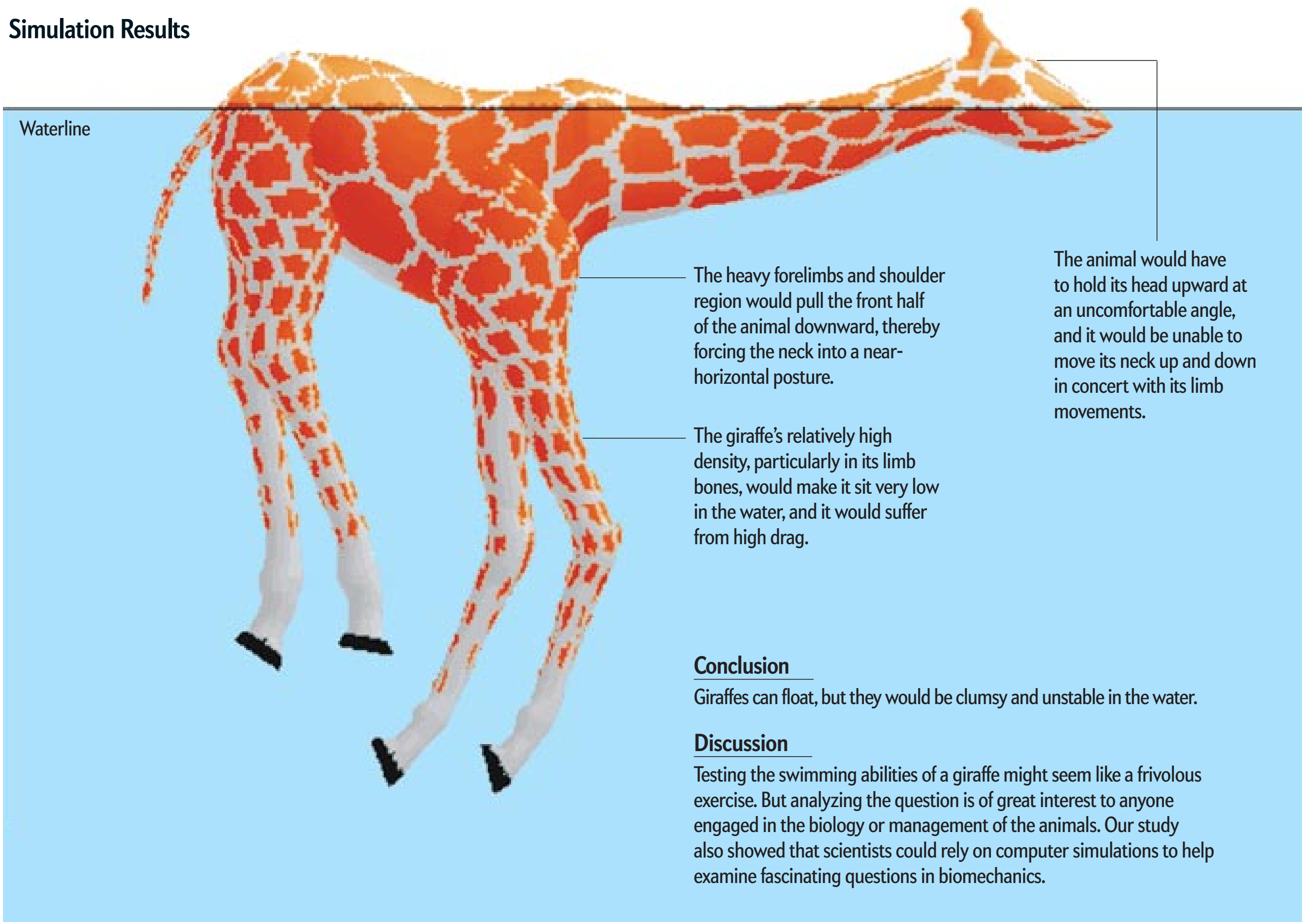
Strange as it may seem, the floating and swimming abilities of giraffes—or rather their supposed lack of floating and swimming abilities—have often been written about by experts. It has been asserted that giraffes "sink like stones" and "cannot swim, even in an emergency," and that "rivers are an impassable barrier to them." Although a few rare photographs and segments of film show that giraffes will wade into deep rivers when they have to, definite observations of them swimming have yet to be reported.

One way to examine the behavior of giraffes in water would be to push one into a deep pool and observe the results. Ethical and practical concerns make this hypothetical experiment impossible, so I thought of another solution. Inspired by sheer curiosity, I approached Donald Henderson of the Royal Tyrrell Museum of Palaeontology in Drumheller, Alberta, who had created a three-dimensional computational model of a giraffe for another project and had also tested the buoyancy of assorted living and extinct animals by using flotation-simulating software. Could Henderson, I wondered, test the buoyancy of his "digital giraffe" in the same way? If he could, we might be able settle this question once and for all.

To compare the model's aquatic behavior with that of other animals, we performed calculations to determine an immersed giraffe's centers of mass and buoyancy, the resistance it encountered when moving its limbs, and the friction it encountered across its whole surface. We had to take account of the giraffe's unusually shaped lungs, the size of which has been the subject of disagreement among experts. Having tweaked the model to make it as plausible as possible, we were ready to see whether the giraffe could float and swim. Our analysis and conclusion appear below. *—Darren Naish*

Naish is a paleontologist and science writer affiliated with the University of Portsmouth in England.

Simulation Results



Conclusion

Giraffes can float, but they would be clumsy and unstable in the water.

Discussion

Testing the swimming abilities of a giraffe might seem like a frivolous exercise. But analyzing the question is of great interest to anyone engaged in the biology or management of the animals. Our study also showed that scientists could rely on computer simulations to help examine fascinating questions in biomechanics.

COURTESY OF DONALD HENDERSON AND DARREN NAISH

FOOD

The Science of Sous Vide

How underwater cooking differs from the broiler method

Order a medium-rare steak at a high-end restaurant these days, and you may slice through the meat to find that it is a perfect rosy pink not just in the center but from edge to edge and is encased in only the slimmest crust of browned meat. The secret to getting such stunning results consistently is the surprisingly simple yet powerful technique called cooking sous vide. Chefs first seal the food in special plastic bags, often in a vacuum chamber (*sous vide* is French for "under vacuum") but sometimes with air or other gases. They then slow-cook the bagged food at relatively low temperature, typically 122 to 149 degrees Fahrenheit, for hours or even days in a water bath or steam oven.

To steakhouse chefs used to placing dishes under 1,800-degree broilers, this approach may seem unorthodox. But thanks in part to some famous chefs who have championed the technique, including Joël Robuchon, Joan Roca and Thomas Keller, cooking sous vide has started catching on quickly—even among home cooks.

The simple act of vacuum-packing food and immersing it in hot water changes the physics of cooking more than you might think. The usual goal in cooking is to bring the food to the specific temperature at which it is perfectly "done." For many foods, such as fish and certain vegetables, the margin of error is quite narrow. But in traditional cooking, the high temperature of the pan, oven or grill pushes heat into the exterior of the food so quickly that a large temperature gradient forms between the surface and the core. A charbroiled steak, for example, soon becomes boiling hot just under the surface where the water in the meat is flashing to steam; that boiling zone can be a good 86 degrees F hotter than the medium-rare center, and conduction keeps transmitting the heat there even after the steak is pulled from the broiler.

When cooking sous vide, in contrast, chefs typically set the water bath temperature just one or two degrees higher than the core temperature they want to reach. A computer-controlled heater can hold the bath within half a degree of that temperature while the food slowly equilibrates. Because the temperature can't go very high, overcooking is not really possible, so timing is much less critical. The vacuum packing prevents air from insulating the food, improves food safety and greatly slows oxidation reactions that can lead to unwanted color changes or off-flavors. Low temperatures won't brown food, but a quick sweep with a blowtorch or a fast sear on a griddle can apply the final color and crust. The food can be done to a chef's specifications, every time.

—W. Wayt Gibbs and Nathan Myhrvold

Gibbs is editor and Myhrvold is author of Modernist Cuisine: The Art and Science of Cooking, *scheduled for publication in March.*

RYAN SMITH *Modernist Cuisine LLC*

In hot water: Chefs can cook just about anything sous vide, including beef stew.

SCIENTIST IN THE FIELD

Practically Green

As the Chevy Volt, the first extended-range electric car, rolls into showrooms, its chief engineer talks about what's under the hood and why it's not a hybrid

COURTESY OF STEVE FECHT *Chevrolet*

GM developed the Volt in only 29 months. Its lithium-ion battery powers the car for the first 25 to 50 miles, at which point a small gasoline engine kicks in to replenish the battery, allowing the car to travel up to another 300 miles. What were some of your biggest engineering challenges? One was the question of how to integrate the combustion engine with the generator when the car is in its extended-range mode. We wanted the "character" of the car to be as consistent as possible between electric and extended-range operation [when the battery runs down]. To do that, we created a "load-following behavior" for the engine: as power is drawn from the battery, the engine comes in to make up that power. This lets us lead with the battery, and gives the Volt some "EV-ness," even in range extension.

At the same time, we wanted the engine to respond in a manner that drivers would expect. The Volt's engine does not have to behave like an engine in a conventional vehicle; its speed does not have to follow the vehicle speed or the throttle directly. So we added some audible cues to assure the driver that the engine "hears" the commands that the driver is giving, such as reducing the speed or load slightly when the driver backs out of the throttle.

Other than having no tailpipe, the Volt looks like many other sedans. Why didn't GM give the car an edgier design? I have found that people like the fact that this car has a sportiness to it without being overly aggressive. You can be green without driving a spaceship.

The EPA recently classified the Volt as a plug-in hybrid electric vehicle and not as an electric car. What is your reaction to that? Anytime you're first, those are the kinds of issues that come up. I see the Volt as an electric car with extended range. No kidding—you can have the full performance of the car without the engine ever coming on. These blended plug-ins that are being talked about don't do that.

PROFILE

NAME:
Pamela Fletcher

TITLE:
GM's Global Chief Engineer for Volt and Plug-In Hybrid Electric Powertrains

LOCATION:
Milford Proving Grounds, Michigan

What led you to this career path? My dad raced all kinds of cars as a hobby, and I had no brothers. I was the older of two girls, so I was the one who always got corralled into working on the cars and going to the track. After a while, you get addicted to the adrenaline. Not only do you get addicted to the styling, you can also get addicted to the scale and the scope of the industry. I learned to love cars, and I think cars are the greatest consumer product. —*Anna Kuchment*

QUOTABLE

"He actually blows hot and cold."

—Admiral Mike Mullen, chairman of the Joint Chiefs of Staff, on North Korean leader Kim Jong-il after news spread that the country had built a new plant to enrich uranium

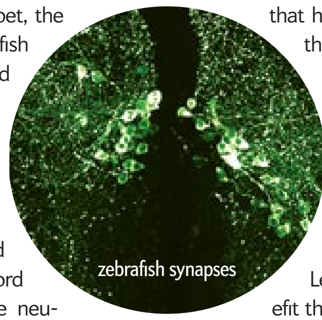
NEUROSCIENCE

Why Sleep Is Good for You

See-through fish are helping neuroscientists settle a scientific debate about whether slumber improves the brain's performance

The benefits of sleep seem obvious. And yet scientists have long debated precisely how it improves brain performance at the cellular level. One camp argues that sleep reduces the unimportant connections between neurons, preventing brain overload. Another camp maintains that sleep consolidates memories from the previous day.

A group of researchers recently tried to settle this debate by studying the larvae of a common see-through aquarium pet, the zebrafish. Like humans, zebrafish are active during the day and sleep at night. Unlike humans, zebrafish larvae are transparent, which allowed researchers to watch their brains as they slept. The researchers, led by Lior Appelbaum and Philippe Mourrain of Stanford University, tagged the larvae neurons with a dye so that active neuron connections, or synapses, appeared green, whereas inactive ones appeared black. Decreased synaptic activity would show that sleep pruned unnecessary memory connections, whereas memory consolidation would have a different pattern. After following the fluctuations of these synapses over the course of a day, the team found that the zebrafish did indeed have lower overall synapse activity during sleep. The researchers published their results in the journal *Neuron*, becoming the first to show the effects of sleep/wake cycles and time of day on the synapses of a living vertebrate. "Sleep is an active process that reduces the activity in the brain," Mourrain says. "It allows the brain to recover from past experiences." Without the synapse reduction that happens during sleep, he notes, the brain would not have the ability to continually take in and store new information.

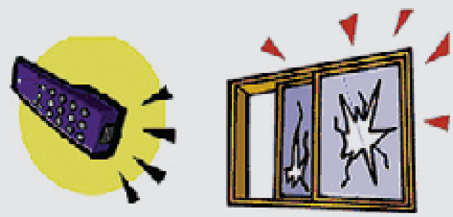

zebrafish synapses

But the debate is not yet settled. Among the team's other findings was that not all neural circuits are affected by sleep in the same way. Learning and memory may benefit the most, Mourrain says. For this reason, the two hypotheses about sleep "may not be mutually exclusive," says neuroscientist Jan Born of the University of Lübeck in Germany. A resolution may not be far off; Mourrain and Applebaum's new imaging technique will allow for more detailed study of the brain during sleep in years to come. —*Carrie Arnold*

PATENT WATCH

PATENT NO. 7,806,310

A REMOTE THAT SHATTERS GLASS



"In Case of Fire Break Glass." *The instructions are simple enough to follow when they apply to a fire alarm, especially when there is a tiny hammer attached to the alarm box. But victims trapped inside burning buildings or totaled cars would have a much harder time shattering a full-size window to make their escape. Giuseppe Longobardi, a researcher at IBM in Castellammare di Stabia, Italy, recently patented a device that would allow a disaster victim to press a button on a remote control and safely shatter a window several feet away, or engineers could install a sensor to the window that would make it break automatically in case of smoke or extreme heat.*

Longobardi's invention exploits the same phenomenon that makes a wineglass ring when you rub its rim: resonance. A small resonator placed in a window pane creates acoustical or mechanical vibrations at just the right frequency to make the glass shatter. "The energy in the window builds up until the glass breaks," Longobardi says. During the manufacturing process, technicians could embed so-called frequency channels within the glass that would direct the vibrations to certain break points. In this way, instead of shattering randomly and creating numerous shards and jagged edges, the glass would break into "harmless little cubes," Longobardi says. Film studios could also use the technology for special effects. —Anna Kuchment

COURTESY OF GORDON WANG AND PHILIPPE MOURRAIN *Stanford University (synapses);* U.S. PATENT AND TRADEMARK OFFICE *(remote and window)*

COURTESY OF GERRY GOODSTEIN

Eureka moment: Watson (*right*) and Wilkins as portrayed in *Photograph 51.*

BIOLOGICAL SCIENCES

For Whom the Nobel Tolls

An evening out with James Watson and colleagues

Never make the mistake of opening a reporter's notebook inside the River Club. James Watson, the Nobel laureate who co-discovered the double-helical structure of DNA in 1953, which has been getting renewed attention with the release of a play and the publication of a trove of lost letters, is seated on a leather banquette in the posh Manhattan establishment. "People don't do work here. It's just not done," he admonishes. Our companions grow jittery, and an awkward silence falls. I relent, tucking the notebook inside my purse. "These are just WASP conventions," says Watson as we make our way from the cocktail lounge to the dining room, and all is well again.

Watson, now 82, is easily recognizable as the young upstart who, with co-conspirator Francis Crick, beat out a field of big-name scientists to what was then a holy grail in biology. (He succeeded because he had few distractions. "There was DNA and no girls," he quipped.) In his book, *The Double Helix,* Watson described the events leading up to the discovery as a tense race among rival labs, an account that many had suspected was overdramatized and that Watson said over dinner was influenced by Evelyn Waugh's *Brideshead Revisited.* Watson was particularly excited about the collection of letters that belonged to Crick and were published in *Nature* in September, because they confirm his account of heightened emotions. In one, Maurice Wilkins, who was at first a rival but later shared their Nobel Prize, writes of feeling weighed down by inter-lab politics: "We are really between forces that may grind all of us into little pieces." He wrote the letter after Watson and Crick built their first, incorrect, DNA model. Instead of feeling embarrassed, the duo wrote to Wilkins: "Cheer up."

The play *Photograph 51* focuses on x-ray crystallographer Rosalind Franklin, who worked with Wilkins and died before the Nobel was awarded. Watson noted that the Wilkins character "talked too much," that the Crick character lacked charisma and that the Franklin character had perhaps too much of it.

As the dinner was winding down and waiters were serving profiteroles with silver pitchers of chocolate sauce, Watson mentioned that he was writing what he called his first scientific paper in 40 years. We can cure a major scourge of humankind (he wouldn't say which) with the drugs we have now. The manuscript has been rejected once, but he is trying again. Fear of failure has never stopped Watson. —*Anna Kuchment*

EDUCATION

The Bright Spots of Kids' TV

Four programs may help stimulate an early interest in the sciences

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PBS recently debuted its newest science series for preschoolers, *The Cat in the Hat Knows a Lot About That!* Children's television may be educational in many ways, but can it really teach kids science? Research on how children learn provides a useful guide for determining whether this show and others are worth watching.

Because preschoolers have a limited capacity for processing information, they are more likely to comprehend educational content that links directly into a narrative, says Shalom Fisch of MediaKidz Research & Consulting. In that way, the plot and the lesson do not compete for cognitive resources. *Cat* accomplishes this goal well by, for example, teaching kids about twigs, mud and grass through a plot about saving a baby bird.

Other shows support preschoolers' learning by accounting for their attention spans and modeling behaviors for them to emulate. After demonstrating a scientific concept, such as how shadows work, *Peep and the Big Wide World* (WGBH) depicts youngsters experimenting with that concept—say, by making shadow puppets. The show models curiosity and exploration for kids while narrator Joan Cusack offers wry observations aimed at adults. This kind of grown-up appeal is a nice bonus because research suggests that when parents join their children in active TV viewing, kids understand more of what they see.

Dinosaur Train (PBS) focuses on laying the groundwork for good reasoning skills. Each episode begins with an introduction like "Today we're going to visit the *Triceratops* and find out what they eat!" which helps kids focus their attention where it is needed. Then the characters deduce, for example, what kinds of food different dinosaurs eat by examining their mouths and teeth. This offers a template on which kids can base their own critical thinking.

Go, Diego, Go! (Nickelodeon), a cartoon whose young narrator helps animals in danger, takes a more interactive approach, asking viewers direct questions and leaving enough time for them to process and shout answers. Being asked to participate might help motivate learning or even promote a sense of mastery, which is of tremendous value to children.

—Lauren Rubenzahl

Rubenzahl, Ed.M., is program coordinator for the Center on Media and Child Health at Children's Hospital Boston.

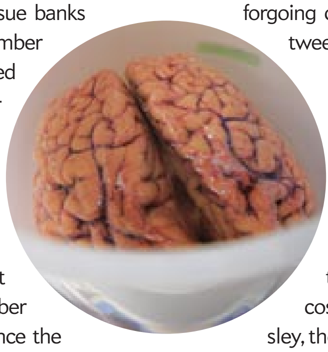
RECESSION ECONOMICS

Donate Your Brain, Save a Buck

Hard times are making tissue donation more appealing

The Great Recession changed the way many people live—and its repercussions appear to be altering how some people choose to die.

At least two prominent tissue banks have seen an increase in the number of individuals who are interested in donating their bodies to research in exchange for a break in funeral costs.



COURTESY OF BANNER SUN HEALTH RESEARCH INSTITUTE

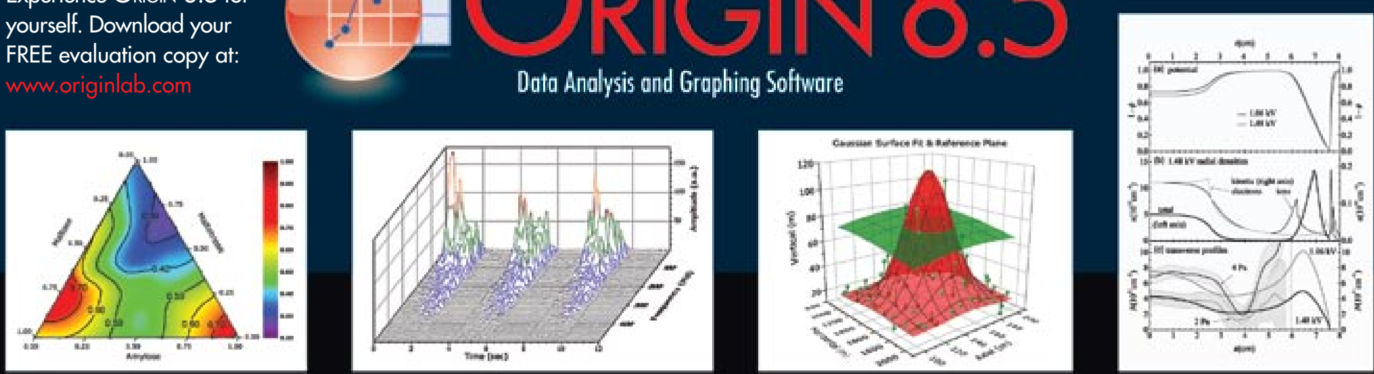
The Banner Sun Health Research Institute near Phoenix typically receives some 1,000 inquiries every year about making donations. That number has increased by 15 percent since the beginning of the recession in 2008, and a waiting list for donors has lengthened. "People have less valuation in their 401Ks, and on top of that their home values started to take a hit, so they started to look at alternative ways [of making death arrangements]," says Brian Browne, a spokesperson for the institute, which uses the donated tissue for research on Alzheimer's and Parkinson's disease, among other disorders. Savings from forgoing cremation costs can range between $1,000 and $1,500.

The Anatomy Gifts Registry, a nonprofit in Glen Burnie, Md., that supplies tissue for medical research, has seen donor calls increase from 150 to 250 a month to as many as 400. "People are turning to this option because of the high cost of funerals," says Brent Bardsley, the registry's executive vice president, who also attributes the uptick to the downturn. Bardsley has even talked to undertakers trying to help desperate families unable to afford the full costs of a funeral. A small savings on last arrangements could translate into a valuable contribution for science. —*Gary Stix*

QUOTABLE

"... alcohol and caffeine can mask the normal signs of intoxication, leading to a state of wide awake drunk."

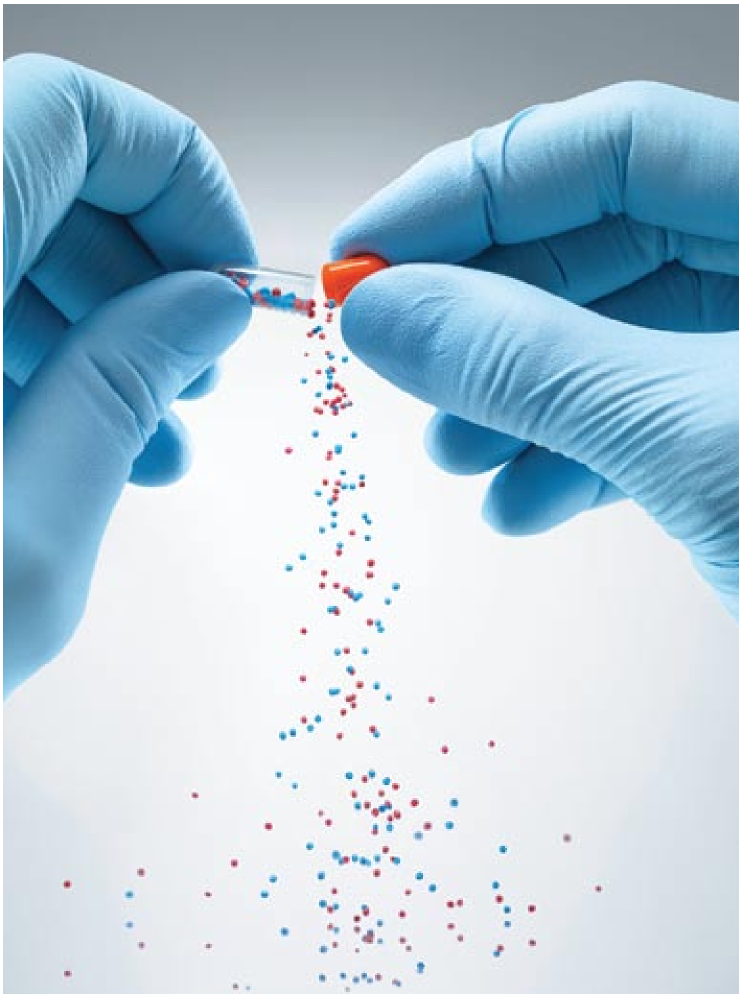
—FDA Commissioner Margaret Hamburg, citing concerns that led her agency to send warning letters to manufacturers of caffeinated malt drinks such as Four Loko in November



Veronique Greenwood is a science writer who reports frequently on biology and health.

Curing the Common Cold

Be careful what you wish for. The remedies may be far worse than the illness



ADRIANNA WILLIAMS *Corbis*

Who has not dreamed of a cure for the common cold? It might be a pill that banishes the sniffles, to be taken as soon as you notice the symptoms. Or better yet, a vaccine administered before kindergarten, along with those for measles and mumps. Imagine a world without colds—without weeks of wet Kleenex and phlegmy avalanches in your sinuses. It sounds pretty perfect.

Scientists, in fact, are working toward a vaccine against rhinoviruses—the group that causes 30 to 50 percent of colds. But, ironically, even if it succeeds or if drugs that stop colds in their tracks are found, we may well decide that most of us are better off without these wonder drugs, after all.

Goodness knows our dreams of becoming sniffles-free have been dashed before. Take the case of the anticold drug pleconaril, which received sensational media coverage in 2002 while it was still in clinical trials. Heralded as "the miracle drug," "the magic bullet" and "the Holy Grail," it performed well in cell culture, but its effects in human subjects were not very impressive—it shortened colds by one day. What prompted the U.S. Food and Drug Administration to reject pleconaril, however, were the side effects. It caused some women to bleed between menstrual periods and interfered with hormonal birth control. Indeed, two women in a trial became pregnant while taking it. Numerous other candidates have been abandoned owing to their adverse effects, including nasal inflammation worse than the infection. The common cold, it turns out, is not that bad, compared with some treatments.

Much effort has also gone into vaccines, particularly against rhinoviruses. (Colds are also caused by adenoviruses, coronaviruses and other virus families.) Like HIV, a rhinovirus consists of an RNA genome cocooned in a shell of proteins called a capsid. The virus attaches to the membrane of a host cell, injects its genetic material and then hijacks the host's machinery to make more of itself. It is the body's own inflammatory immune response, not viral replication itself, that causes symptoms.

In searching for vaccine candidates against rhinovirus, researchers have concentrated on looking for some piece of the capsid that is the same across all types. A vaccine containing that piece, when given to a healthy person, should, in theory, cause the immune system to produce antibodies against it so that he or she is primed to fend off a later infection by all viral strains bearing that piece. The goal is to pick a shared fragment that does not change much over time; the best vaccines and drugs can be rendered useless by a significant alteration in a target.

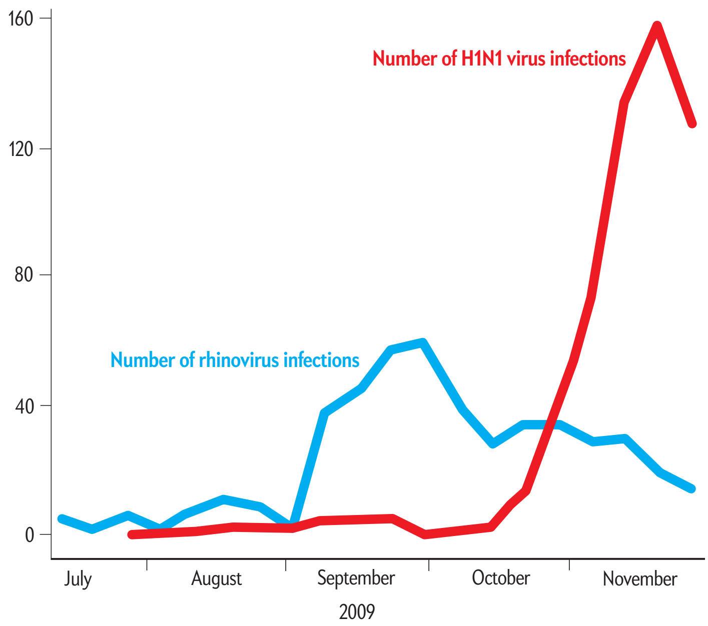
For years researchers met disappointment after disappointment in their efforts to find a conserved element in rhinoviruses. Examination of more than 100 variants of the virus had turned up no commonality, says Thomas J. Smith, who studies the structure of the virus at the Donald Danforth Plant Science Center in St. Louis. This variability occurs because, as an RNA virus, a rhinovirus is prone to mutations. The enzymes that replicate RNA do not have any of the proofreading mechanisms possessed by the enzymes that replicate DNA, so each new virus may be peppered with changes in its code, and each type can drift considerably from the others in its capsid makeup. In contrast, a vaccine has been developed against adenovirus, which is a DNA virus—although its use has been restricted to military personnel.

About 10 years ago, though, to Smith's surprise, he found that parts of the rhinovirus that researchers thought were buried—and thus out of view of the immune system—actually appeared on the surface, at least some of the time. He and his colleagues eventually concluded that the capsid might be more dynamic than previously thought, shifting and exposing hidden regions. They called the process "breathing."

As it turns out, one of these pieces, a protein called VP4 that helps the virus attach to the cell, is very similar across nearly all rhinoviruses. It had been overlooked because it was exposed only sometimes on the outside of the capsid.

Preliminary research in cell cultures done by Smith's team in 2009 demonstrated that a VP4-type vaccine conferred immunity to three strains of rhinoviruses, suggesting that a vaccine of that kind might be useful for protecting against many colds. But the prospect is far from a sure thing. "I'm not going to oversell it," Smith remarks. It turns out that VP4 is not normally prominent enough to provoke a serious response. To use a protein like VP4 in a vaccine, he says, you would have to somehow convince the immune system to go after it.

Data from a French hospital showing a lag between rhinovirus and influenza infections



Competition: **The H1N1 pandemic was unexpectedly delayed in France. An immune response to rhinovirus may have staved off the more serious bug: one reason why eliminating colds may be a bad idea.**

SOURCE: EUROPEAN SOCIETY OF CLINICAL MICROBIOLOGY AND INFECTIOUS DISEASES

An idea put forth two years ago by Gregory Tobin of Biological Mimetics in Frederick, Md., may offer a way around this difficulty. Tobin and his colleagues suggested that delivering large amounts of a protein not normally recognized by the immune system might evoke a protective immune response. This strategy has shown some encouraging signs in early work with foot-and-mouth disease and is being investigated for HIV, but the strategy is not yet proven.

As for drugs that might act once a cold sets in, the pitfalls of pleconaril still await. "The infection won't kill you, so the treatment has to be safe as water," Smith says. Ronald B. Turner, a cold virus researcher at University of Virginia, echoes that thought: "It has to be very effective, it has to be absolutely cheap, and it has to be completely safe." The bar is thus set very high. Even after more than 50 years of work on the rhinovirus, not a single drug that targets it is on the market.

Although few drug companies are working on the common cold anymore, some are still taking aim at rhinoviruses. Over the past few decades research has implicated the viruses in serious complications of asthma, emphysema and cystic fibrosis. "From a drug discovery perspective, if you have efficacy for a more severe illness, the risk that your drug is going to wash out based on toxicity, safety and cost issues becomes less," Turner says.

Targeting closely related groups of rhinoviruses offers one direction for treatment. In 2009 Stephen B. Liggett of the University of Maryland and his colleagues published the complete genomes of 109 rhinoviruses, including an evolutionary tree depicting their relationships. "If you could look at that tree and draw a circle around a group of viruses that cause a really powerful exacerbation of asthma, you could target those [viruses] directly," Liggett says. And closely related viruses might respond more consistently to a treatment than hundreds of more diverse viruses do.

In the end, it may not be the worst thing that rhinoviruses have so cleverly evaded our grasp. Some research suggests that colds may provide temporary immunity to more severe infections. For example, the 2009 pandemic H1N1 flu did not spread in earnest in France until after the cold season was over. Jean-Sebastien Casalegno of the French National Influenza Center reports that colds among children appeared to reduce the likelihood of infection with H1N1, although he emphasizes that the connection is still just a hypothesis. "If we completely succeed in eliminating all rhinovirus infections, other respiratory viruses, such as influenza, may move into that niche," he speculates.

It is possible that virus-fighting cold treatments in the future would not eliminate infection but might still make you feel better. Turner points out that a third of all rhinovirus infections do not produce cold symptoms. "Clearly, the inflammatory response isn't necessary for elimination of the virus, because those people get over their infections just like everybody else," he says. To that end, future treatments might tamp down the immune response or reduce the amount of virus in the body just enough to elude symptoms. But as with all the potential cold cures, there is a caveat—would we want to impede our immune systems? In so doing, we might trade a minor nuisance for ailments or side effects that are even more severe. That, unfortunately, is the inescapable, central conundrum of curing the cold: the cure may be worse than the inconvenience. SA

COMMENT ON THIS ARTICLE ONLINE
ScientificAmerican.com/jan2011

David Pogue is the personal-technology columnist for the *New York Times* and host of the new science miniseries *Making Stuff* on PBS.

Don't Worry about Who's Watching

Privacy concerns are overblown, even in our always connected world

In 2004 Google unveiled Gmail: a powerful e-mail account with a gigabyte of storage. That was 500 times what Hotmail was offering—so much storage, the original Gmail didn't even offer a delete button—and all for free.

But not everyone rejoiced. Gmail paid for all of this goodness by displaying small text ads, off to the right of each incoming message, relevant to its contents. Privacy advocates went ballistic. It didn't seem to matter to them that a software algorithm—not a human being—was scanning your messages for keywords. The Electronic Privacy Information Center called for Gmail to be shut down, and a California state senator proposed a bill that would make it illegal to scan the contents of incoming e-mail.

Two years later a service called Futurephone let anyone make free unlimited overseas calls. You just dialed a line in Iowa and then, at the prompt, entered the number. You were never asked for your name, e-mail address or any information at all.

When I reviewed Futurephone for the *New York Times,* I thought I was doing my readers a favor—but it drove them crazy. They whipped themselves into a frenzy trying to figure out how Futurephone made money. Many concluded that it was an elaborate scam to harvest phone numbers.

But why, I responded on my blog, would Futurephone go to all that trouble, when there's already a central list of American phone numbers in the phone book? All right, then, my concerned readers said, in that case, Futurephone must be *listening in on our calls.*

To many people, it seems that the more time we spend online, the more often we are offered convenience in exchange for our privacy. Grocery stores' affinity cards give us discounts—but let them track what we are buying and eating. Amazon.com greets us by name and remembers what we have bought. Facebook has amassed the largest database of personal information in human history (more than half a billion people).

Of course, convenience-for-privacy deals have been going on for years. Credit cards leave a trail. Phones give phone company employees a record of who you've been calling. It's nice to have a house to live in—but buying one leaves a permanent record of your whereabouts.

There are some good reasons to protect certain aspects of our privacy, of course. We would never want our medical or financial details to keep us from getting a job—or a date. We might not want our sexual exploits or our voting patterns made public.

But beyond those obvious exceptions, privacy fears have always been more of an emotional reaction than a rational one. (Does anyone really care what groceries you buy? Does it matter if they do?) And in the online world, much of it is simply fear of the unknown, of what's new.

In time, as the unknown becomes familiar, each new wave of online-privacy terror seems to fade away. Nobody bats an eye over Gmail's ad-scanning feature anymore. Even middle-agers and grandparents are signing up for Facebook.

(And Futurephone? It's out of business. Blogger sleuths uncovered its more likely business model: it was exploiting a government subsidy that pays Iowa a few cents per incoming long-distance call. Iowa was sharing the revenue with Futurephone.)

The younger generation can't even comprehend why their elders worry about privacy. Indeed, the entire appeal of the new age of online services is to broadcast personal information. On purpose. Foursquare, Gowalla and Facebook Places even publicize your current location, so that your friends can track your movements (and, of course, join you).

If you were among those who thought that Google overstepped privacy lines with Gmail, you must be positively freaked about these developments. For all we know, Google is collecting data about what we watch (Google TV), where we go (Google Maps), whom we call (Android phones), what we say (Google Buzz), and what we do online (Google Chrome browser).

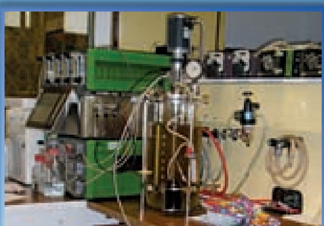
But at least some aspects of your privacy have been gone for years. The fear you feel may be real, but the chances of someone actually *looking up* the boring details of your life are reassuringly small. As with fear of flying, shark attacks or lightning, your gut may not be getting realistic data from your brain. SA

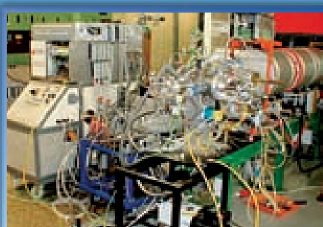
HOW TO CONTROL YOUR ONLINE PRIVACY
ScientificAmerican.com/jan2011/pogue

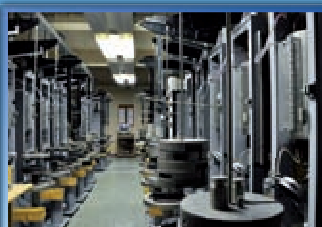
Illustration by Jakob Hinrichs

THE ACADEMY OF SCIENCES OF THE CZECH REPUBLIC

CZECH ENERGY







electro mobility

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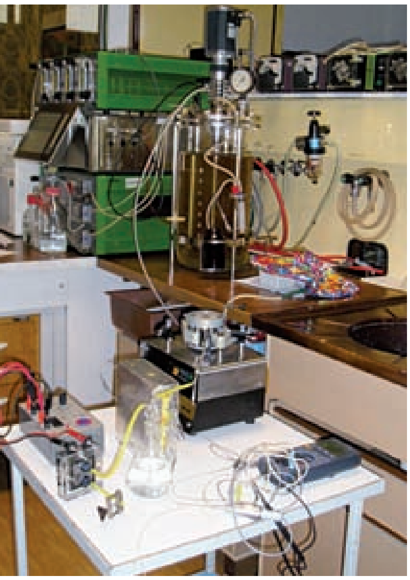
Institute of Macromolecular Chemistry Academy of Sciences of the Czech Republic



A fermenter that produces hydrogen as part of bio-gas, a polymer foam module that serves as a membrane for hydrogen separation, and a fuel cell in which this hydrogen is converted to electricity.

Polymer materials and macromolecular systems are becoming indispensable components of nearly all current advanced technologies. Unique properties of synthetic polymers applicable for energy conversion and storage technologies rank among key areas of interest at the Institute of Macromolecular Chemistry of the Academy of Sciences of the Czech Republic in Prague (IMC).

IMC is recognized as one of the largest academic research centers in polymer science worldwide, with areas of focus ranging widely from bio-macromolecular systems applicable for medicine and biotechnologies to advanced polymer materials. The latter includes research on *polymer photonics, organic photovoltaic materials, conductive polymers* and novel *polymer membranes for fuel cells* as well as *membrane systems for separation and storage of hydrogen*.

The hydrogen story. Hydrogen is becoming a key element in the energy economy and in modern energy-saving technologies. In addition to traditional production technologies, hydrogen can also be made using biotechnologies and as a byproduct of various organic processes. In such cases, the hydrogen concentration in gases is typically rather low, and traditional processes of hydrogen separation and purification are inconvenient. New hydrogen separation technology was developed at IMC that deals with this problem by using polymer foams with closed pores for selective sorption, transport and separation of gases, namely hydrogen. Polymer foams can be seen as systems of membranes that divide up space into closed, isolated cells. The permeability of polymer membranes for gases differs, with hydrogen permeating most easily. As such, when a mixture of gases flows through a system of polymer cells, hydrogen penetrates the cells faster than the other gases (Fig 1a). The polymer cells hold the gas inside until the partial pressure of hydrogen outside drops sufficiently. After that point, the hydrogen is released from the foam, again faster than any other gases (Fig. 1b). Polymer foams can be made from a variety of commodity polymers and can find use as efficient sorbents to separate and purify of hydrogen from mixtures of gases.

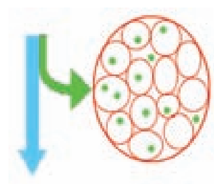


Fig. 1a

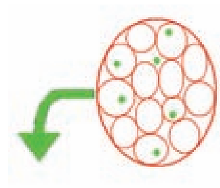


Fig. 1b

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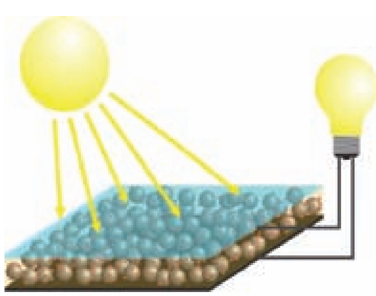
J. Heyrovský Institute of Physical Chemistry



Solar cell based on mesoporous titanium dioxide thin films sensitized with a dye.

J. Heyrovský Institute of Physical Chemistry in Prague has more than 25 years of history in research into energy conversion and storage. Activities there are mainly focused on the photo-electrochemical solar energy conversion in dye sensitized solar cells (DSCs), as well as on electrochemical power sources and development of catalysts for more energy-efficient industrial applications.

DSCs can demonstrate solar conversion efficiencies exceeding 11% at very competitive costs, thus presenting attractive alternatives to solid-state photovoltaics. Key issues when it comes to optimizing DSC efficiency lie in engineering the morphology of the titanium dioxide photoanode and the maximizing electrode surface area. Low-temperature synthetic approaches, such as supra-molecular templating or solvo-thermal or freeze drying syntheses, can not only lead to improved titanium dioxide film electrodes, but novel metal oxide based catalysts for direct methanol fuel cells or highly selective electrolytic production of gases such as chlorine as well. Catalyst research, another area relevant to energy efficiency with a long tradition at the Institute, relies on the rational design of transition metal and protonic centers at the atomic level in the new generation of zeolite-based heterogeneous catalysts for hydrocarbon transformation and nitrogen oxides abatement. Nanocrystalline materials and composites are developed for applications in Li-ion batteries with high charging rate, power density and safety.

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Institute of Geonics ASCR

Conical probe for rock stress measurement constructed at the institute.

For centuries, energy involved using the Earth's crust as a source of coal, oil, gas, uranium and geothermal power. Now, rock mass is also key in gas storage and future plans to contain pollutants from energy production, such as carbon dioxide or nuclear waste. These many roles motivate research activities at the *Institute of Geonics of the Academy of Sciences of the Czech Republic*.

The Institute was founded in Ostrava, the center of the Czech part of the Upper Silesian Coal Basin, and much its research concerned coal mining at great depths. Gradually, the Institute's focus expanded substantially, and now includes coal and uranium mining, construction of gas reservoirs, carbon dioxide sequestration and deep deposition of spent nuclear fuel. Besides solving geotechnical problems, such as rock burst prevention, the Institute contributes to rock stress measurements, seismic monitoring, systematic investigations of geomaterials, development of new mathematical modeling tools and investigation of social aspects of energy.

The Institute's investigations are currently supported by the Academy and many research projects, and its results benefit the Czech Mining Authority, Czech Radioactive Waste Repository Authority, mining companies and others. It participates in the worldwide DECOVALEX project devoted to reliably modeling processes in rocks crucial for nuclear waste deposition, and in EU projects on coal carbonization and brownfields. The Institute expects to open two large EU-supported projects in 2011, which promise new equipment for rock mechanics and CT laboratories, further development of new water-jet technology and involvement in a new supercomputing facility.

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More details can be found on the web page
www.ugn.cas.cz., Contact: geonics@ugn.cas.cz

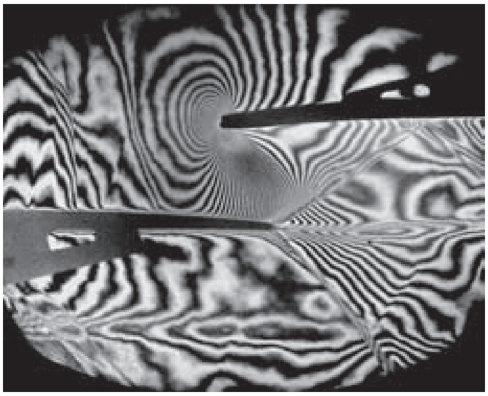
Institute of Thermomechanics, Academy of Sciences of the Czech Republic

The Institute was founded in 1953 to undertake and promote fundamental research in engineering sciences. Several long-term areas of study include power generation, aerodynamic investigation and optimization of transonic and supersonic turbine cascades, and monitoring of blade vibrations in rotating turbines.

In 1965, a unique blowdown wind tunnel was built there with a 6000m^3 vacuum storage in former gold-ore mines to investigate 2D transonic and supersonic cascades. Since then, more than 110 turbine and compressor cascades, were also tested there, contracted mostly by Czech industry. Research programs covered detailed investigations of turbine cascades at $0.3 < M_1 < 1$, M_2 up to 2 and at extreme off-design incidences. The universal test section with ventilated walls allows measurements even through M ~1. In parallel, basic research focused on boundary layers, shock wave boundary layer interaction and separated flows.

The Institute was the first to show how the full system of shock waves in a cascade develops, and how supersonic flow in a compressor cascade starts and behaves at various operational conditions. Based on basic research in transonic flows, the tip sections of the last stages of a 1000 MW turbine were optimized and reshaped, decreasing the losses at the design point by almost 30 %.

In addition, a contactless diagnostic method for complex nonlinear systems has been developed at the Institute and successfully applied in large steam turbines to monitor and analyze vibrations of individual rotor blades. This has helped predict the necessity of possible replacements of the blades during planned revisions.



Interferogramme of a tip section of a steam turbine rotor blade.

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Institute of Physics of Materials Academy of Sciences of the Czech Republic

Laboratory for high-temperature creep testing.

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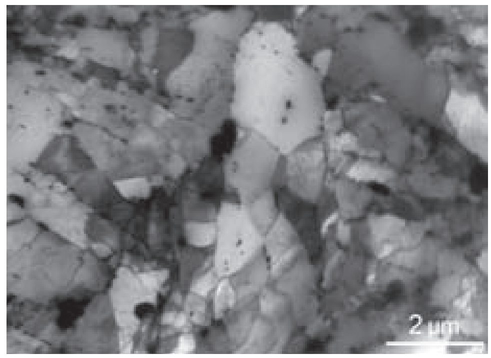
High-temperature materials are the key to the construction of thermal and nuclear power generation plants. However, further improvements in efficiency and massive direct reductions of thermal power plant CO_2 emissions are limited by the availability of new, stronger high-temperature materials.

One of the main goals of the Institute is to elucidate the relationship between the behavior and properties of advanced high-temperature materials of high strength and corrosion resistance and their structural and microstructural characteristics. Particular emphasis is focused on the physical nature of processes which occur in high-temperature materials during creep, fatigue, oxidation and/or corrosion and their combinations in relation to the evolution of structure and microstructure. On this basis, it is possible to optimize the microstructure and resulting properties as well as design completely new materials with more advantageous properties.

High-tech machines for complex testing of mechanical properties, along with electron microscopy laboratories and computer and software facilities from world-class producers, are also available at the Institute. The Institute co-operates with many Czech firms such as ŠKODA Works and international industrial companies such as ALSTOM, Siemens AG Power Generation, and VoestAlpine, as well as research institutions such as NIMS Japan and the University of Southern California. Over the past two decades, the Institute has been deeply involved in the design and development of new creep-resistant steels for boiler, piping and turbine components of ultrasupercritical thermal power plants under the European cooperation program COST.



Microstructure of creep-resistant steel P92 after creep test.

Nuclear Physics Institute of the ASCR

In order to transmute the radioactive, toxic, long-lived spent fuel from existing nuclear power plants into safer forms, next-generation reactors will need new sets of neutron data. At the same time, plans for fusion power plants will require detailed information on the damage that materials can experience from neutrons that have substantially higher energies than ones seen with current fission reactors. As such, to develop future nuclear energy technologies, there is considerable need for ongoing basic research into nuclear physics.

Cyclotron-based fast-neutron sources at the Nuclear Physics Institute (NPI) are well-established in research aimed at obtaining and benchmarking relevant data on fast neutron interaction with matter. In particular, the high-power neutron source and its heavy-water target (Fig.) well simulates the neutron spectrum of the planned International Fusion Material Irradiation Facility (IFMIF). The NPI research, supported in part by the European Fusion for Energy program and by the Czech Ministry of Trade and Industry, is concerned mainly with the validation of the neutron activation properties of materials used in fusion technologies. In close collaboration with specialists from KIT Karlsruhe, NEA Culham and ENEA Frascati, NPI is currently carrying out experimental tests of the integral and differential neutron cross-sections and investigating neutron flux monitors for IFMIF.

Under support of the Energy Plus Transmutation project and the European Facilities for Nuclear Data Measurements (EFNUDAT), neutron data for future fission reactors are investigated in close collaboration with The Svedberg Laboratory (TSL) Uppsala and the Joint Institute for Nuclear Research (JINR) Dubna. In the cooperation with Czech Technical University in Prague, the fast neutron response of various blanket modules of the sub-critical next-generation fission reactors is being investigated using NPI neutron sources.

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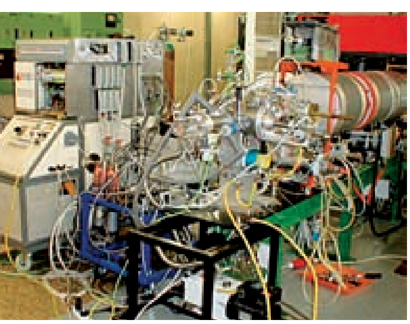


The fast-neutron source of NPI cyclotron.

EVOLUTION

Dawn of the Deed

Fish fossils push back the origin of copulation in backboned animals and suggest that it was a key turning point in our evolution

By John A. Long

Illustration by Owen Gildersleeve

John A. Long studies the early evolution of fishes. Currently vice president of research and collections at the Natural History Museum of Los Angeles County, he recently moved to the U.S. from Australia, where he was head of sciences at the Museum Victoria in Melbourne. He is the author of 18 books, including *The Rise of Fishes* (second edition, Johns Hopkins University Press, 2010).

On a hot August day in 2005 my team and I were out hunting for fish fossils in the tall, grassy paddocks of Gogo Station, a vast cattle ranch located in the heart of northwestern Australia. Today the arid region is hardly suitable for aquatic creatures. But some 375 million years ago, during the Late Devonian period, a shallow sea covered the area and Gogo was home to an enormous tropical reef that teemed with marine life, including a plethora of primitive fishes. Luckily, many of their remains have survived across the ages. Nestled among the clumps of spiky *Spinifex* bushes and sleepy death adders lie softball-size nodules of limestone—the products of millions of years of erosion of the local shales—some of which harbor pristine fossils of the fishes that lived on the primeval reef. And so over the course of our terrestrial fishing expedition, we would spend our days cracking the nodules open, one after another, hoping to glimpse a treasure inside.

The most abundant of the fishes that patrolled the Gogo reef were armored creatures called placoderms ("plated skin")—some of the first backboned animals with jaws. Though gone today, placoderms ruled the planet for nearly 70 million years, making them the most successful vertebrate group of their time. Scientists have long debated exactly how they are related to other backboned creatures, and we had come to Gogo to look for specimens that might help resolve this and other questions about fish evolution. On this particular day our efforts were rewarded with a nodule containing what appeared to be a fairly complete fish. It did not strike me as especially remarkable in its anatomy, though, just another placoderm fossil to add to our haul and take back to the lab for extraction from its limestone tomb at a later date. Little did I know that this seemingly modest find would upend scientists' understanding of a very intimate aspect of vertebrate biology—the origin of sexual intercourse and internal fertilization.

Researchers used to believe that internal fertilization and the carrying of the young inside the mother's body until birth together made up a specialized form of reproduction that first appeared in the sharks and their kin (a group known as the chondrichthyans) roughly 350 million years ago, some 70 million years after the first members of this group evolved. Before then, piscine procreation was supposedly limited to spawning, a decidedly impersonal affair in which the females deposit eggs into the water, the males then fertilize them and the embryos develop out in the open. But recent analyses of the fish we found back in 2005, along with other placoderms from Gogo and elsewhere, have revealed that copulation and live birth arose millions of years earlier than previously thought and in a vertebrate group more primitive than the chondrichthyans.

It is hard not feel astonished when some major trait turns out to have evolved much earlier than was thought. But the significance of the findings goes beyond mere surprise. It turns out that placoderms are directly on the long line leading to creatures with four limbs (the tetrapods, including humans). In the sexual equipment of these ancient placoderms, we can thus see the earliest rudiments of our own reproductive system and other parts of our body and gain a clearer idea of how the anatomy changed over time to become what it is today. The paired pelvic fins that in placoderms permitted the males to deposit sperm into the females eventually gave rise to the genitalia and legs of tetrapods. And jaws may have originally evolved to help male fish grab ahold of females and stabilize them during mating, only later taking on the role of food processing. Sex, it seems, really did change everything.

Fossilized umbilical cord belongs to an embryo found in the ancient fish *Materpiscis,* the earliest example of an animal that had sex and gave birth like we do.

COURTESY OF JOHN A. LONG

IN BRIEF

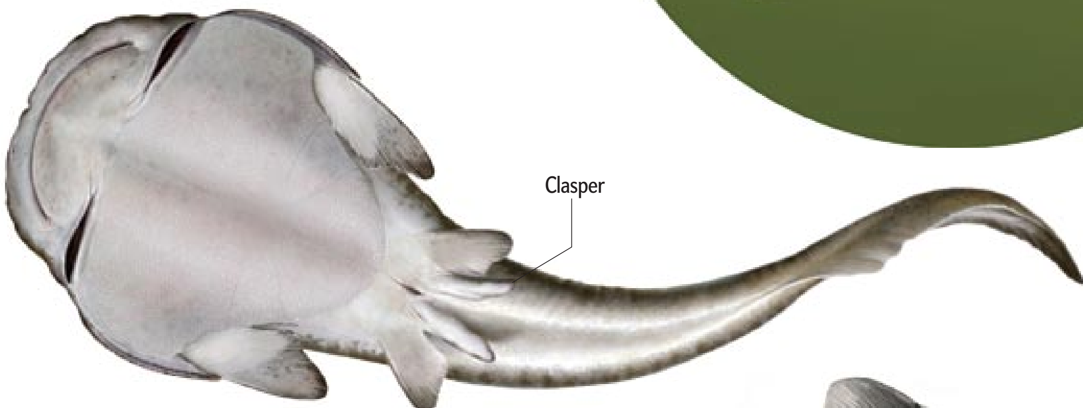
Scientists thought that among backboned animals, internal fertilization arose 350 million years ago in the group that includes sharks and their kin.

But new fossil discoveries indicate that copulation—and the carrying of the offspring in the mother's body until birth—debuted millions of years earlier and in a more primitive group of fish.

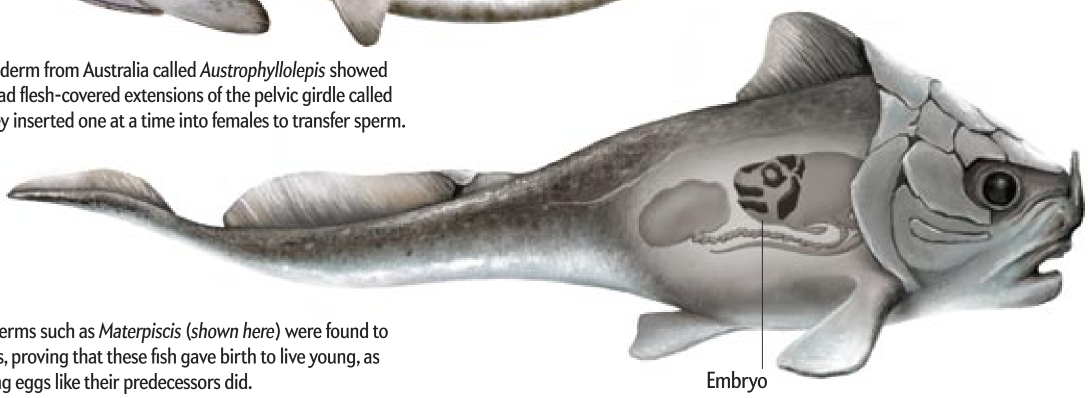
These findings are casting new light on the origin of our own reproductive organs and other body parts.

The Origin of Intercourse

Extinct fish called placoderms that lived some 375 million years ago during the Late Devonian period were the first backboned creatures to copulate and give birth to live young, rather than deposit their eggs in the water for external fertilization and development. Although animals that procreate this way have far fewer offspring than those that spawn, the babies are larger and hardier than the ones that result from spawning. This reproductive strategy may have imparted a key survival advantage back in the Devonian, when the sea was thick with predators.



Fossils of a placoderm from Australia called *Austrophyllolepis* showed that the males had flesh-covered extensions of the pelvic girdle called claspers that they inserted one at a time into females to transfer sperm.



Fossils of placoderms such as *Materpiscis* (*shown here*) were found to contain embryos, proving that these fish gave birth to live young, as opposed to laying eggs like their predecessors did.

MOTHER LODE

GOGO FOSSILS ARE FAMOUS for their extraordinary preservation. Unlike most fish fossils, which tend to be flattened, the ones from Gogo often exhibit pristine three-dimensional preservation. Fully exposing the skeletons is time-consuming business, however—we must painstakingly dissolve the limestone matrix by applying diluted vinegar (acetic acid), which leaves the fossilized bone unharmed. It was not until November 2007 that I got around to cleaning the specimen my team found on that hot August day two years earlier. Based on its robust jaws and teeth built for crushing, my colleague Kate Trinajstic, now at Curtin University in Australia, and I determined that the fossilized animal, which was about the size of a mackerel, belonged to the so-called ptyctodontid family of placoderms. This finding in and of itself was good news, because the ptyctodontids are a poorly known group and ours looked like it was probably a new species. But the discovery was about to get much more interesting.

As I removed more of the limestone, I spotted some unusual structures near the base of the animal's tail. On closer examination under the microscope, I saw a set of delicate little jaws alongside a scattering of other tiny bones. Then the penny dropped, and I experienced one of those sublime eureka moments that scientists get once in a lifetime, if they are lucky. Typically I would have assumed these were the remains of the fish's last meal. But the minute jaws bore exactly the same distinctive features as those of the larger animal, and they were undamaged and still partially articulated—all signs that the miniature bones were those of a developing embryo, not an entrée. Furthermore, I could see a twisted structure wrapped around the tiny skeleton. Using a scanning electron microscope, we were soon able to identify this feature as a mineralized umbilical cord, which would have supplied the embryo with nutrients from a yolk sac. The case was clear: we had found a 375-million-year-old expectant mother fish and the oldest vertebrate embryo on record. We named the new fish *Materpiscis attenboroughi,* meaning "Attenborough's mother fish," in honor of the great British nature presenter David Attenborough, who introduced the Gogo fossil sites to the world in the 1979 documentary series *Life on Earth*.

Illustration by Peter Trusler (*inset* and Austrophyllolepis); *illustration by Jen Christiansen* (Materpiscis)

Materpiscis solved a long-standing mystery about ptyctodontids. Back in the late 1930s British anatomist D.M.S. Watson observed that males of a fossil ptyctodontid species from Scotland have long, cartilaginous extensions coming off the bony girdle that supports the animal's pelvic fins. In life, these extensions would have been encased in flesh and skin, forming structures akin to the two claspers present in males of all living chondrichthyans, which insert one or the other into a female to transfer sperm during copulation. But the claspers on the Scottish ptyctodontid were covered in bony plates, which would have made them rigid and ungainly. Furthermore, although all chondrichthyan claspers are tipped with scalelike hooks that help to hold the claspers in place during mating, the ones in this ptyctodontid were so pronounced that they appeared to be more of a deterrent to mating than an aid.

Subsequent ptyctodontid discoveries showed the same features, leaving scientists to wonder whether these fish actually inserted their bizarre claspers into the females, or used them to grasp the females while mating, or whether they were just for show—spiky adornments used to attract a mate. At that point, based on the available fossil evidence, paleontologists could not say definitively whether the ptyctodontids mated through copulation or spawning. Our mother fish and her baby showed without a doubt that at least some ptyctodontids reproduced through internal fertilization and live birth.

The *Materpiscis* revelation prompted us to reexamine previously discovered Gogo ptyctodontid fossils to see if they, too, might harbor babies. This search led us to a specimen of a different genus of ptyctodontid, *Austroptyctodus,* that I had prepared 20 years earlier. Scrutinizing it under higher microscope magnification and using the first discovery of the embryo as our Rosetta Stone, I could see that features that I had originally interpreted as dislodged scales were in fact tiny bones belonging to embryos. We had found another ancient mother, one that had died at the prime of life with triplets inside her.

Following our discoveries of the pregnant ptyctodontids, which my colleagues and I published in *Nature* in 2008, we began to look at even more Gogo placoderms. Our work had determined that ptyctodontids copulated and gave birth to live young, but they were just one of seven groups of placoderms. How widespread was this novel means of reproducing? We turned our attention to a specimen of a placoderm in the genus *Incisoscutum* that had previously been identified as having "stomach contents" in the form of bones of a smaller fish. Both this fossil and another one in the same genus turned out to be carrying embryos.

Incisoscutum belongs to the largest placoderm group, the arthrodires. This group consists of more than 300 species, including the biggest placoderms that ever lived, such as the fearsome six-meter-long *Dunkleosteus.* Before our discovery, there was no evidence to indicate whether male and female arthrodires differed in their external anatomy nor to reveal how they mated. The embryos we found showed unambiguously that *Incisoscutum* reproduced by internal fertilization. Eventually we proved using examples from Gogo and other sites that arthrodire males also had claspers to facilitate this type of mating—findings that we published in two more *Nature* papers in 2009. Thus, at least two of the seven main groups of placoderms, including the most successful one, reproduced by copulation at least 25 million years before the sharks and other chondrichthyans did.

SEXUAL REVOLUTION

IN LIGHT OF THESE FINDS, it now appears that placoderms were the originators of intimate sexual reproduction. We also now have a better understanding of where they fit on the vertebrate family tree. Previously the leading theory held that the placoderms gave rise to just one of the two living groups of jawed vertebrates, namely, the sharks and their chondrichthyan kin. But the new

EVOLUTIONARY CONTEXT

Family Ties

Placoderms reside directly on the line leading to animals with four limbs (the tetrapods, including humans). Although internal fertilization arose in placoderms, the bony fishes that succeeded them mostly reverted back to spawning. With the evolution of the tetrapods from the bony fishes, however, internal fertilization came back into vogue, and the pelvic anatomy inherited from the placoderms (including the claspers they used for copulation) provided the foundation for tetrapod hips, legs and genitalia. In place of claspers, the tetrapods evolved bilobed reproductive organs called hemipenes, as well as penises. The diagram below shows the predominant form of reproduction for major vertebrate groups.

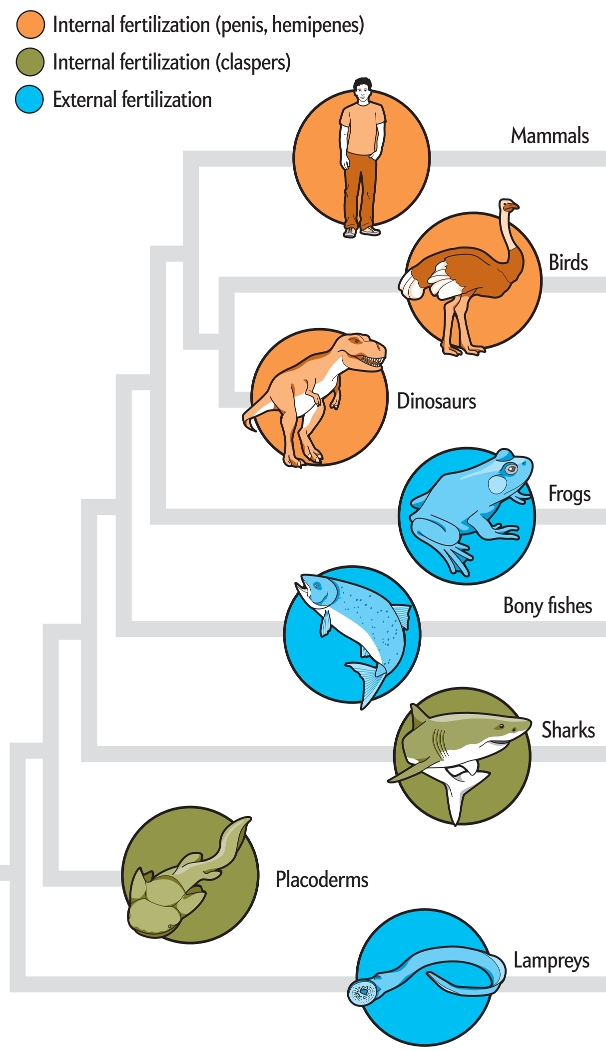


Illustration by Brown Bird Design

discoveries, along with analyses of evolutionary relationships among early vertebrates conducted in 2009 by Martin Brazeau, now at the Natural History Museum in Berlin, suggest placoderms could be ancestral to both early chondrichthyans and an extinct group of fishes called acanthodians. Some of these acanthodians are thought to be ancestral to the first bony fishes, the lineage that led to the four-limbed animals, including humans.

This revised scenario for the start of sex as we know it raised important new questions, however. My collaborators and I began to contemplate how the emergence of copulation as a reproductive strategy might have affected subsequent vertebrate evolution. From anatomical comparisons made by others and us, we already suspected the hind limbs and genitalia of the tetrapods evolved from the pelvic girdle (including the claspers) of early fishes. One of the most compelling pieces of evidence supporting this view came from studies led by Martin J. Cohn of the University of Florida, who showed in 2004 that the *Hoxd13* gene, involved in the development of the pectoral and pelvic fins in modern-day jawed fishes, is also active in the developing limbs and genitalia of mammals, an indication that our legs and sex organs could both have been derived from the early fish pelvic girdle.

If the new work indicated that we descended from placoderms, then those features clearly also came from those fishes. But we wondered what other anatomical legacies we inherited from placoderms. Among modern-day sharks, males must court females before they can mate with them. In some species, such as the white-tipped reef shark, the male makes his overture by biting the female's back, neck and then her pectoral fin—a move that then helps him to hold onto her while copulating. This observation led us to speculate that perhaps jaws first evolved not for food processing, as scholars have traditionally envisioned, but to improve mating success. Such an innovation would have then laid the ground for the jaws to become pressed into later service for chewing. Although most bony fishes reverted back to spawning and thus did not use their jaws for mating, they were preadapted to chewing, thanks to their placoderm ancestors. (Internal fertilization later reevolved in land animals using the pelvic-fin foundation established by the placoderms, a shift that freed them from having to return to the water to reproduce.) Knowing that internal fertilization first appeared in placoderms, not sharks, and that placoderms are ancestral to bony fishes helped us to draw this tentative connection between copulation and chewing in the line of animals leading to humans.

WATCH A VIDEO ON THE MOTHER FISH
ScientificAmerican.com/jan2011/sex

Looking at the bigger evolutionary picture, my colleagues and I could not help but notice that the new timing for the origin of copulation dovetailed with the explosion of diversity in the arthrodire fishes—the first big species radiation of any jawed animal in the fossil record. Could this early switch in reproductive biology in vertebrates from spawning to internal fertilization have been the main driver of this major evolutionary event? Our search of the scientific literature turned up some interesting clues. In 2004 Shane Webb of the University of St. Andrews in Scotland and his colleagues reported that a group of fishes known as goodeid fishes, which today inhabit freshwater streams in Nevada and west-central Mexico, split into two lineages around 16.8 million years ago. One continued to spawn in water and branched into just four species. The other evolved a form of internal fertilization and today comprises 36 species. Another group of fishes known as the Bythitoidei, which includes three lineages, exhibits a similar pattern. The one that evolved internal fertilization contains 107 species. Of the other two lineages, which maintained the spawning strategy, one contains 22 species and the other just three. The fact that in both these groups the lineages that switched to internal fertilization underwent much higher species diversification than spawners did is a hint that we might be on the right track with our hypothesis.

At first glance, the suggestion that internal fertilization drove the arthrodire radiation might seem counterintuitive. In theory, spawning—which involves laying tens of thousands of eggs—should yield many more offspring than internal fertilization and live birth, in which the mother invests a lot of energy into raising just a few babies at a time. And the greater the number of offspring, the greater the chances that one will inherit a mix of genes that could lead to the beginnings of a speciation event. But during the Devonian, most fishes fed on other fishes, and the tiny, weak hatchlings that resulted from spawning would have been easy targets. A reproductive method in which the mother nurtured fewer offspring with larger body size—equipping the babies with better odds of surviving to reproductive age themselves—might well have given arthrodires an evolutionary edge.

GETTING IN THE MOOD

MANY QUESTIONS about the origin and evolution of internal fertilization in vertebrates remain. For instance, scientists still do not know exactly how placoderms made the transition from spawning to internal fertilization. Lacking the ability to observe them in action, I can only speculate about the nature of this sea change. From a mechanical standpoint, it may have started with males and females spawning closer to each other to achieve a higher success rate for fertilization or to better protect the fertilized eggs. There might also have been an intermediate stage whereby rather than depositing the eggs in water, the female or male carried the egg mass, as do some fishes, such as seahorses, which brood their eggs in pouches. Perhaps the use of well-developed pelvic fins to transfer sperm more accurately to the egg mass then brought the male closer to the female, and this arrangement created natural selection pressure for larger, more elongated pelvic-fin lobes, which eventually became claspers.

As for the neurological factors that made males want to insert parts of their pelvic fins inside females for mating, perhaps this desire evolved as a by-product of natural selection acting to encourage fertilization of the eggs before the female had laid them, thus boosting the chances of beating other males to the punch. Further study of the chemical signals and neural triggers that govern mating behavior in sharks and other fishes may provide additional clues to how the first step toward the hookup evolved. SA

MORE TO EXPLORE

Developmental Genetics of the External Genitalia. Martin J. Cohn in *Advances in Experimental Medicine and Biology,* Vol. 545, pages 149–157; March 31, 2004.

Swimming in Stone. John Long. Fremantle Press, 2006.

Live Birth in the Devonian Period. John A. Long, Kate Trinajstic, Gavin C. Young and Tim Senden in *Nature,* Vol. 453, pages 650–652; May 29, 2008.

Devonian Arthrodire Embryos and the Origin of Internal Fertilization in Vertebrates. John A. Long, Kate Trinajstic and Zerina Johanson in *Nature,* Vol. 457, pages 1124–1127; February 26, 2009.

Pelvic Claspers Confirm Chondrichthyan-like Internal Fertilization in Arthrodires. Per Ahlberg, Kate Trinajstic, Zerina Johanson and John Long in *Nature,* Vol. 460, pages 888–889; August 13, 2009.

SPACE

CONTACT
THE DAY AFTER

If we are ever going to pick up a signal from E.T., it is going to happen soon, astronomers say. And we already have a good idea how events will play out

By Tim Folger

Photograph by Grant Delin

The 100-meter-wide radio dish at Green Bank, W.Va., is the largest steerable antenna in the world. Astronomers use the dish as part of the search for extraterrestrial intelligence, a worldwide collaborative effort, to scan the skies for artificially produced radio signals.

Tim Folger has been writing about science for more than 20 years. In 2007 he won the American Institute of Physics science writing award. His work has appeared in *Discover, National Geographic, Science* and other national publications.

ONE DAY LAST SPRING FRANK DRAKE RETURNED TO the observatory at Green Bank, W.Va., to repeat a search he first conducted there in 1960 as a 30-year-old astronomer. Green Bank has the largest steerable telescope in the world—a 100-meter-wide radio dish. Drake wanted to aim it at the same two sunlike stars he had observed 50 years ago, Tau Ceti and Epsilon Eridani, each a bit more than 10 light-years from Earth, to see if he could detect radio transmissions from any civilizations that might exist on planets orbiting either of the two stars. This encore observing run was largely ceremonial for the man who pioneered the worldwide collaborative effort known as SETI—the search for extraterrestrial intelligence. As a young man, Drake had half-expected to find a cosmos humming with the equivalent of ET ham radio chatter. The elder Drake did not expect any such surprises from Tau Ceti or Epsilon Eridani. The Great Silence, as some astronomers call the absence of alien communiqués, remains unbroken after five decades of searching. And yet so does Drake's conviction that it is only a matter of time before SETI succeeds.

"Fifty years ago, when I made the first search, it took two months—200 hours of observing time at Green Bank," says Drake, who is now chairman emeritus at the SETI Institute in Mountain View, Calif. "When I went back this year, they gave me an hour to repeat the experiment. That turned out to be way too much time. It took eight tenths of a second—each star took four tenths of a second! And the search was better. I looked at the same two stars over a much wider frequency band with higher sensitivity and more channels, in eight tenths of a second. That shows how far we've come. And the rate of improvement hasn't slowed down at all."

Computer-processing power has roughly doubled every two years for the past 50. Drake and other SETI scientists believe that within 30 years or so, computing advances will allow them to sift through enough frequencies from enough of the 200 billion stars in our galaxy to have a reasonable shot at finding a signal from an extraterrestrial civilization. "My guess—and 'guess' is the right word—is that the number of detectable civilizations in our galaxy right now is 10,000," Drake says. "That means one of every some millions of stars has a detectable civilization." His estimate, he adds, assumes an average life span of about 10,000 years for a technological civilization. "In 20 or 30 years we will be able to look at 10 million stars. That's the challenge, even though it's based on a guess."

Drake may be too conservative, says Seth Shostak, senior astronomer at the SETI Institute. "If this experiment has merit, it's going to succeed within two or three decades," he says. "If it doesn't, then there's something fundamentally wrong in our assumptions. If it's going to happen, it's going to happen soon."

Drake and Shostak could, of course, be wildly off base. It is not hard to find astronomers who would peg the number of civilizations in our galaxy at one—our own. But if Drake and Shostak are right—if we are within a few decades of discovering that we are not alone in the universe—what then? What happens after we detect a signal from an alien intelligence? Could we even translate the message? How likely is it that the message might contain knowledge that would transform our culture? Would it be dangerous to respond and reveal our existence to beings from other worlds?

One thing that definitely *won't* happen if SETI scientists discover such a signal is a government cover-up or any sort of conspiratorial secrecy. The world will learn the news almost immediately. Shostak is certain of this. So is Jill Tarter, director of the SETI Institute's research center. They know exactly how events will unfold when they finally find a signal because on a June morning 13 years ago, they thought they had received one.

DRESS REHEARSAL

IT HAPPENED AT ABOUT 6 A.M. Tarter was at the Green Bank observatory when the signal came in. It was bunch of signals at discrete frequencies, with uniform spacing between them, which looked on a graph like a comb. "It was clearly an engineered signal," she says. Tarter and her colleagues at Green Bank followed their protocols to rule out false alarms. They swung the telescope away from the target star. The signal vanished. They aimed at the star again. The signal came back. Ordinarily they would have verified the precise origin of the signal with a separate telescope at an observatory in Woodbury, Ga. But lightning had recently struck that telescope and fried its hard drive.

"It was rural Georgia, and it took about three days to get FedEx in there with a replacement drive," Tarter says. "In the

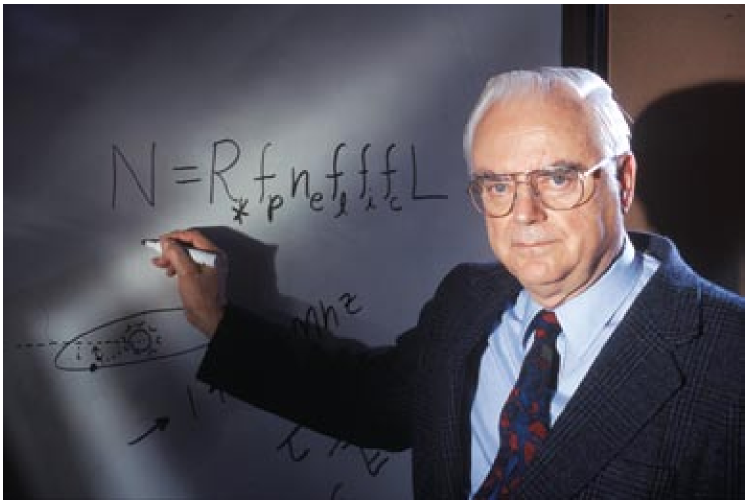
IN BRIEF

Within decades advances in computing power will allow astronomers to scan enough stars in our galaxy to have a reasonable chance at detecting a signal from an extraterrestrial civilization.

News of the discovery of an extraterrestrial signal will reach the public almost immediately. A conspiracy to hide or suppress the evidence of alien intelligence would be all but impossible.

The content of the signal may never be understood. The assumption that mathematics or physics could serve as a cosmic lingua franca among civilizations may be misguided.

Would revealing our existence to the universe at large attract the attention of hostile aliens? Such fears are probably groundless, despite the warnings of some prominent scientists.



Frank Drake first scanned for extraterrestrial signals 50 years ago.

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meantime, we had telescope time in West Virginia"—SETI observations typically piggyback on other, mainstream astronomical research—"and we were going to use it. Without our second site, the only thing we could do was nod back and forth between two different stars."

Tarter, who had been scheduled to fly home to California at noon that day, canceled her flight and left a phone message for Chris Neller, her assistant in Mountain View, to tell her about the change in plans. By late afternoon the target star that was thought to be the source of the signal began to set below the horizon. That is when Tarter and her team realized something was wrong. Although the target star was setting, the source of the signal seemed to be climbing, its strength undiminished. The signal, they eventually determined, was coming from a NASA satellite, the Solar and Heliospheric Observatory, or SOHO.

During all the excitement, no one remembered to call the Mountain View office to tell them the whole episode had been a false alarm. Meanwhile Ann Druyan, Carl Sagan's widow, had by chance called Mountain View to talk with Tarter about something unrelated. Neller told Druyan that Tarter was delayed at the Green Bank observatory, studying what might be a signal from an extraterrestrial civilization. Druyan immediately called William J. Broad, a science reporter for the *New York Times*. Broad in turn called Shostak to confirm the story.

"The beauty of a false alarm is that you see what really happens," Shostak says. "It's no longer theoretical. Not a false alarm that lasts five minutes, but where for the better part of a day you think, maybe this is it. You have these nifty protocols, but what really happens? People don't follow protocols. It's not that people do anything mischievous or malevolent—you're so caught up in the excitement of the moment, the media are immediately calling you on the phone, people send e-mails to their friends."

In the event of a signal that survives initial scrutiny—one that is quickly verified by a second observatory—the astronomers who made the discovery would send an International Astronomical Union (IAU) telegram—now delivered as an e-mail—to observatories around the world. Astronomers use IAU telegrams to notify one another of time-sensitive observations: supernovas, comets or gamma-ray bursts. Tarter says a SETI observation would be treated like any other astronomical discovery. "If something like that happens, we'll want everybody who can to look at it right away," she says. "We'd like people to look in the signal's direction, with different tools, checking different frequencies, and try to figure it out."

VERIFYING THE MESSAGE

SETI SCIENTISTS THINK they know, in broad terms, what an ET signal will look like. To stand out as obviously artificial against a background of natural cosmic radio emissions, the signal would have to be narrow, with a lot of energy packed into a few frequencies. Natural phenomena, such as pulsars and interstellar gases, spew out radio emissions at many different frequencies. If an observatory ever receives a narrowband signal coming from an astronomical distance, the source would almost certainly be artificial.

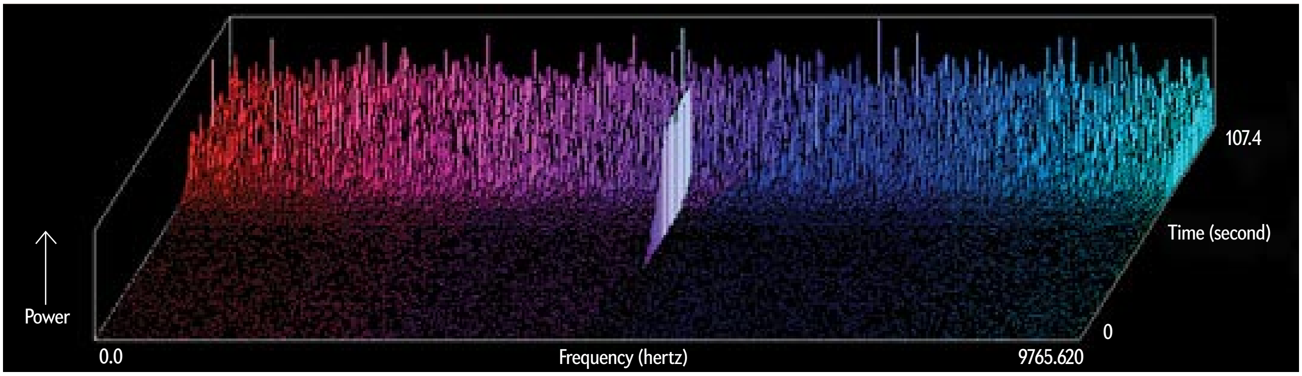
According to voluntary, nonbinding protocols adopted by SETI researchers around the world, if IAU astronomers confirmed a signal as genuine, they would then notify the United Nations and various world leaders. Tarter says that some generous SETI sponsors would also receive discreet thank-you calls. At that point the astronomers who made the discovery would be free to hold a press conference—if the story had not already been leaked. But even those modest constraints would probably be breached. "The protocols are just a nice idea," Shostak says. "They're like red lights in Naples, Italy," he laughs. "They're suggestions."

The story of the discovery would monopolize the headlines for a while, but our collective attention span would inevitably move on while scientists sought to translate the message.

What happens next? A triumphant announcement, followed by headlines? Panic? New Age celebrations of galactic harmony? Probably none of the above, except for the headlines, if Douglas Vakoch is right. A psychologist by training, Vakoch has an office across the hall from Tarter at the SETI Institute and must have the world's most unusual job title: director of interstellar message composition.

"While we may be able to detect that there is a signal that at least initially appears distinctly artificial, I suspect even that claim would be questioned," Vakoch says. "There would be a lot of people trying to come up with natural explanations. I think the assumption that one day someone is going to announce that we've discovered extraterrestrial intelligence, and now the world knows, is a fallacy, because there's going to be much more ambiguity in the process. It might be similar to what was recently considered a plausible claim that there was evidence of fossils in Martian meteorites—interesting enough to consider, but now let's look at this over the next few months."

Even if the signal is confirmed as an authentic transmission from an extraterrestrial civilization, it is unlikely that astronomers would be able to extract any information from it for many years. SETI's instruments are designed to search for steady, pe-



ET's signal, astronomers assume, would arrive in a narrow frequency band at about 1,420 megahertz, the spectral frequency of common hydrogen. In the simulation above, the signal (*at center*) pokes through background noise.

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riodic narrowband radio pulses—carrier waves powerful enough to be detectable across many light-years. The pulse itself would yield no information, other than its artificial nature. Any message content would likely be in the form of changes in amplitude or frequency buried within the pulse. Even a large radio telescope would need to repeatedly scan a small patch of sky to build up the signal pulse above background radio noise. In doing so, it would average out modulations on finer timescales that might contain a message. Resolving the message would require an antenna far more powerful than Earth's largest, the 305-meter dish at Arecibo, Puerto Rico.

"You would need something on the order of 10,000 times bigger than Arecibo," Shostak says. Rather than a single enormous dish, such a telescope would probably consist of many smaller antennas spread across a large area and linked electronically. Constructing such an instrument would require international collaboration and funding, with no guarantee that the message—if the signal contained one—could ever be deciphered. "That's not something you'd do overnight," Shostak observes. "That's a big project. I think we would do it, because—gosh darn it—we would want to know what they're saying."

THE FALLOUT

TAKING INTO ACCOUNT political debates and the time needed to build a telescope sensitive enough to analyze the signal, years would pass before astronomers or cryptographers could begin to attempt to decipher a message from the stars. So whereas that first contact with another intelligence would in itself be one of the most important scientific discoveries of all time, the lack of any further knowledge about the nature of that alien intelligence would limit the immediate cultural impact. The story of the discovery would monopolize headlines for a while, but our collective attention span would inevitably move on while scientists sought to translate the message.

"I have no doubt that the receipt of such a message would be a huge and genuinely exciting moment," says Charles T. Rubin, a political philosopher at Duquesne University who studies the social issues raised by SETI research. "But I don't think it would cause a great cultural shift, because the notion of extraterrestrials is common both in popular culture and in scientific circles. It would confirm what many already suspect to be true."

If some nation or group of nations decides to build an instrument that would give us a shot at cracking an extraterrestrial message, how likely is it that we would succeed? Sagan, an early advocate of SETI, imagined that we might receive an *Encyclopedia Galactica,* filled with the accumulated wisdom of many advanced extraterrestrial civilizations. Some SETI researchers assumed—and still assume—that the language of science might provide common ground for communication. Kathryn Denning, an anthropologist at York University in Toronto and a member of the SETI Post-Detection Taskgroup, is less sanguine.

"We run into an irreducible problem with communication that isn't face to face, and that is the problem of establishing a referent," Denning says. "If you and I speak different languages, and we're in the same room, I can point to a table, and I can say 'table,' and you infer that 'table' is my word for that thing, and then we can go from there. That's the time-honored way of learning languages. If you're not in direct contact, if you can't do that kind of pointing exercise, there's always this question of what you're referring to in these initial communications. Scientists—physical scientists and mathematicians in particular—tend to be more prone to thinking that because we'll be dealing with the same physical structures in the universe, we can use those as our Rosetta Stone, so to speak, and build up from there—send each other the value of pi, and then we're off to the races. But anthropologists tend not to be so comfortable with that. Errors can take place right at the get-go. For example, if I give you a signal—beep, beep, beep—is that three or two? Are we counting the beeps or the spaces? We have fundamental assumptions built in."

Stephen Hawking said that transmitting messages could be dangerous. He warned of the possibility of predatory aliens ravaging the resources of world after world.

John R. Elliott, a researcher at Leeds Metropolitan University in England who studies artificial intelligence and the structure of languages, is already preparing for the day we receive the first extraterrestrial message. Even if it proves impossible to directly translate the message, it might be possible to discover patterns that Elliott suspects are fundamental to all languages. Those patterns might reveal something about the nature of the beings who sent the message, particularly how their level of intelligence compares with our own.

Elliott has devised a computer program that compares any unknown language with a database of 60 human languages. All languages, he says, share what he calls functional elements—words such as "if," "and" and "but"—that break up the complexity of a language into manageable chunks. The length of those chunks—the nouns, verbs and other words contained between the functional elements—provides a measure of our cognitive abilities. "It opens a window on our way of embedding information, the way we structure our sentences," Elliott notes. "It shows the constraints on us as intelligent authors."

Elliott says his computer program shows that the functional elements in all human languages are typically separated by no more than about nine words. Assuming an ET signal arrives as a binary stream of ones and zeros, his program would search for patterns in the message and attempt to identify the occurrence of functional elements. The program would, ideally, give us a rough measure of alien IQ by comparing the average interval between our if's, and's and but's with theirs. "Anything above 10 means it would exceed human cognition," he says. Elliott thinks he could determine whether a signal bears the characteristics of a language within a few days; he might be able to tell if it contains images. "For the semantic side? We might never interpret it."

WORTH THE RISK?

SOME SETI PROPONENTS suggest we should do more than passively wait for a signal. They believe we should transmit messages and let anyone who might be listening know that we are here. Last spring, in a Discovery Channel series, Stephen Hawking of the University of Cambridge said that transmitting messages without knowing what is out there could be dangerous. He warned of the possibility of predatory aliens ravaging the resources of world after world. "If aliens visit us," he said, "the outcome would be much as when Columbus landed in America, which didn't turn out well for the Native Americans."

The SETI community seems to be divided about the wisdom of sending messages versus quietly biding our time. But in any case, it is probably too late. Radio and television signals have been leaking from our planet for decades now. "*I Love Lucy* has already passed 10,000 stars," says Dan Werthimer, a SETI researcher at the University of California, Berkeley, who helped to develop the SETI@Home project, which allows anyone to download software to a home computer to help process SETI data. Moreover, there is no reason why an extraterrestrial civilization couldn't spot Earth using the same—or better—techniques that terrestrial astronomers are already using to find planets around other stars. Geoffrey W. Marcy, an astronomer at Berkeley who has played a leading role in the discovery of dozens of extrasolar planets, says that by the end of this century, space-based telescopes will enable us to map the continents and oceans of these worlds. And if we will soon be doing that, it is likely that extraterrestrial civilizations—if any exist—are doing it, too.

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"Aliens who have a mere 1,000-year head start on us could listen to our conversation right now," Marcy says. "They could read our lips. So this passive versus active thing makes no sense to me. We can't hide—that's crazy! Any more than ants can hide from us humans. It would be like one ant talking to another ant, 'Oh, we'd better not talk because the humans would know we're here, and they might step on us.' No, sorry, guys, you ants can't hide from us!"

Drake believes Hawking's fears are unfounded, largely because interstellar travel may be practically impossible, which he believes also answers the Fermi paradox, named for Enrico Fermi, the Italian physicist who first posed it: If extraterrestrial civilizations exist, why haven't we seen them yet? Given the age of the galaxy, and its 200 billion stars, surely at least one civilization should have colonized the galaxy by now. Drake demurs.

"To give you an idea why even a very small mission won't work, just imagine a spacecraft the size of a 737 airplane, with perhaps 50 passengers. Suppose the nearest star with a habitable planet is only 10 light-years away, which is quite close—there are only a few stars that close. And assume you can go 10 percent the speed of light. Why that number? It never gets mentioned in all these discussions about space travel, but if you're going a little faster than that, about 12 percent the speed of light, if you impact a pebble, the energy in that impact is equal to what that same mass would release if it was used in a nuclear fusion bomb. It would blow up the spacecraft. One pebble in the whole trip ends the mission." But Drake believes that SETI's limited funds should go to searching, not broadcasting.

Marcy says the Fermi paradox presents a genuine problem for SETI researchers, and he sees only three possible solutions. "The fact that aliens haven't landed tells you they're rare, or that space travel is very hard, or that it's not just worth doing."

Perhaps Hawking's fears say more about us than about any aliens we might encounter. Given the history of our own species, who would have more to fear from contact, humans or extraterrestrials? SETI, unavoidably, reflects our own dreams and night terrors about our place in the universe. In postulating the presence of civilizations on other worlds, we are extrapolating wildly from a single known example—our own fragile, remarkable existence.

Realistically, though, the quest to make contact will be an endeavor that spans centuries—if our own civilization lasts that long. SETI is, perhaps, the strangest and most profound experiment in the history of our world. One of the founding fathers of SETI, the late Philip Morrison, a physicist at the Massachusetts Institute of Technology, likened the SETI project to the medieval and Renaissance recovery of the knowledge of classical antiquity, in which scholars labored for generations. The patient transcribing of ancient texts revealed a world that had been lost and eventually transformed the world the scholars thought they knew.

One day we may learn that we are not alone and, indeed, that intelligence is common in the universe. "If SETI succeeds, then intelligence happened in at least one other place," Shostak says. "So it probably happened in lots of places. In astronomy, the only numbers are one, two and infinity. So if you get two, there are probably lots more. It's like finding two elephants." SA

MORE TO EXPLORE

The Eerie Silence: Renewing Our Search for Alien Intelligence. Paul Davies. Houghton Mifflin Harcourt, 2010.

A debate between Carl Sagan and Ernst Mayr on the chances of finding E.T. life: www.planetary.org/explore/topics/search_for_life/seti/seti_debate.html

For aliens only! An informal group of 100 scientists, artists and futurists put together an open invitation to all E.T.s in an early attempt at planetary outreach: **www.ieti.org**

The International Academy of Astronautics quantifies the significance of possible E.T. signals: **www.setileague.org/iaaseti/rioscale.htm**

The SETI Institute's home page has information on telescopes, essays on E.T. signals, podcasts, and more: **www.seti.org**

INFECTIOUS DISEASE

CARLA GOTTGENS *Getty Images*

FLU FACTORIES

The next pandemic virus may be circulating on U.S. pig farms, but health officials are struggling to see past the front gate

By Helen Branswell

Helen Branswell is a medical reporter for The Canadian Press who has covered flu for the past seven years. Currently she is a Nieman Fellow for Global Health Reporting at Harvard University.

THE 2009 INFLUENZA PANDEMIC APPEARED TO COME OUT of nowhere. It started as what seemed like a lethal outbreak in Mexico, then spread north of the border. By the time health officials learned that the virus responsible for the alarming explosion of cases was new and an infection threat to most of humankind, they had no way to keep it from spreading around the world. By a stroke of luck, symptoms were mild in the vast majority of cases. What if next time we are not so lucky?

That question weighs heavily on the minds of influenza scientists and public health planners as they prepare for the next big outbreak. And there will be a next time. Flu viruses mutate constantly. Occasionally those changes result in viruses so different from what our immune systems have seen before that they are able to trigger global waves of disease, or pandemics. Someday there may be a vaccine that can fend off all subtypes of influenza, but such a vaccine remains a dream for now. So new viruses can and will come at us from birds or pigs or other animals. The best we can do is try to spot new invaders soon enough to get a jump on producing vaccines against those particular bugs, to shorten the time from first infections to mass immunizations. No one wants a repeat of 2009, when a vaccine arrived about the time the outbreak was peaking and public interest was waning.

But spotting new threats can happen only if scientists know what viruses are circulating among the species most likely to give rise to new pandemic viruses—birds and pigs. And whereas surveillance in the former has improved over the past five or six years thanks to concerns about bird flu (the H5N1 virus), scientists know too little about the viruses that infect the estimated 941 million domesticated pigs around the world.

Intensive monitoring of pig viruses is unlikely to come any time soon, however. Most pork-producing countries do not test their pigs at all, and in some that do—such as the U.S.—the testing is done on behalf of the pork producers, who have little economic incentive to share what they find. The reason: pig farmers know pork prices plummet when pigs and flu are linked in the news. In the U.S., government agencies have pieced together a new program they hope will extract badly needed data without threatening the livelihood of producers. But many human health experts fear the compromises made to get pig farmers onboard may hobble the effort.

INCREASING MUTATION RATES

YOU COULD CALL PIGS the Achilles' heel of global influenza surveillance. For the animals and the people who raise them, flu is more of a nuisance than a serious threat; it typically causes only mild symptoms in pigs. Swine influenza is not even a reportable disease, a classification saved for diseases deemed a threat to the entire industry, such as foot-and-mouth disease. On the other hand, pig flu viruses can be a big problem for the general population. That is because pigs are a genetic crucible for new flu viruses. They can be infected with flu viruses from birds, other pigs and people, creating opportunities for a melding of genes in new combinations known as reassortants. The fear is these new hybrids will prove capable of infecting people readily, while being sufficiently foreign to cause serious illness once they do.

Since the start of the 2009 pandemic, scientists have tried to piece together how the responsible virus emerged and where. Although the puzzle is still missing many pieces, what they have been able to surmise only underscores the need for vigilance.

For decades the flu viruses that infected pigs remained largely stable. They were genetic descendants of the influenza A virus that caused the 1918 Spanish flu pandemic, an outbreak that killed upward of 50 million people. This family of viruses is named H1N1; the H stands for hemagglutinin and the N for neuraminidase, two proteins on the pathogen's surface that laboratories—and immune systems—use to tell one flu virus from another. (There are 16 groups of H proteins and nine groups of N

IN BRIEF

Emerging threat: While the flu pandemic of 2009 was apparently mild, there is no way of knowing whether the next one will be a repeat or more closely resemble the killer disease of 1918.

Early warning: After the 1997 avian flu scare, researchers developed pretty good surveillance programs to detect potentially deadly viruses that might jump from birds to people.

Blindsided: The 2009 pandemic underscored the possibility that the greater threat may come from pigs, not birds, because it is typically easier for pig viruses to make the jump to people.

Hamstrung: Economic considerations make it harder to get viral samples from pig farms in a timely manner, which frustrates health officials who want to be better prepared for the next pandemic.

proteins.) Distant cousins have also been infecting people for most of the decades since the 1918 pandemic. The pig variants, known as classical swine flu viruses, evolved far more slowly than the human varieties. This picture changed dramatically about a dozen years ago. For unknown reasons, influenza viruses in pigs began to evolve at a dizzying rate in North America, where enormous numbers of pigs are raised.

The U.S., in fact, is the world's second-largest pork producer, after China; 115 million hogs went through U.S. slaughterhouses in 2009. Commercial pig farms vary in size and style of operation. These days many operations segregate the animals by phase of development, keeping pregnant sows away from piglets, for example, to cut down the spread of profit-threatening diseases.

In 1998 herds in Minnesota, Iowa and Texas were found to be infected with a new H3N2 virus, a so-called triple reassortant containing classical swine flu virus genes, along with genes from viruses that normally infect birds as well as those that infect people. Since then, other triple reassortant viruses have formed and spread. These included yet another version of H1N1, as well as an H1N2 and an H3N1 virus. Even H2N3 viruses were briefly spotted in pigs in Missouri in 2006, a potentially dangerous turn of events given that no one born after 1968 has any antibodies to the H2 family of viruses. H2 viruses are high on the list when scientists muse about which ones might go on to cause a future pandemic.

Researchers at the U.S. Department of Agriculture and at diagnostic laboratories reported on the new viruses in scientific journals. But most scientists and officials who focus on the human health side of influenza were distracted by a different and dangerous threat: bird flu. In 1997 an H5N1 virus surfaced in Southeast Asia, traditionally thought of as the epicenter of new

REPLICATION AND REASSORTMENT

Shuffling the Flu Gene Deck

Influenza viruses are well adapted to rapid evolution. First, however, they must infect a cell because they cannot replicate on their own. The diagram below shows how and when flu viruses get into human cells and under what circumstances different strains can mix and match genes with one another, yielding potentially dangerous new types.

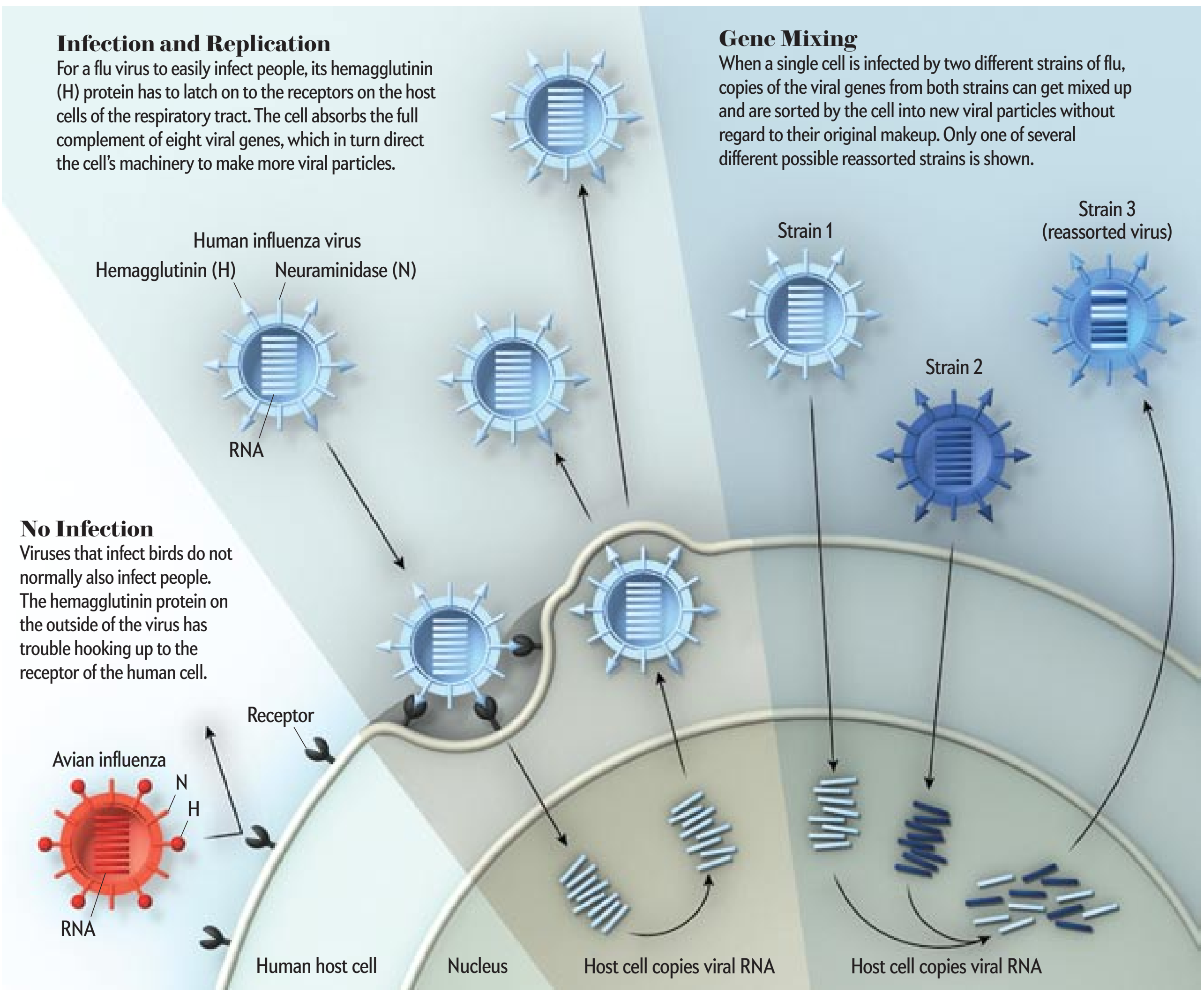
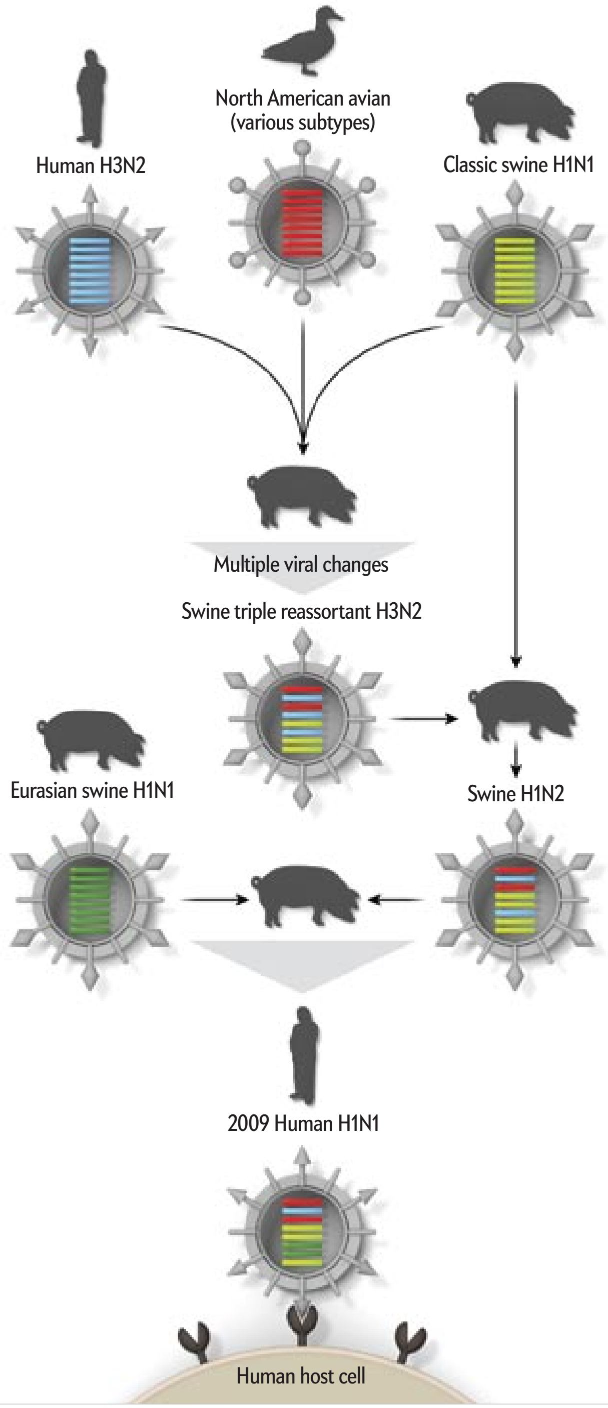


Illustration by Emily Cooper

COMPLEX VIROLOGY

Making a Pandemic Flu

The pandemic flu virus of 2009 belongs to a group called H1N1 viruses. Immunity to one H1N1 virus does not automatically protect you against the others. Part of what made the 2009 H1N1 virus so alarming is that its recent forebears infected three species—humans, birds and pigs. In other words, the virus contained genetic material that was unfamiliar enough to the human immune system to cause a pandemic, albeit a mild one. We may not be so lucky next time.



SOURCE: "GEOGRAPHIC DEPENDENCE, SURVEILLANCE, AND ORIGINS OF THE 2009 INFLUENZA A (H1N1) VIRUS," BY VLADIMIR TRIFONOV ET AL., IN *NEW ENGLAND JOURNAL OF MEDICINE*, VOL. 361, NO. 2; JULY 9, 2009

Illustration by Emily Cooper

flu viruses. The initial outbreak, in Hong Kong, was contained after the city ordered a cull of all poultry within its territory. By late 2003, however, the virus had returned and was rampaging through poultry flocks in China, Vietnam and Thailand and later beyond. Untold millions of birds have died from infection or been culled to stop its spread, and more than 300 people have died.

Those bird flu episodes underscored the urgency of being on the lookout for new flu strains in animal reservoirs. Virologists Malik Peiris and Guan Yi, along with other colleagues at the University of Hong Kong, have conducted groundbreaking surveillance in birds in China. For more than a decade the team has also run a program testing pigs for flu as they come to slaughter. About 80 percent of the animals slaughtered in Hong Kong's abattoirs come from nearby farms on the Chinese mainland. Although the data collected in Hong Kong do not tell China's whole story, the program nonetheless opens a larger window on what is happening with swine influenza in that vast nation—a country not known for its openness—than currently exists in the U.S.

TESTING PIGS

THE IRONY OF THAT JUXTAPOSITION IS not lost on the influenza scientists, who remember how aggressively the U.S. pushed China, Indonesia and other Asian countries to be more transparent about their H5N1 outbreaks. Guan and others are frustrated by the dearth of surveillance data on pigs, not just from the U.S. but elsewhere as well. Surveillance data from the U.S. are inadequate, but there is virtually no monitoring for swine influenza in South and Central America, Africa, India and some other parts of Asia. "The current situation is really not at all comforting," Peiris declares. "We know the pathway," says Guan of the role pigs can play in the creation of novel flu viruses. "Why are we not looking?"

In the U.S., a better question might be "Why aren't they sharing?" Farmers have historically had their pigs tested for flu, often at the diagnostic laboratories of the National Animal Health Laboratory Network (NAHLN). And companies that make flu vaccine for hogs need to know what flu threats the animals face so that they can tailor their vaccines accordingly. But the information that is gathered by the animal health sector is rarely shared with the researchers and officials who safeguard human health. In fact, in the wake of the 2009 outbreak, testing for flu on pig farms screeched to a halt. "Basically the producers really didn't want to know, and so the usual stream of respiratory specimens going into the NAHLN labs dried up," says Nancy J. Cox, head of the influenza division at the Centers for Disease Control and Prevention.

The priorities of these labs and companies are shaped by what is best for pigs and their owners. The NAHLN labs—often housed in universities, such as the University of Minnesota and the Iowa State University—work for the farmers, their clients. Any findings, positive or not, are kept confidential, explains Montse Torremorell, who holds a chair in swine health and productivity at the University of Minnesota. "There is a lot of actual sequencing surveillance, if you will, but that information is fed back to the people who have submitted the samples."

Noteworthy findings, such as the discovery of the first triple reassortant, H3N2, do eventually end up in the scientific literature, but the process can take a year or longer. That is hardly a stand-in for real-time surveillance, which would give human health officials a current picture rather than a historical perspective. Every so often, someone catches swine flu directly from a pig, and the CDC gets a call. (For example, it happened twice this fall. Fortunately, both cases turned out to be isolated episodes.) But such calls generally come too late to allow for a thorough investigation. The pigs "had often gone off to slaughter by the time we were able to figure out what the exposure actually was," Cox says.

Spotting new threats can happen only if scientists know what viruses are circulating among the species most likely to give rise to new pandemic viruses—birds and pigs.

Efforts by other researchers to shed light on the kinds of viruses circulating in pigs have also met with resistance. Richard J. Webby, head of the World Health Organization's collaborating center for influenza at St. Jude Children's Research Hospital in Memphis, encountered the problem when he and a few colleagues tried to set up a short-term study to swab seemingly healthy pigs for flu viruses. In a bid to gain access to the animals, Webby's team promised to put all the specimens it collected into a freezer for three months before studying them. This was a good faith gesture designed to assure farmers who cooperated that they would not find public health folks in hazmat suits at their farm gate a week after the swabbing took place. Webby says the offer, which was accepted by several farmers, was made to "grease the wheels." Some producers probably would not have signed on without it, he acknowledges.

At present, though, far too few genetic sequences of viruses found in pigs are being uploaded to online databases such as GenBank or GISAID, where they could be viewed by flu researchers anywhere. That has left the human health researchers with a giant blind spot. "You couldn't possibly say that the sequences in GenBank or GISAID or anywhere else are representative of what is actually circulating in pigs at the moment," Cox says. "And this is what the public health side is very concerned about. We understand all of the issues on the agricultural side. But we want to work toward a solution where there is a greater sharing of information that is available."

LISTEN TO A PODCAST WITH THE AUTHOR
ScientificAmerican.com/jan2011/flu

COOPERATION NEEDED

THE CDC STARTED DOWN THE ROAD of greater cooperation even before the 2009 pandemic, negotiating with the USDA on a program that would see the findings of animal health diagnostic testing shared with the human health side. But the program, which is still getting off the ground, cannot work without the cooperation of pork producers, who have to date been reluctant to support what many see as a bid by government to meddle in their affairs. "The pigs are owned by the farmer. And what happens to their pigs is the farmer's business, not the government's business, as long as the infection that is going on in those pigs is not what's termed a program disease that is considered to be a risk to the national herd," says Paul Sundberg, vice president for science and technology for the National Pork Board.

To overcome the farmers' hesitancy, the CDC-USDA surveillance system has several key compromises built into it. For starters, anonymity is assured. Viruses found in specimens that producers submit to diagnostic labs may be fed into a more widely accessible surveillance system. Yet unless a producer gives prior consent, anything that might identify his or her farm is stripped from the data before they are passed on. The human health officials can tell which state the virus was found in but not which particular county or farm. "The anonymous surveillance stream is the default, meaning that test results from the surveillance will be provided to the program anonymously. No owner or submitting veterinarian information will accompany the data," says John R. Clifford, the USDA's chief veterinary officer.

Producers can agree to let identifying information remain attached to the data, but few are expected to drop the shield of anonymity. The system's rules also stipulate that if a person is infected with a swine influenza virus, the owner of any herd that person had contact with must give consent before authorities can test the pigs. If the CDC sees a human case or a virus that looks like it might be able to make the jump to people, would the anonymity veil be lifted in the interest of protecting human health? That is not yet clear. Sundberg says if the CDC saw a problematic virus, it could alert the relevant state health department to be on the lookout for human cases.

Producers are not uncaring about the threat swine flu viruses hold for people, says Sundberg, who supports the new CDC-USDA surveillance system, but they think the threat is sometimes exaggerated. Millions of pigs come in contact with people every day, yet human cases of infection from pigs are rare. Farmers saw what happened to Arnold Van Ginkel, the Canadian producer whose herd was the first in the world to test positive for pandemic H1N1. Van Ginkel's pigs recovered, but he had to put down the animals because no one would buy them.

Although the number of viral samples submitted to the new CDC-USDA surveillance system started increasing in the second half of 2010, many doctors and epidemiologists fear that the built-in compromises are still too restrictive. They worry that they will not be able to identify new pig viruses or to detect the jump from a pig to a person in time to make a difference to human health. They have not given up on getting better data. The CDC's Cox and Ilaria Capua, who heads a World Organization for Animal Health reference laboratory in Padua, Italy, are organizing a meeting in Italy in early February of key human and animal health agencies and scientists to try to find a way to overcome the barriers. Capua is cautiously optimistic that there are ways around the obstacles. "We just have to figure them out," she says.

The politics of pork may be sluggish, but influenza is evolving at an alarming rate. "The biological rules have changed in the last 20 years, and so I think the thinking has to change," says Earl Brown, a virologist who specializes in influenza evolution at the University of Ottawa. Pork producers stand to lose a great deal from any negative publicity. If a virulent successor to the 2009 pandemic virus emerges from pigs, however, everyone loses. SA

MORE TO EXPLORE

The Pig as a Mixing Vessel for Influenza Viruses: Human and Veterinary Implications. Wenjun Ma et al. in *Journal of Molecular and Genetic Medicine*, Vol. 3, No. 1, pages 158–166; November 27, 2008.

Characterization of an Influenza A Virus Isolated from Pigs during an Outbreak of Respiratory Disease in Swine and People during a County Fair in the United States. Amy L. Vincent et al. in *Veterinary Microbiology*, Vol. 137, pages 51–59; May 28, 2009.

Emergence and Pandemic Potential of Swine-Origin H1N1 Influenza Virus. Gabriele Neumann et al. in *Nature*, Vol. 459, pages 931–939; June 14, 2009.

Antigenic and Genetic Characteristics of Swine-Origin 2009 A(H1N1) Influenza Viruses Circulating in Humans. Rebecca J. Garten et al. in *Science*, Vol. 325, pages 197–201; July 10, 2009.

ENERGY

In Search of the Radical Solution

The greatest energy payoffs, says investor Vinod Khosla, will come from fundamentally reinventing mainstream technologies

Interview by Mark Fischetti

Vinod Khosla has become the most widely recognized investor in clean technologies—those that generate or save energy with the least environmental impact. He founded Khosla Ventures in 2004 to fund new companies, after being a long-time partner at the giant investment firm Kleiner Perkins Caufield & Byers. His entrepreneurial roots stretch back to 1982, when he co-founded Sun Microsystems, which became a $7-billion workstation and software company. In a one-on-one dialogue, conducted before an audience of energy entrepreneurs and financiers at the recent GoingGreen conference in San Francisco, *Scientific American*'s Mark Fischetti asked Khosla (an adviser to the magazine) to assess, with his venture capitalist's eye, which new energy innovations are most likely to succeed and why. Edited excerpts of the conversation follow.

Scientific American: One of your mantras as an investor is: If it doesn't scale, it doesn't matter. How are clean technologies doing in this regard?

Khosla: Wind power is scaling, but I'm surprised at how little innovation there is. What wind really needs is energy storage technology, and storage hasn't yet started to scale. I would call most of the attempts toyish; we need something radical. Solar seems to be doing well, but way too many companies are doing the same thing. Costs are declining, but not enough to reach unsubsidized market-competitiveness—which is also one of my mantras. That's mostly the fault of investors and entrepreneurs who are trying to do the next marginal thing as opposed to the next radical thing.

The most interesting area is the one that people have soured on the most: biofuels. Amyris just had an initial public offering that was very, very successful. Another one of our companies, Gevo, is on track to do the same. There's enough proof that half a

IN BRIEF

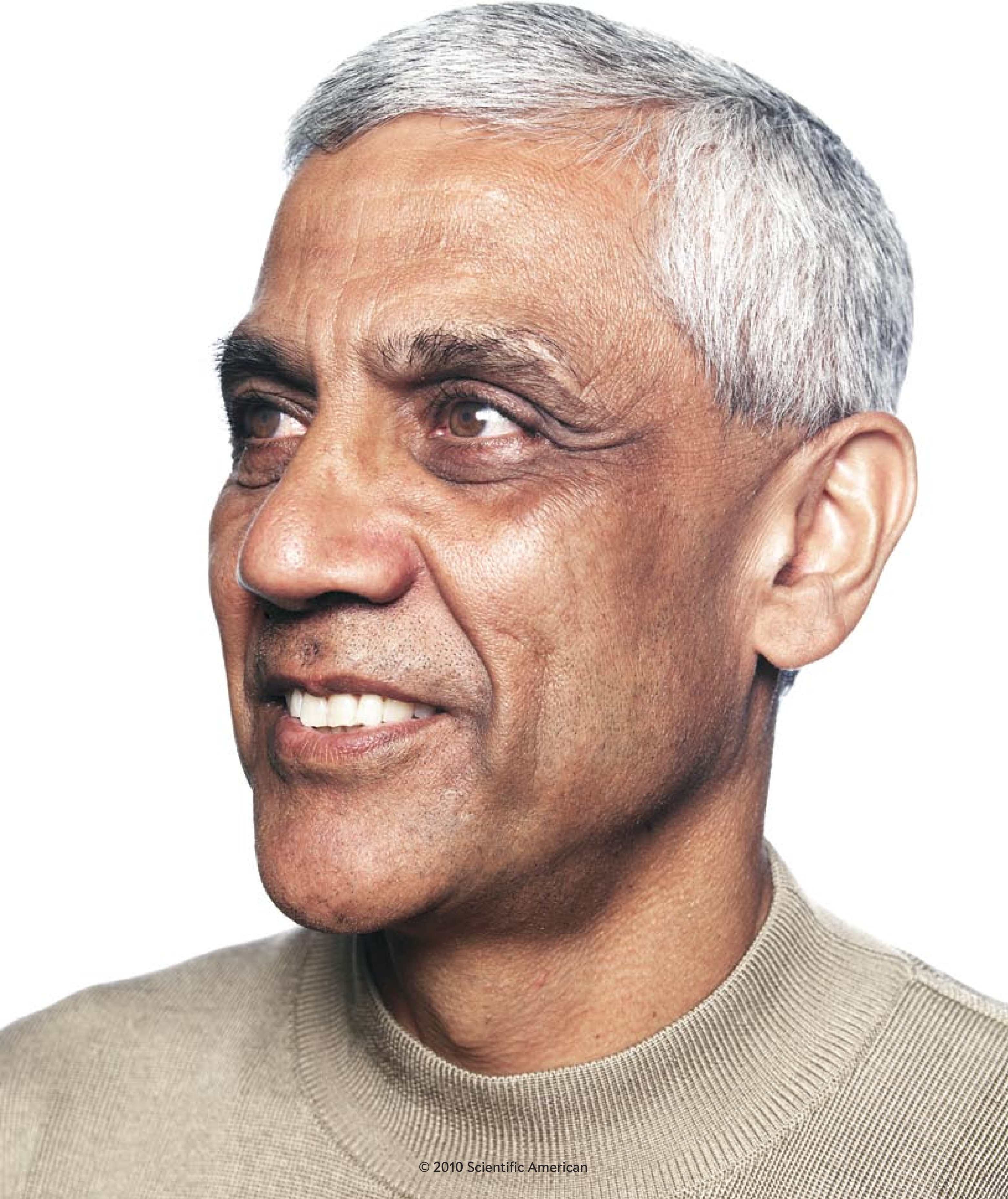
Radical innovation, not incremental improvement, is needed to make clean, efficient energy technologies that can compete, unsubsidized, in big markets.

Mainstream technologies such as air conditioning and automobile engines may be the best targets for breakthroughs that change the energy game.

More people with Ph.D.s in technical disciplines are needed to create true breakthroughs. Students are beginning to flock to these areas.

A low-carbon-electricity standard, not renewable energy standards or cap and trade, would most encourage cleaner technologies, including fossil fuels.

DAVID YELLEN *Corbis Outline*



dozen technologies will make economic sense, some with government subsidies, some without subsidies. The ones without subsidies are the most interesting because they'll scale infinitely.

Another mantra: Don't invest in clean tech, invest in main tech. What is "main tech," and why is that where the most promise lies?

Solar and wind form a very narrow definition of clean tech, probably the least interesting segment. Our firm is investing in radically new automobile engines from EcoMotors that are 50 percent more efficient, at less cost, than today's engines. We are investing in air conditioners that use a new thermodynamic cycle. That to me is main tech. Air conditioning that doesn't cost any more than it does now but uses 80 percent less energy—that's worth talking about. Efficient lighting that pays for itself in the first 12 months, not in 12 years—that's worth talking about.

We are investing in glass. We are investing in cement [*see box below*]—the infrastructure of society, not the sort of fringe, clean tech stuff that depends on subsidies. If you're going to create, as a community, say, 10 new Googles that are in clean tech, they are going to be main tech companies in mainstream markets that work unsubsidized.

Anything that doesn't achieve unsubsidized market-competitiveness within seven years of starting to scale is not worth subsidizing. You may need three, four or five years to do R&D before you start scaling, but if you can't get to market-competitiveness you're not going to work in China or India. There are no subsidies in India. There are no subsidies for solar in Chile or Africa or most of the world. Most of the interesting energy markets are high-growth, developing world markets. If you're not competitive there, unsubsidized, forget it. You're a niche company.

So what is the price point for being competitive? For years investors have said new energy technology must compete with oil at $40 a barrel. Some would say $50. But oil has been well above that price for years, and the big oil states have said they want to make their basement $80 a barrel. Where is the line?

You have to look long term. Let's say your first production plant for turning biomass into biofuel is producing fuel at the equivalent of $75 a barrel. Chances are by your fifth plant you'll be at $60. By your 15th plant, you'll be at $50. So the first-plant economics have to be roughly in the current price range, and then they will keep declining as more plants are built.

When you build the 50th plant, then the ecosystem around it will start to help you: biomass feedstock will get a lot cheaper; John Deere will build custom equipment for harvesting and shredding your biomass. If biofuel can get to $75 a barrel for a first plant, it won't stop until it goes down to $30. By 2030 the price of oil, in 2006 dollars, will be $30 a barrel—not because we stopped using oil but because oil will face plenty of competition.

Biofuel investments were big two years ago. But before that it was wind and solar. Last year it was the smart grid. Clean tech seems to be a moving target.

One of the problems is that environmentalists have been very, very good about identifying the problems we need to solve. They are horrible at picking the answers. I believe most environmentalists most of the time are getting in the way of answers that make economic sense. Economic gravity always wins. That's why I have the mantra about unsubsidized market-competitiveness.

For example, I don't think the electric cars of today make sense economically. Take the Nissan Leaf: a $26,000 electric car, with $20,000 worth of batteries in it? Give me a break. The Chevy Volt, which is a good [hybrid] car, is expected to ship 40,000 units by 2012. The Tata Nano [a small, inexpensive car made in India] had 200,000 orders the first day. We have to make technologies like the Tata Nano, not the Volt, that are low carbon. The bulk of the growth in the world automotive market is in India and China. That economic gravity is key.

In a $100,000 car like the Tesla, a $20,000 battery pack doesn't matter. It's a fun, sexy car. But that owner is not a price-sensitive buyer. The bulk of the world is price-sensitive, and those people are going to drive the equivalent of the Tata Nano. If you want to solve a climate problem, make a Nano kind of car that has low carbon emissions.

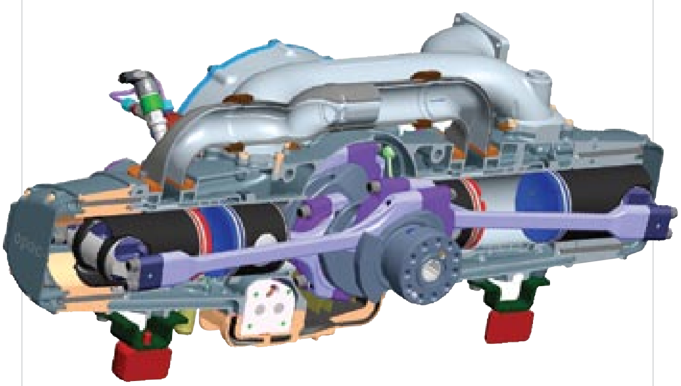
Or build an electric car battery that costs one tenth as much as lithium-ion batteries do now. Almost certainly the traditional lithium-ion bulk batteries will not be around in 15 years. Nobody else believes that, so I'll go on the record.

We are investing in solid-state lithium-ion batteries. Maybe that will work. We are investing in magnesium batteries. Maybe that will work. We are doing other unusual things; I call them "quantum nano thingamajigets." The leading battery in 15 years will be the one that, in people's eyes today, has a very low probability of being a winner.

PORTFOLIO

Khosla Ventures

Vinod Khosla's company has invested in 37 infotech companies and 53 clean-tech companies. Among the latter:



COURTESY OF ECOMOTORS

ECOMOTORS
Allen Park, Mich.
An "opposed piston, opposed cylinder" automobile engine cuts size, weight and fuel consumption (*above*).

CAITIN
Petaluma, Calif.
Air conditioning uses a novel thermodynamic cycle to greatly reduce energy consumed in operation.

AMYRIS
Emeryville, Calif.
Engineered microorganisms convert sugars from biomass into biofuels and specialty chemicals.

CALERA
Los Gatos, Calif.
Process captures carbon dioxide from power plants and uses it as a raw material in cement.

This comes back to radical innovation. The companies that will win the big battle of economic gravity, win in unsubsidized market-competitiveness, will be the companies that are trying radical technologies. If an innovative idea has a 90 percent probability of failing, then I like it. Why? Because it is likely to be the one that has a quantum jump in performance. This is my "black swan thesis of energy." Don't look for solutions in high-probability areas. Those are all incremental. Look for solutions in the tails of the [bell curve] distribution of "likely to succeed."

Are those outliers the focus of the two new funds you've started: $1 billion for energy and information technology and $300 million for high-risk experiments?

We have plenty of money to invest. The problem is finding the people who want to do something other than incremental, nonscalable innovations. You want to do biodiesel from palm oil? Great. Somebody may succeed. But is it even worth succeeding? Not likely.

Other people are trying to make magic work where it hasn't worked. Algae for fuel? I've looked at two dozen business plans, and I haven't found one where the economics work. And it's worse than that; I can't look at their process costs and identify the hypothetical breakthroughs that could create a five-times improvement. Now, could you build an algae company for a high-value product like a neutraceutical [a food product that has health or medical benefits]? Absolutely. Those of you doing algae, I would suggest shifting your guns to high-value products. Might work.

So there's plenty of money. There are not enough breakthrough technologies. There are not enough great Ph.D.s in these fields. I actually add up the number of Ph.D.s in each of the companies [we fund or are considering]. I call every CEO and ask, "How many Ph.D.s did you hire last month?" This is my standard question. There's not enough technical talent for large breakthroughs. Our universities weren't producing many of these people until about two or three years ago, when interest in clean tech or energy technologies increased. The good news is that now smart Ph.D. students are going into these areas, so in 10 years, innovation will explode.

HEAR A PODCAST WITH VINOD KHOSLA
ScientificAmerican.com/jan2011/khosla

You say there's plenty of money, yet critics of clean tech say it takes too much money to scale.

Absolutely wrong. It's a fallacy. The amount of money needed to reach break-even cash flow or to reach an initial public offering or a reasonable point where you can sell the company does not look any different for our clean tech portfolio—our main tech portfolio—than it did for the last 15 years that I was at Kleiner Perkins, when we were looking at information technology or telecom equipment or enterprise software. During the 1990s a lot of companies needed $50 million to $100 million to reach break-even. Our lighting and air-conditioning companies will need equity in this range.

Are there a few companies that need $300 million or $400 million? Absolutely, but we had biotech companies that needed $300 million or $400 million. The distribution looks about the same.

Capital is crucial. But what about legislation to reduce carbon dioxide emissions? A tax on fossil fuels, a cap-and-trade system or renewable energy standards requiring that a percentage of a state or nation's energy supply come from renewables are politically stuck. Instead you advocate a "low-carbon-electricity standard," which would require states to reduce emissions of their electricity sources by a set amount, say, 80 percent by 2030. Why would that work?

Under a low-carbon-electricity standard, the only metric is how much carbon dioxide is produced, not which energy source or clean technology is used to achieve that goal. Each state could pick the technologies most appropriate to it, such as solar in Arizona, wind in Texas or biomass in Arkansas. States with coal or natural gas plants could use carbon capture and sequestration to lower emissions without switching fuels, which also creates a competitive pressure to improve that technology, pressure that does not currently exist.

A low-carbon-electricity standard also allows the conventional fossil guys and new nuclear plants to compete. We need everyone trying to develop radically lower-carbon technologies, not just solar and wind. Carbon capture from natural gas could be almost as low carbon over a plant's lifetime as solar and also be cheaper. If fossil-fuel plants are not included in a plan to reduce emissions, carbon capture will never become economic. It will be limited to expensive Department of Energy projects.

The added benefit is that the U.S. would develop many economic low-carbon technologies, making the country a leading exporter of carbon-capture technologies to India and China, where much of the world's coal-fired capacity is located.

You're enthusiastic about carbon capture. You've said, "I only work on things that are intriguing to me, so I switch every few years. It becomes time to learn something new." Which technologies are most exciting in the next five years?

Every area I look at is exciting. I'm not being facetious. I didn't think we'd be inventing a brand-new engine type. When we looked at air conditioning, we expected to find better compressors—something marginal. But we discovered a brand-new thermodynamic cycle, developed by engineers at the Caitin company. Nobody has really commercialized a new thermodynamic cycle in 50 or maybe even 100 years. I wouldn't have expected that.

What's clear is that people who have been in old energy areas for 30 years are not taking a fresh look, even though the world around them has changed. Take, for example, mechanical engineering. We are still using old mechanical systems like cams to time the valves and cylinders in cars. A cam is a fixed piece of hardware, but driving conditions change, so timing should change. What you need for precise but variable timing are better power electronics devices that can rapidly switch valves on and off. Why aren't all valves in engines electronically controlled? Why do wind turbines have to run at a particular speed with a gearbox, instead of using power electronics to convert all the energy into power at the frequency and phase you need? These are just two examples; there are 100 cases like that in power electronics that would change applications dramatically.

In every area, no matter how archaic, there's innovation to be had. That's a surprise to me. I wouldn't have expected that. SA

MORE TO EXPLORE

Sun Co-Founder Uses Capitalism to Help the Poor. Vikas Bajaj in *New York Times,* October 5, 2010.

Khosla Ventures's clean tech investments can be seen at **www.khoslaventures.com**

Vinod Khosla's argument for a low-carbon-electricity standard can be found by searching for "khosla, LCES" at **www.greentechmedia.com**

1

Olax

FAMILY: Olacaceae
GENUS: *Chaunochiton*

2

Bean

FAMILY: Fabaceae
GENUS: *Enterolobium*

3

Squash

FAMILY: Cucurbitaceae
GENUS: *Melothria*

4

Palm

FAMILY: Arecaceae
GENUS: *Desmoncus*

ECOLOGY

Seeds of the Amazon

Botanists have collected seeds from one of the most biologically diverse places on earth

By Anna Kuchment

SOME LOOK LIKE BRAINS, SOME LIKE ARROWheads, others like beads, propellers or puffs of cotton. Seeds have evolved many of these striking features to help them propagate in the wild. The bead-like seeds of the *Ormosia* tree (*8*) attract birds with their bright red color. Mistaking them for berries, birds pluck the seeds from fruit and excrete them over a wide territory. Seeds with wings (*18, 19*) waft on wind currents; some (*12*) are weighted at the bottom so they can plant themselves on the forest floor; others (*5, 22*) can extend their journey by floating down rivers or streams. The seeds shown here are just some of the 750 that botanists Fernando Cornejo and John Janovec of the Botanical Research Institute of Texas have recently catalogued from the Amazonian wilderness. They range in size from five millimeters (*10*), about the size of a lentil, to 100 mm (*1*), about the size of a doughnut. "Seeds are the root of plant diversity," Janovec says. "They represent the genetic blueprint being carried forward." Their field guide, *Seeds of Amazonian Plants,* published by Princeton University Press, will help scientists understand how forests regenerate, how plants disperse, and how the varied species of this tropical region evolve together as a single ecosystem. SA

VIEW A SLIDESHOW OF SEEDS
ScientificAmerican.com/jan2011/seeds

17

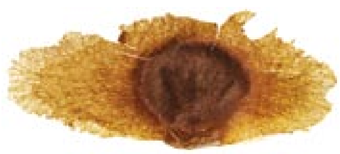
Monimia

FAMILY: Monimiaceae
GENUS: *Mollinedia*

18

Dutchman's Pipe Vine

FAMILY: Aristolochiaceae
GENUS: *Aristolochia*



19

Trumpet Creeper

FAMILY: Bignoniaceae
GENUS: *Anemopaegma*

20

Squash

FAMILY: Cucurbitaceae
GENUS: *Selysia*

Photography by David Liittschwager

5
Loosestrife
FAMILY: Lythraceae
GENUS: *Lafoensia*

6
Cashew
FAMILY: Anacardiaceae
GENUS: *Antrocaryon*

7
Euphorb
FAMILY: Euphorbiaceae
GENUS: *Hevea*

8
Bean
FAMILY: Fabaceae
GENUS: *Ormosia*

9
Morning Glory
FAMILY: Convolvulaceae
GENUS: *Calycobolus*

10
Passion Flower
FAMILY: Passifloraceae
GENUS: *Passiflora*

11
Bean
FAMILY: Fabaceae
GENUS: *Dialium*

12
Buckwheat
FAMILY: Polygonaceae
GENUS: *Triplaris*

13
Palm
FAMILY: Arecaceae
GENUS: *Hyospathe*

14
Dogbane
FAMILY: Apocynaceae
GENUS: *Macoubea*

15
Passion Flower
FAMILY: Passifloraceae
GENUS: *Passiflora*

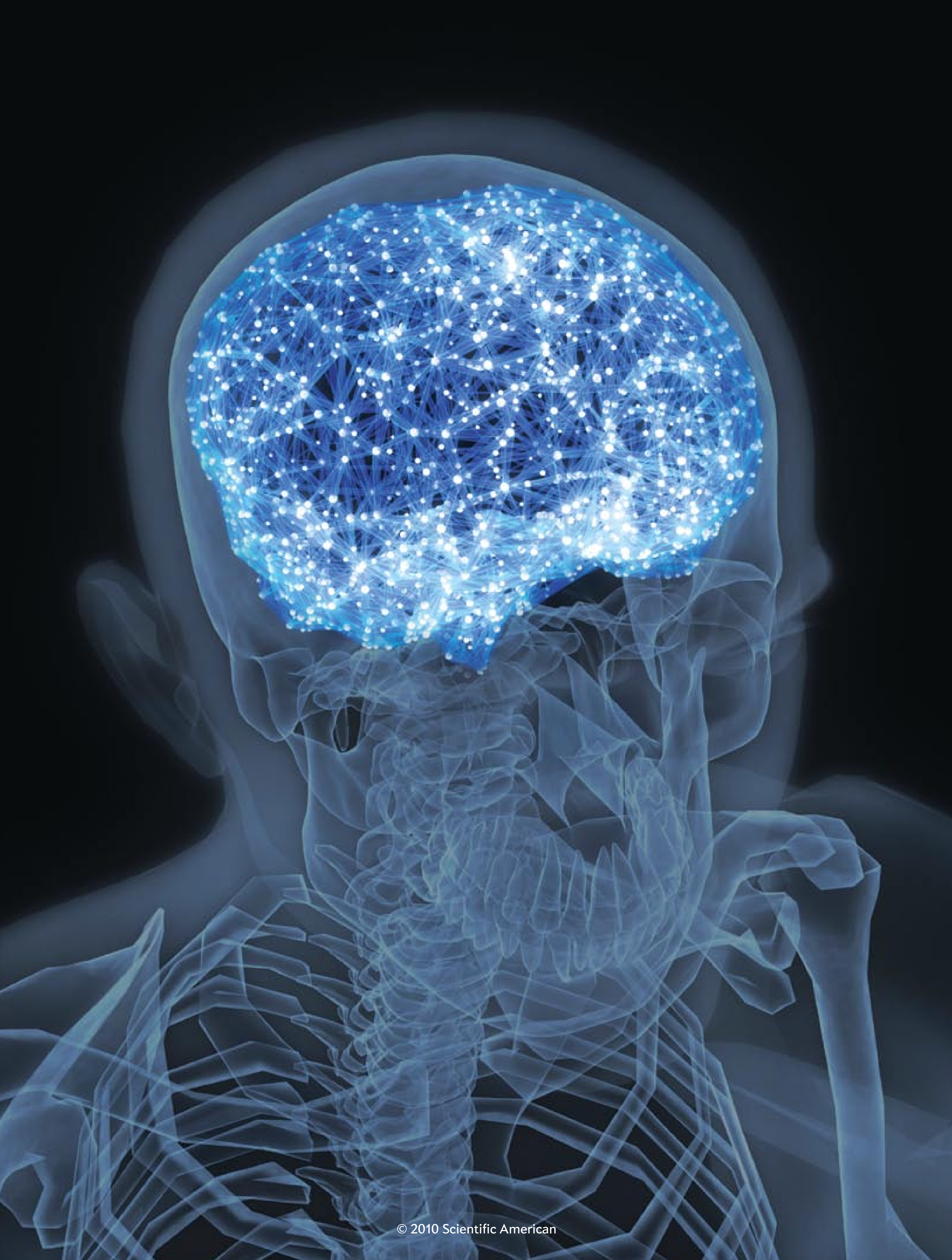
16
Bean
FAMILY: Fabaceae
GENUS: *Parkia*

21
Icacina
FAMILY: Icacinaceae
GENUS: *Calatola*

22
Brazilian Rose
FAMILY: Cochlospermaceae
GENUS: *Cochlospermum*

23
Sabia
FAMILY: Sabiaceae
GENUS: *Meliosma*

24
Souari
FAMILY: Caryocaraceae
GENUS: *Caryocar*



Carl Zimmer is the author of nine books and writes frequently about science for the *New York Times, National Geographic* and *Discover,* where he is a contributing editor. He is the author of the new e-book, *Brain Cuttings: Fifteen Journeys Through the Mind* (Scott & Nix), a chapter of which is excerpted at www.ScientificAmerican.com/e-zimmer

NEUROSCIENCE

100 Trillion Connections

The noise of billions of brain cells trying to communicate with one another may hold a crucial clue to understanding consciousness

By Carl Zimmer

A SINGLE NEURON SITS IN A PETRI DISH, CRACKLING in lonely contentment. From time to time, it spontaneously unleashes a wave of electric current that travels down its length. If you deliver pulses of electricity to one end of the cell, the neuron may respond with extra spikes of voltage. Bathe the neuron in various neurotransmitters, and you can alter the strength and timing of its electrical waves. On its own, in its dish, the neuron can't do much. But join together 302 neurons, and they become a nervous system that can keep the worm *Caenorhabditis elegans* alive—sensing the animal's surroundings, making decisions and issuing commands to the worm's body. Join together 100 billion neurons—with 100 trillion connections—and you have yourself a human brain, capable of much, much more.

How our minds emerge from our flock of neurons remains deeply mysterious. It's the kind of question that neuroscience, for all its triumphs, has been ill equipped to answer. Some neuroscientists dedicate their careers to the workings of individual neurons. Others choose a higher scale: they might, for example, look at how the hippocampus, a cluster of millions of neurons, encodes memories. Others might look at the brain at an even higher scale, observing all the regions that become active when we perform a particular task, such as reading or feeling fear. But few have tried to contemplate the brain on its many scales at once. Their reticence stems, in part, from the sheer scope of the challenge. The interactions between just a few neurons can be a confusing thicket of feedbacks. Add 100 billion more neurons to the problem, and the endeavor turns into a cosmic headache.

Yet some neuroscientists think it is time to tackle the chal-

IN BRIEF

A single neuron cannot do much, but string a few hundred together and a primitive nervous system emerges, one sophisticated enough to keep a worm going.

More neurons equate to a more complex organism. A central preoccupation of neuroscience is deducing the way billions of neurons produce the human mind.

Neuroscientists have begun to unravel the brain's complexity by adopting research on other elaborate systems, ranging from computer chips to the stock market.

Understanding the workings of the brain's intricate networks may provide clues to the underlying origins of devastating disorders, including schizophrenia and dementia.

Illustration by Mirko Ilic

lenge. They argue that we will never truly understand how the mind emerges from our nervous system if we break the brain down into disconnected pieces. Looking only at the parts would be like trying to figure out how water freezes by studying a single water molecule. "Ice" is a meaningless term on the scale of individual molecules. It emerges only from the interaction of a vast number of molecules, as they collectively lock into crystals.

Fortunately, neuroscientists can draw inspiration from other researchers who have been studying complexity in its many forms for decades—from stock markets to computer circuits to interacting genes and proteins in a single cell. A cell and a stock market may not seem to have much in common, but researchers have found some underlying similarities in every complex system they have studied. They have also developed mathematical tools that can be used to analyze those systems. Neuroscientists are picking up those tools and starting to use them to make sense of the brain's complexity. It's still early days, but their results so far are promising. Scientists are discovering the rules by which billions of neurons are organized into networks, which, in turn, function together as a single, coherent network we call the brain. The organization of this network, scientists are finding, is crucial to our ability to make sense of an ever changing world. And some of the most devastating mental disorders, such as schizophrenia and dementia, may be partly the result of the collapse of the brain's networks.

> Interaction among just a few neurons creates a thicket of feedbacks. Billions more brain cells in the mix elicit the essence of a complex system.

Neurons form networks by extending axons that make contact with other neurons. These contacts enable a signal traveling through one nerve cell to trigger a wave of current in the other neurons. Because each neuron can join to thousands of other cells—both those nearby or on the other side of the brain—networks can take on an inconceivable number of arrangements. How your brain's particular network organizes itself has a huge effect on how it works.

BUILDING A TOY BRAIN

JUST HOW DOES ONE go about studying the brain's network of neurons? What experiment could scientists do to trace billions of network connections? One answer is to make a miniaturized model of a brain that can demonstrate what happens when neurons interact in different ways. Olaf Sporns of Indiana University and his colleagues made just such a model. They created 1,600 simulated neurons, which they arrayed around the surface of a sphere. Then they linked each neuron to other neurons. At any moment, every neuron has a tiny chance of spontaneously firing. Once a neuron fires, it has a small chance of triggering other neurons linked to it to fire as well.

Sporns and his colleagues tinkered with the connections between the neurons and watched their toy brain in action. First they connected each neuron only to its immediate neighbors. With this network, the brain produced random, small flickers of activity. When a neuron spontaneously fired, it created a wave of electricity that could not travel far. Next Sporns and his team linked every neuron to every other neuron in the entire brain, which produced a very different pattern. The entire brain began to switch on and off in regular pulses.

Finally, the scientists gave the brain an intermediate network, creating both local and long-distance links between the neurons. Now the brain became complex. As neurons began to fire, they gave rise to great glowing patches of activity that swirled across the brain. Some patches collided with one another. Some traveled around the brain in circles.

Sporns's toy brain offers an important lesson about how complexity emerges. The architecture of the network itself shapes its pattern of activity. Sporns and other researchers are taking the lessons they glean from models of the brain and looking for similar patterns in the real ones in our heads. Unfortunately, scientists cannot monitor every single neuron in a real brain. So they are using clever techniques to record the activity in relatively few neurons and drawing some big conclusions from their results.

BRAINS IN A DISH

DIETMAR PLENZ, a neuroscientist at the National Institute of Mental Health, and his associates have been probing the brain's architecture by growing pieces of brain tissue the size of sesame seeds in petri dishes. They stick 64 electrodes into the tissue to eavesdrop on the spontaneous firing of the neurons. Their electrodes detect a rapid-fire staccato of activity, known as neuronal avalanches.

At first, it seems as if the neurons are just crackling with random noise. If that were true, then each neuronal avalanche would be equally likely to be tiny or widespread. That's not what Plenz and his colleagues found, however. Small avalanches were the most common; large avalanches were rare; even larger avalanches were rarer still. On a graph, the odds of each size form a smooth, descending curve.

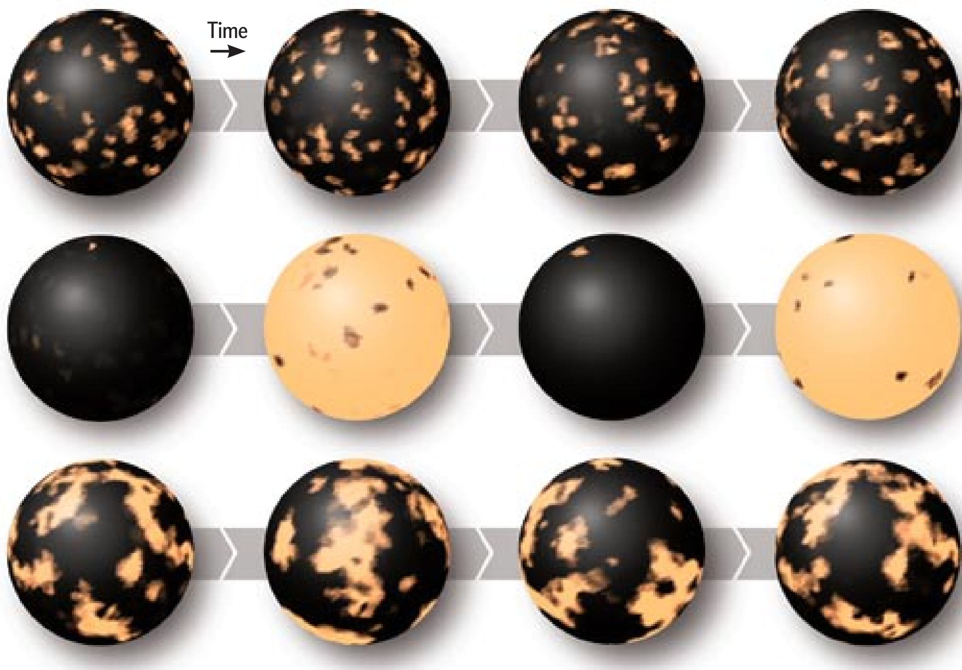
Scientists have seen this kind of curve before. Heartbeats, for example, are not all alike. Most of them are a little longer or shorter than the average. A smaller number of beats are a lot longer or shorter, and a far smaller number are even further away from average. Earthquakes follow the same pattern. The shifting continental plates produce many small earthquakes and a few large ones. During epidemics, each day may typically bring a few cases, with a burst of new cases coming from time to time. And if you plot heartbeats, earthquakes or numbers of new cases on a graph, they form an exponentially falling curve.

This curve, known as a power law, is a hallmark of a complex network that encompasses both short- and long-distance links. A tremor in one spot on the earth may, in some cases, spread across only a limited area. In rare cases, the motion may be able to extend across a much wider domain. Neurons work in the same way. Sometimes they excite only their immediate neighbors, but other times they can unleash a widespread wave of activity.

The shape of a power-law curve can give scientists clues about the network that produced it. Plenz and his co-workers tested out a number of possible networks of neurons to see which ones would produce neuronal avalanches in the same way real neurons do. They got the closest fit with a network of 60 clusters of neurons. The clusters were linked, on average, to 10 other ones. These links were not scattered randomly among the clusters. Some clusters had lots of connections, although many had just a few. As a result, the number of links from any given cluster to any other one was very few. Scientists call this kind of arrangement a small-world network.

Anatomy of a Toy Brain

A brain simulation crafted by Olaf Sporns and his colleagues at Indiana University gives rise to three different patterns of connections among 1,600 virtual neurons arrayed around a sphere. The simulation—in which some neurons activate spontaneously (*yellow areas*) while the rest remain dormant—helps researchers deduce how different types of networks produce complex interactions, some of which replicate activity that occurs throughout actual brain circuits.



OLAF SPORNS *Indiana University*

It turns out that this kind of network may make our brains exquisitely sensitive to incoming signals, in much the same way a powerful microphone can amplify a wide range of sounds. Plenz and his team applied electrical shocks of different strengths and measured how the neurons responded. They found that faint shocks produced responses from a limited number of neurons. Strong shocks triggered a strong response from a wider range of cells.

To see how the network structure affected this response, Plenz and his colleagues added a drug to the neurons that weakened the connections between the neurons. Now the cells failed to respond to faint signals. The scientists got a different result when they injected a drug that made neurons more likely to fire in response to signals from their neighbors. Now the neurons responded intensely to weak signals—so intensely that their response to weak signals was no different than it was to strong ones. These experiments revealed how finely tuned neural networks can be and how that fine-tuning lets them relay signals accurately. If the neurons were organized in a different network, they would produce meaningless, incoherent responses instead.

Neuroscientists ultimately wish to know how activity in a lab dish relates to everyday mental processes. Looking across the entire brain, experimenters discover patterns of spontaneous activity that mirror the kind Plenz finds in his small bits of brain tissue. Marcus E. Raichle of Washington University in St. Louis and his collaborators have found that waves of electricity can travel across the entire brain in complex patterns when we are just resting, thinking of nothing in particular. Recent experiments suggest this spontaneous activity may play a vital part in our mental life. It may allow the resting mind to reflect on its inner workings, reviewing memories and making plans for the future.

NEURAL CARTOGRAPHERS

TO UNDERSTAND HOW these waves behave, neuroscientists are trying to map the connections between neurons across the entire brain. Given how hard it is for scientists such as Plenz to figure out what is going on in a bit-size piece of tissue, this is no small challenge. Sporns has been leading one of the most ambitious of these mapping projects. Teaming up with Patric Hagmann of the University of Lausanne in Switzerland and his neuroimaging group, he analyzed data acquired from five volunteers' brains, using a method known as diffusion spectrum imaging, or DSI. DSI readily captures images of axons that are covered by a thin layer of fat, the long fibers linking the different regions of the cortex, known as white matter. The scientists selected almost 1,000 regions of the cortex and mapped the white matter links from each one to the others.

The scientists then created a simulated version of these 1,000 regions and experimented with it to see what kind of patterns it would produce. Each region generated signals that could travel to or fall. In turn, the entire network can influence the lowest levels. When the stock market begins to rise, for example, individual traders may want to jump on a rally, driving the market even higher.

Rockmore and Pauls and their colleagues developed a set of mathematical tools to uncover the structure of the network underlying the New York Stock Exchange. They downloaded the daily close prices of 2,547 equities over 1,251 days and searched for similarities in the changing prices of different equities—a tendency to rise and fall around the same time, for example.

This search revealed 49 clusters of equities. When the scientists turned back to their financial information, they found that the clusters mostly corresponded either to particular sectors of the economy, such as software or restaurants, or to particular places, such as Latin America or India.

That they had found these categories simply by analyzing the data gave the scientists some confidence in their methods. It makes sense, after all, that the stocks of companies that provide Internet access would tend to rise and fall in tandem. A dangerous Internet worm could spell trouble for the entire group.

Rockmore and Pauls also found that these 49 clusters were actually organized into seven superclusters. In many cases, these superclusters corresponded to industries that depend on one another. The strip-mall business and the construction business move hand in hand. The two researchers found that these superclusters were linked in a giant loop. That loop was likely the result of a common practice of investment managers called sector rotation. Over the course of several years these managers move their money from one part of the economy to another.

A mathematical model that simulates the interactions underlying buying and selling in the stock market can also represent the networks underlying brain activity.

Now Rockmore and Pauls are using the same mathematical methods to build a model of the brain. Instead of financial information moving from one part of the market to another, they now look at information moving from one region of the brain to another. And just as financial markets have mutable networks, the brain can reorganize its network from one moment to the next.

To test out their model, Rockmore and Pauls recently analyzed functional MRI images that Raichle and his colleagues recorded of a subject's resting brain. They noted the rising and falling activity in each voxel, the peppercorn-size chunk of brain that is as small as fMRI can measure. They then searched for close relations in the patterns. Just as the two found clusters of equities in the stock market, they now discovered that the voxels could be grouped into 23 clusters. And these clusters, in turn, belonged to four larger clusters. Remarkably, these four larger clusters carry out a neurological version of the sector cycling Rockmore and Pauls found in the stock market. They are joined together in a loop, and waves of activity sweep through them in a cycle.

Now that Rockmore and Pauls can reconstruct the network in a resting brain, they are turning their attention to the thinking brain. To understand how the brain changes its organization, they are analyzing fMRI data from people who are shown a series of objects. If their model works, Rockmore and Pauls may be able to predict what kind of results a neuroscientist would get from a scan of someone seeing a particular kind of stimulus, such as the face of an old friend. Such an achievement would push neuroscience toward a truly predictive science.

Studies like these won't let scientists completely decipher the human brain's complexity for a very long time. The nematode worm *C. elegans* offers a cautionary tale. More than 20 years ago researchers finished mapping every connection bridging all its 302 neurons. But investigators still do not know how that simple network gives rise to a working nervous system.

NETWORK NEUROLOGY

SCIENTISTS MAY NOT HAVE TO DRAW a complete diagram of the brain's wiring before they can learn some important practical lessons. A number of studies suggest that some brain disorders are not the result of any particular part of the brain malfunctioning. Instead the network itself may go awry. Sporns and his colleagues wondered how the small-world network they identified might change if they turned off different nodes. If they shut down a region of the brain with only a few connections to its neighbors, the network as a whole continued to behave much as it had before. But if they shut down a single hub, the patterns of activity across the entire network changed dramatically. This finding may explain the puzzling unpredictability of brain damage. A tumor or a stroke can sometimes cause devastating harm by knocking out a tiny patch of neurons. But other times they may wipe out a lot of neurological real estate without causing any noticeable change to the workings of a brain.

A number of diseases of the brain may also turn out to be network disorders. Ed Bullmore, a neuroscientist at the University of Cambridge, and his colleagues have been investigating the possible link between the brain's networks and schizophrenia. In a recent study the scientists took fMRI scans of 40 people with schizophrenia and 40 healthy people lying quietly with their eyes open. Bullmore and his team then mapped the network of regions still active in their resting brains. The scientists found that some regions of this resting-state network were more in sync in the brains of schizophrenics than in normal brains.

Scientists do not yet know how schizophrenia and these changes to the brain's network are related. At the very least, it may be possible to use this understanding to develop sensitive tests for schizophrenia, as well as a range of other disorders such as autism and ADHD, which show signs of being diseases of the brain's networks. Doctors might also be able to track the progress of their patients by observing whether their brains' networks have returned to a healthy state. That would be a welcome advance, even if we had to wait still longer for neuroscientists to decipher the brain's full complexity. SA

MORE TO EXPLORE

Theoretical Neuroanatomy: Relating Anatomical and Functional Connectivity in Graphs and Cortical Connection Matrices. O. Sporns, G. Tononi and G. M. Edelman in *Cerebral Cortex,* Vol. 10, No. 2, pages 127–141; February 2000.

Mapping the Structural Core of Human Cerebral Cortex. Olaf Sporns et al. in *PLoS Biology,* Vol. 6, No. 7, e159; July 2008.

Efficient Network Reconstruction from Dynamical Cascades Identifies Small-World Topology of Neuronal Avalanches. Sinsia Pajevic and Dietmar Plenz in *PLoS Computational Biology,* Vol. 5, No. 1, e1000271; January 2009.

Networks of the Brain. Olaf Sporns. MIT Press, 2010.

READ FROM ZIMMER'S NEW E-BOOK www.ScientificAmerican.com/e-zimmer linked regions, causing neurons there to send out similar signals as well. When the scientists powered up this virtual brain, it began to produce slowly shifting waves of activity. Remarkably, these waves resemble the real ones, seen by Raichle and others, in resting brains.

The network that Sporns and his colleagues have mapped across the brain is organized very much like the smaller one Plenz found in his small pieces of tissue—it is a small-world network, with a few well-connected hubs. This large-scale architecture may help our brains save resources and work faster. It takes a lot of resources for us to grow and maintain white matter. With a few well-connected hubs, our brains require much less white matter than they would with other kinds of networks. And because it takes few links to get from one part of the brain to the other, information gets processed faster.

Neuroscientists are going to be able to make much better maps of the brain's networks in years to come, thanks to a $30-million project launched last year by the NIH. Known as the Human Connectome Project, it will survey every connection between neurons in an adult brain. But even this map will not, on its own, capture the brain's full complexity. That is because neurons use only a subset of the brain's connections to communicate with other neurons. From moment to moment, this network can change shape as neurons switch from some connections to others. Creating models of the brain that can capture these dynamic networks will demand all the tricks of the trade that complexity theory can offer.

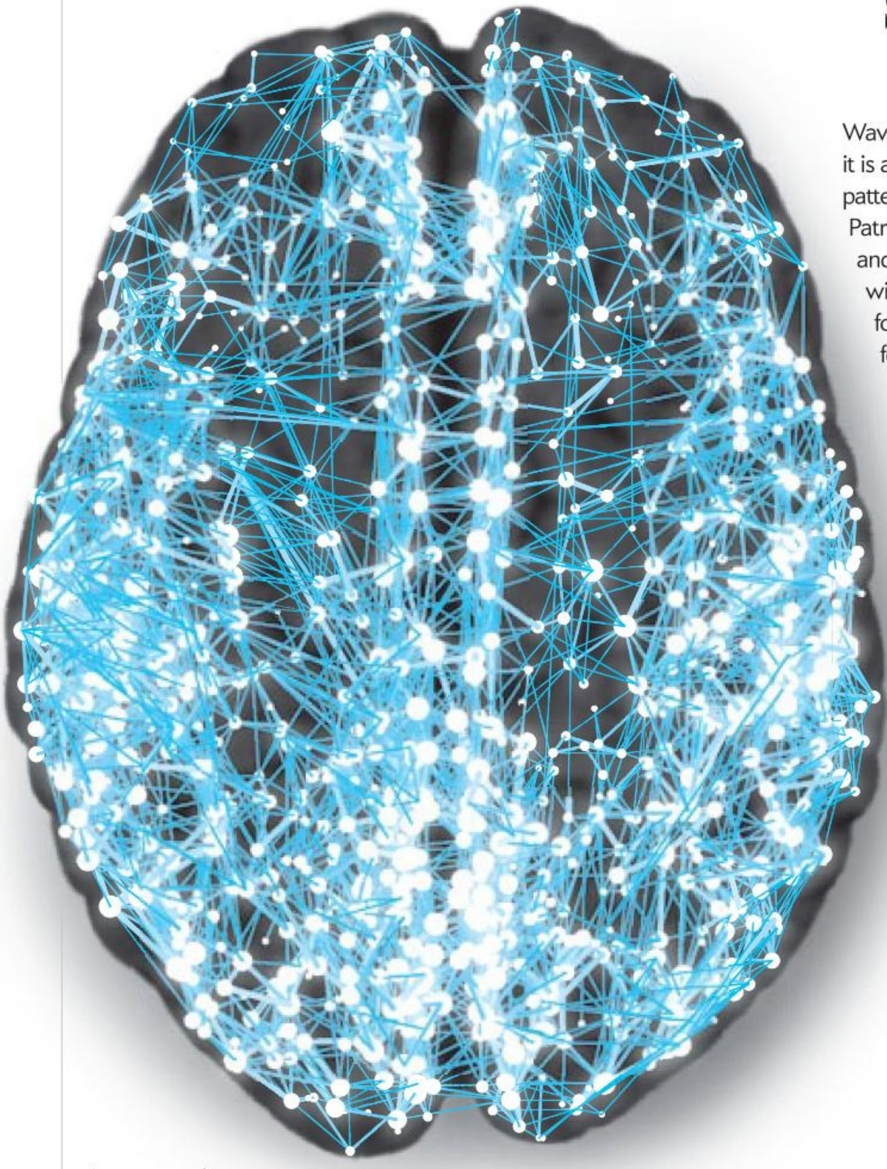
THE WALL STREET NEURON

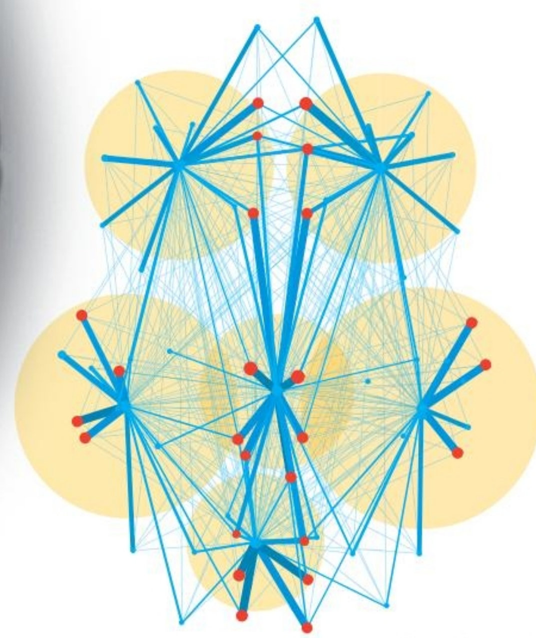
TWO MATHEMATICIANS at Dartmouth College, Daniel N. Rockmore and Scott D. Pauls, are attempting to parse this complexity by treating the brain like the stock market. Both the brain and the stock market consist of lots of small units—traders, neurons—that are organized into a large-scale network. Traders can influence one another in how they buy and sell, and that influence can rise up to affect the entire network, making the stock market rise

HACKING THE BRAIN

Small Worlds from Large Networks

Waves of electrical activity sweep across the brain, even when it is at rest. A number of studies now try to map these neural patterns because they may play a critical role in mental life. Patric Hagmann of the University of Lausanne in Switzerland and Olaf Sporns of Indiana University have charted the brain with a technique called diffusion tensor imaging. They found that the dense network of connections (*left*) has a few well-connected hubs (*red dots*) through which many links pass (*below*). Such "small-world" networks of hubs may help our brains process information more rapidly and allow the organ to maintain its structural integrity efficiently.


Large network


Small-world network

SOURCE: "MAPPING THE STRUCTURAL CORE OF HUMAN CEREBRAL CORTEX," BY P. HAGMANN ET AL., IN *PLOS BIOLOGY*, VOL. 6, NO. 7; 2008

Illustration by Jen Christiansen

Alex de Sherbinin is a senior researcher at Columbia University's Earth Institute and deputy manager of the NASA Socioeconomic Data and Applications Center.

Koko Warner researches climate change, adaptation and environmentally induced migration at the United Nations University Institute for Environment and Human Security.

Charles Ehrhart coordinates global response to climate change at CARE International, a nonprofit organization dedicated to alleviating global poverty.

ENVIRONMENT

Casualties of Climate Change

Shifts in rainfall patterns and shorelines will contribute to mass migrations on a scale never before seen

By Alex de Sherbinin, Koko Warner and Charles Ehrhart

SINCE THE BEGINNING OF RECORDED TIME, CLIMATE-FORCED MIGRATIONS HAVE RESHAPED CIVILIZATION. Four thousand years ago a prolonged drought and the resulting famine in Canaan drove Jacob and his sons to Egypt, setting the stage for the famous exodus led by Moses. Three millennia later a prolonged dry period and lack of grazing lands helped to push Mongol armies out of Central Asia as far west as Europe, where many settled and intermarried. And in the 20th century the American Dust Bowl, an ecological catastrophe precipitated by drought and compounded by bad land-management policies, displaced 3.5 million people from the Midwest.

Today this age-old story has a new twist. We are entering an era marked by rapid changes in climate

IN BRIEF

Climate change caused by global warming will disrupt the livelihoods of millions of people, prompting many to move from their homelands.

Here we examine three regions around the world that have already begun to suffer the effects of climate change, leading many to leave.

Predicting exactly who will move and where they will go to is an impossibility, but leaders can implement policies to help alleviate the inevitable suffering.

TOM STODDART *Getty Images*

Wanderers: A family wades through the streets of Chokwe, Mozambique. Increasingly frequent floods there have caused many families to permanently relocate.

brought on by man-made greenhouse gas emissions. Anticipated changes include higher rainfall variability, greater frequency of extreme events (such as droughts and floods), sea-level rise, ocean acidification, and long-term shifts in temperature and precipitation—any of which can profoundly disrupt the ecosystems that supply our basic needs. In our more densely settled world, people may be forced from their homes in numbers never seen before.

Most attention has centered on the plight of low-lying island states threatened by rising sea levels. Under certain scenarios, many of the world's 38 small island states could disappear by the end of this century. Yet the problem faced by the inhabitants of these states is just the tip of the atoll. In India alone, 40 million people would be displaced by a one-meter sea-level rise. Unfortunately, this coastal flooding is far from the only climate-related challenge in South Asia. Models developed by Arthur M. Greene and Andrew Robertson of Columbia University suggest an increase in total monsoon rainfall but a decrease in the frequency of rain, implying more intense rainfall in fewer days. Shifts in the seasonality of river flows (as winter snowpack declines and glaciers shrink) would affect the agricultural livelihoods of several hundred million rural Asians, as well as the food supplies of an equal number of Asian urbanites.

Although it may take decades to understand the full impacts of glacier melting and sea-level rise, the increase in climate-related catastrophes is already a fact. The frequency of natural disasters has increased by 42 percent since the 1980s, and the percentage of those that are climate-related has risen from 50 to 82 percent. The United Nations Office for the Coordination of Humanitarian Affairs and the Internal Displacement Monitoring Center estimates that in 2008, climate-related calamities drove 20 million people from their homes—more than four times the number displaced by violent conflict.

SEE MORE MAPS
ScientificAmerican.com/jan2011/migrations

Forced migration and displacement prompted by climate change is therefore poised to become the international community's defining—and potentially overwhelming—humanitarian challenge in coming decades. In this article, we offer a sense of what the future holds by looking at the factors that have already begun to instigate such movements in three regions of the world. First we consider Mozambique, where a combination of catastrophic floods and periodic droughts has caught rural populations in a double bind. Next we examine the Mekong Delta. Floods there have long been part of the rhythm of life, yet the scale in recent years has surpassed historic precedent, and the country is facing catastrophic losses of productive land from projected sea-level rise. We close with Mexico and Central America, where tropical storms and cyclones have displaced thousands, and drought looms as a constant danger.

It would be folly to attempt to predict the precise size, direction and timing of the migrations to come, and so we will refrain from doing so. It is our hope that by presenting these case studies we can spur fuller analyses of where mass migrations are likely to occur and the development of international and regional plans to help those forced to leave their homes.

The evidence we present in the stories that follow comes from the European Commission's Environmental Change and Forced Migration Scenarios project (EACH-FOR), a global study on environmentally induced migration, and from a mapping exercise conducted by the Center for International Earth Science Information Network (CIESIN) at Columbia's Earth Institute. SA

We would like to acknowledge the contributions by Susana Adamo and Tricia Chai-Onn of CIESIN and the EACH-FOR case study authors Mark Stal, Olivia Dun and Stefan Alscher.

MORE TO EXPLORE

In Search of Shelter: Mapping the Effects of Climate Change on Human Migration and Displacement. Koko Warner et al. Available at **www.ciesin.columbia.edu/documents/ClimMigr-rpt-june09.pdf**

Environmental Change and Forced Migration Scenarios Project. Case studies and final report available at **www.each-for.eu**

CARE International Climate Change Information Center: **www.careclimatechange.org**

Low Elevation Coastal Zone Data and Maps: **http://sedac.ciesin.columbia.edu/gpw/lecz.jsp**

MOZAMBIQUE:

THE DOUBLE BLOW

Mozambique, a country the size of California and Montana put together, lies along Africa's eastern coast between Tanzania in the north and South Africa in the south. It has a history of migration and government-sponsored resettlement stemming from the nation's socialist past and a 16-year civil war that ended in 1992, during which five million people were forced from their homes. During the four years following the end of the war, more than 1.7 million Mozambicans returned from Malawi, Zimbabwe, Swaziland, Zambia, South Africa and Tanzania.

Although the civil war is behind them, a new crisis is now afflicting Mozambique. In 2000, 2001 and 2007 disastrous floods in the Zambezi and Limpopo river basins displaced hundreds of thousands of people. The floods of 2007 alone displaced more than 100,000 people, half of whom were evacuated to temporary "accommodation centers." In 2007, after earlier high waters had subsided, Cyclone Favio caused the Zambezi to overflow its banks again. During that episode, affected people lost their homes and livelihoods, as well access to medical facilities, sanitation and safe drinking water. Such double and triple blows greatly hinder communities' abilities to recover, given that many people's limited assets have been literally swept away.

In the years after the 2001 floods, the government encouraged residents to permanently resettle away from dangerous floodplains by providing incentives such as infrastructure in a work-for-assistance program. In exchange for making bricks, the government promised to pay for other construction materials and to contribute technical construction assistance. In interviews conducted by EACH-FOR's Mark Stal, displaced people living in resettlement centers indicated that before the past decade, communities would periodically move out of the floodplain to avoid floods but that they had never contemplated relocating permanently.

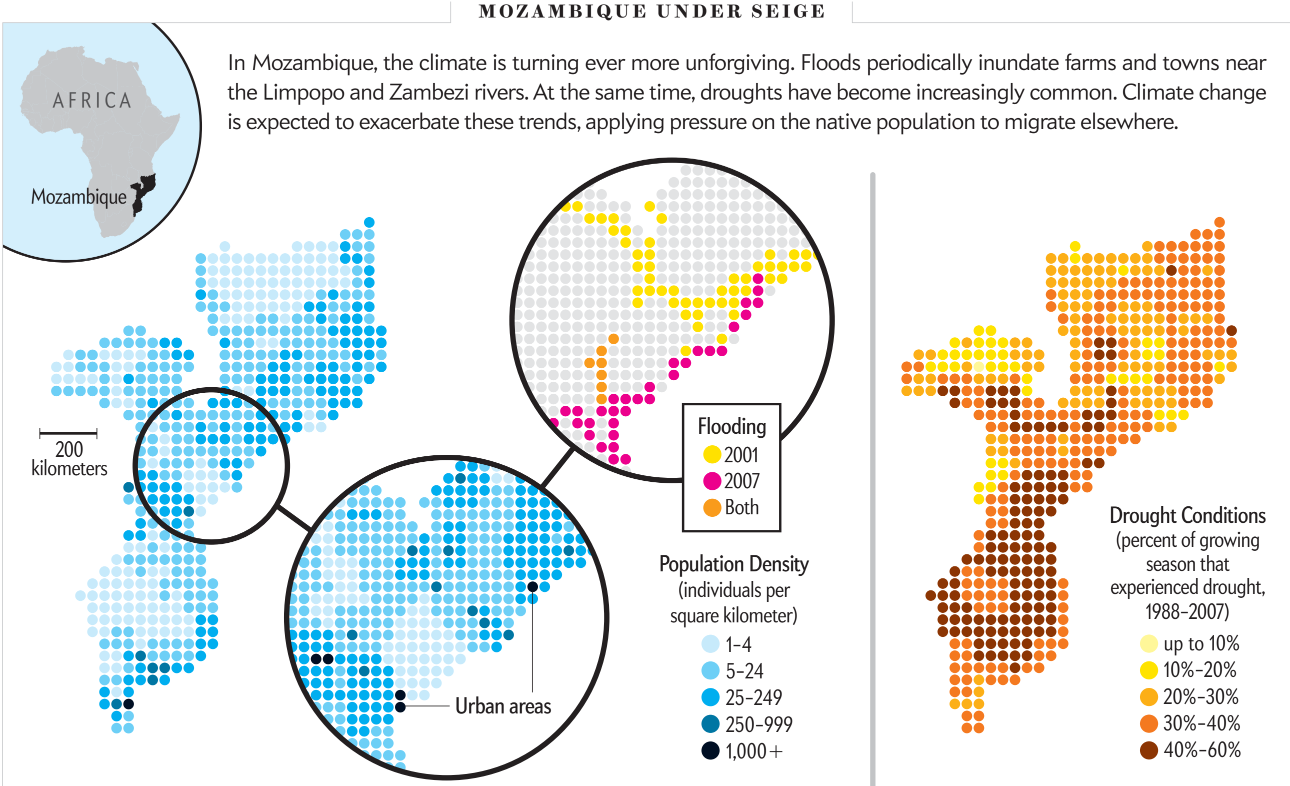
The bitter irony in Mozambique is that the country can be simultaneously hit by drought and flood—as happened in 2007, when the southern part of the country suffered a drought even as the Zambezi farther north was overflowing its banks. Climate models suggest that rainfall levels may increase in the north while decreasing in Mozambique's south. A key element influencing the extent of the trouble will be the spacing and intensity of rainfall; further intensification will only lead to a continuation of the catastrophic flooding that was repeated throughout this decade. Unfortunately, climatologists project even greater variability in this century, with climatic seesawing between extremes of drought and flood, leaving countries such as Mozambique at the mercy of increasingly unpredictable weather patterns.

Wishing well: A woman resorts to collecting any water she can scrounge from a nearly dry well in drought-stricken Malange, Mozambique.

People who have resettled remain heavily dependent on governmental and international aid because areas to which they have relocated typically lack the infrastructure—schools and health clinics, for example—that would allow for a self-sustaining economy. Frequent crop failure is still the norm. Without outside humanitarian assistance, experts and interviewees suggest that people may need to migrate longer distances or across borders. The main destinations will most likely be Maputo (the capital of Mozambique) and South Africa, given that economic prospects in other cities and neighboring countries are not nearly so bright.

MOZAMBIQUE UNDER SEIGE

In Mozambique, the climate is turning ever more unforgiving. Floods periodically inundate farms and towns near the Limpopo and Zambezi rivers. At the same time, droughts have become increasingly common. Climate change is expected to exacerbate these trends, applying pressure on the native population to migrate elsewhere.



The Curse of the Wet
Mozambique's rural population has grappled with increasingly frequent flooding events over the past decade, with some regions suffering from multiple episodes.

The Curse of the Dry
Meanwhile droughts have also hampered food production.

JENNY MATTHEWS *Alamy (photograph)*; SOURCES: CENTER FOR INTERNATIONAL EARTH SCIENCE INFORMATION NETWORK (CIESIN), COLUMBIA UNIVERSITY; INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE (IFPRI); WORLD BANK; CENTRO INTERNACIONAL DE AGRICULTURA TROPICAL (CIAT); 2009, GLOBAL RURAL-URBAN MAPPING PROJECT (GRUMP), BETA VERSION: POPULATION DENSITY GRIDS; SOCIOECONOMIC DATA AND APPLICATIONS CENTER (SEDAC), COLUMBIA UNIVERSITY. HTTP://SEDAC.CIESIN.COLUMBIA.EDU/GPW *(population density)*; DARTMOUTH FLOOD OBSERVATORY: MOZAMBIQUE FLOOD EXTENTS *(flooding)*; BRADFIELD LYON *IRI/Earth Institute, Columbia University*: RAINFALL DATA FROM GLOBAL PRECIPITATION CLIMATOLOGY CENTER (GPCC) AND IRI DATA LIBRARY *(drought)*

Maps by Jen Christiansen

THE MEKONG DELTA:

THE RISING SEA

The Vietnamese portion of the Mekong Delta is home to 18 million people, or 22 percent of Vietnam's population. It accounts for 40 percent of Vietnam's cultivated land surface and more than a quarter of the country's GDP. Its residents grow more than half of Vietnam's rice, produce 60 percent of its fish and shrimp haul and harvest 80 percent of its fruit crop.

All that is threatened. According to the mapping exercise done by Columbia University's Center for International Earth Science Information Network, a one-meter sea-level rise could result in the displacement of more than seven million residents in the delta, and a two-meter rise would double that to 14 million—or 50 percent of delta residents. At that level, even parts of Ho Chi Minh City would be underwater. (We should note that although a two-meter rise in this century is beyond what is generally considered likely, abrupt climate change could create "tipping points" at which the land-based glaciers of Greenland and West Antarctic melt much more quickly than currently anticipated. In this event, a two-meter rise might occur by 2100.)

Flooding has long played an important role in the economy and culture of the area. In the Mekong Delta stretching all the way up into Cambodia, people live with and depend on flood cycles, but within certain bounds. For example, flood depths from half a meter to three meters are considered part of the normal flood regime on which farmers depend. These are referred to as "nice floods" by Vietnamese living in the delta. Higher floods challenge residents' ability to cope and often have harrowing effects on local livelihoods.

In recent decades both the frequency and magnitude of floods exceeding the four-meter mark have increased. EACH-FOR's Olivia Dun conducted interviews with migrants from the delta in Phnom Penh, Cambodia, one of whom noted, "Flooding sometimes threatened our lives. So we came here to find another livelihood." Another said, "My family had crop fields, but in recent years floods occurred very often so the crop was not stable."

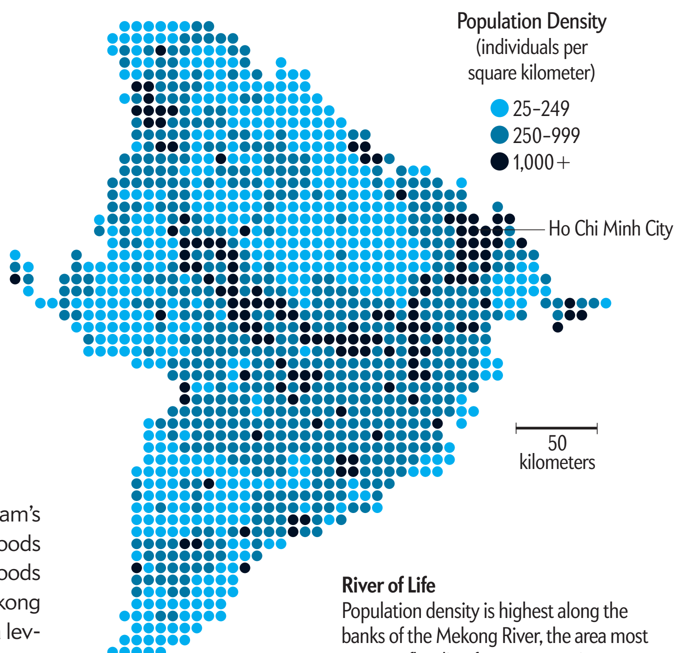
Climate change, then, has combined with existing natural hazards and with the stress placed on the environment by rapid industrialization in Vietnam and upstream countries to put Vietnam's natural resources and those who depend on them in a precarious position. In the face of environmental stressors, people in the Mekong Delta adapt in various ways. Those who have coped by migrating have generally preferred to move to cities, where the economy is growing fastest.

For its part, the government in Vietnam has a program known as "living with floods." As part of this program, agencies are encouraging rice farmers to shift to aquaculture—growing seafood such as shrimp and small fish in enclosed ponds. Along the Mekong River's main stem in An Giang province, the program is also moving people away from the river. Almost 20,000 landless and poor households in this province have been targeted for relocation by 2020. Those scheduled for relocation are generally landless, have nowhere else to go if their houses collapse from flooding or landslides, and are too poor to move to urban areas. For these people, social networks—the fabric of relationships with family, friends and employers—provide the essential links to their livelihoods, because most rely on day-to-day employment as laborers. Although the planned "residential clusters" are generally within a mile of the refugees' former homes, resettlement can tear the social fabric.

SOURCES: CIESIN; IFPRI; WORLD BANK; CIAT; 2009 GRUMP, BETA VERSION: POPULATION DENSITY GRIDS; SEDAC (*population density*)

MEKONG PERIL

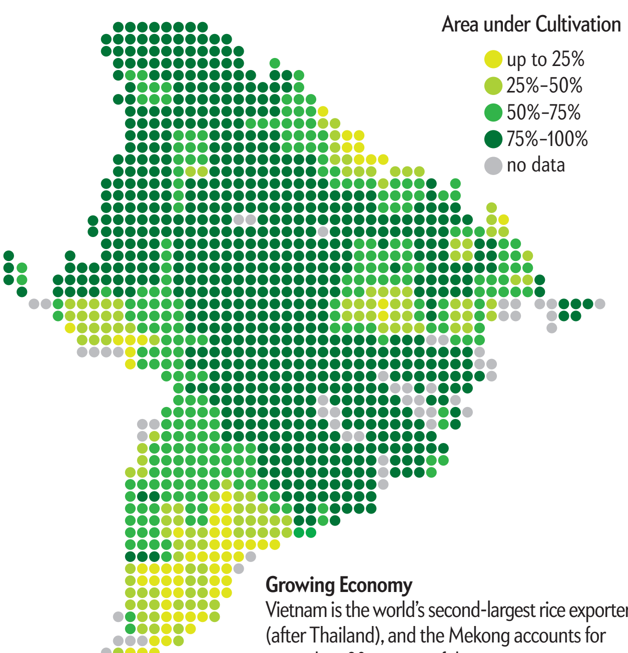
The Mekong Delta region produces a significant portion of Vietnam's food supply. Rice farmers have for centuries used the periodic floods to keep their paddies irrigated. But in recent decades extreme floods have increasingly threatened growing areas. In addition, the Mekong region is vulnerable to sea-level rise. A one-meter increase in sea level would displace more than seven million people from their homes.



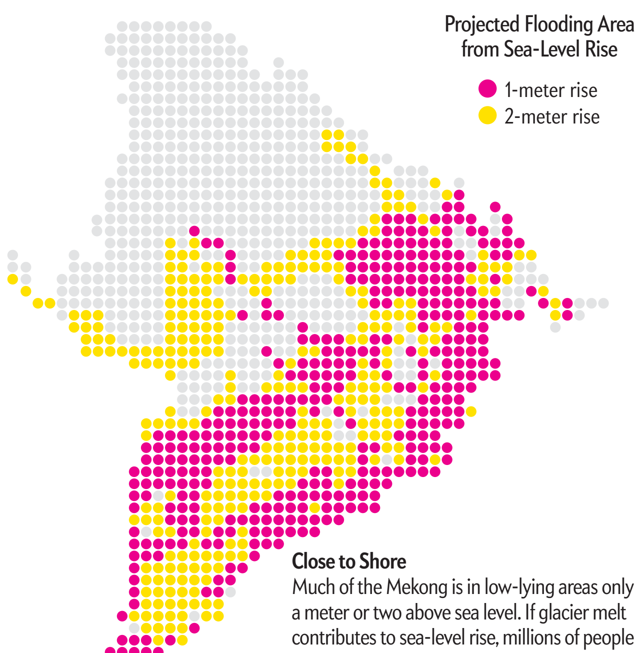
River of Life
Population density is highest along the banks of the Mekong River, the area most prone to flooding from excess rains.

High water: The home in this image, like some 400,000 others, was overcome by the worst floods to hit the Mekong in four decades.

HOANG DINH NAM *Getty Images (photograph)*; SOURCES: NAVIN RAMANKUTTY ET AL.; 2010, GLOBAL AGRICULTURAL LANDS: CROPLANDS, 2000; SEDAC, HTTP://SEDAC.CIESIN.COLUMBIA.EDU/ES/AGLANDS.HTML (*area under cropland*); ANDREW JARVIS ET AL.; 2008, HOLE-FILLED SRTM FOR THE GLOBE VERSION 4, CGIAR-CSI SRTM 90M DATABASE, HTTP://SRTM.CSI.CGIAR.ORG (*projected flooding area*)



Growing Economy
Vietnam is the world's second-largest rice exporter (after Thailand), and the Mekong accounts for more than 80 percent of that output.



Close to Shore
Much of the Mekong is in low-lying areas only a meter or two above sea level. If glacier melt contributes to sea-level rise, millions of people would be forced to migrate.

MEXICO AND CENTRAL AMERICA:

DEADLY STORMS, CRIPPLING DROUGHT

Last drop: A woman walks past a brackish pond in the Tehuacan Valley near Mexico City. Once used for animals, villagers now depend on these ponds for water.

Mexico and Central America are home to almost 10 million farmers, many of whom barely manage to meet their basic needs by growing traditional staples (corn, beans and squash) on steep hillsides. Like farmers anywhere, they depend on moderate rainfall. Too little, and their plants wither and die; too much all at once, and the soil washes down gullies, carrying with it crops and their livelihood.

Sometimes both droughts and storms can hit in the same year. In July 2001, for example, Honduras suffered a drought that affected a quarter of a million people. A few months later a tropical storm flooded the countryside.

Many farmers have already found their livelihoods too precarious and moved north; the great majority of migrants to the U.S. come from poor rural areas in Mexico and Central America. Soil depletion, deforestation and unemployment are among the factors that drive migration—along with the pull of higher wages in El Norte ("the North")—but climatic factors add to the distress. In Tlaxcala in central Mexico, EACH-FOR's Stefan Alscher found that market liberalization in the 1990s and declining rainfall led to lower farm incomes, pushing some to leave. In one interview, a farmer described migration as a last resort: "My grandfather, father and I have worked on these lands. But times have changed.... The rain is coming later now, so that we produce less. The only solution is to go away [to the U.S.], at least for a while."

Climate change is projected to lead to a 10 to 20 percent decline in rainfall runoff in Tlaxcala. Compared with the rest of the region, Tlaxcala may have it easy. Most of the region's irrigation occurs on the coastal plains such as those in Jalisco and Sinaloa—major agricultural states that collectively produce almost 18 percent of the country's agricultural GDP. But according to data from the Intergovernmental Panel on Climate Change, these states may see a 25 to 50 percent decline in water availability by 2080, a change that could lay waste the region's productivity.

Drought is not the region's only worry. Climatologists predict that Central America and Mexico will more frequently suffer from intense tropical storms over the coming century. Past experience provides a taste of what to expect. In 1998 Hurricane Mitch, the most deadly Atlantic storm in more than 200 years, killed more than 11,000 people in Honduras and Nicaragua and caused billions of dollars' worth of damage. In 2007 Tropical Storm Noel flooded up to 80 percent of the state of Tabasco, displacing some 500,000 people. In the past, population displacement triggered by natural hazards has generally been local and short term, but more frequent extreme events may well tempt some to give up and move for good.

Solutions are elusive. In agricultural areas people have long used seasonal migration as a coping strategy. Recognizing that most future migration, like that of the past, is likely to flow toward the U.S. and Canada, policy makers there might consider issuing temporary work visas following climate disasters such as drought or flooding. The money sent back home by migrants can help local economies recover faster and help individual households to better endure the devastation. As for the longer term, regional planners will need to develop water-saving irrigation technologies and alternative livelihoods for farmers depending on rain-fed agriculture.

POLICY SOLUTIONS

What Can We Do?

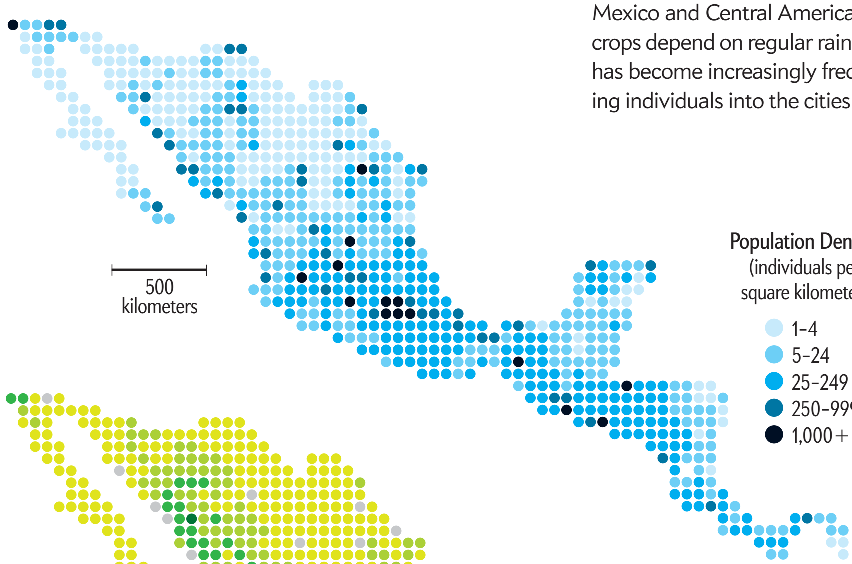
Migrations forced by climate change could very well become the most important humanitarian challenge of the 21st century. When people are impelled to move—whether because of sea-level rise or extreme events—the international community will need to put protections in place, ensuring that movements are orderly and peaceful, that human rights are respected, and that those affected have a voice in their future. We must act now to prepare ourselves for the challenges to come. We urge the international community to pursue the following:

- Reduce greenhouse gas emissions to safe levels.
- Invest in disaster risk management, which has been shown to decrease the likelihood of large-scale migration.
- Recognize that some migration will be inevitable and develop national and international adaptation strategies.
- Establish binding commitments to ensure adaptation funding reaches the people who need it most.
- Strengthen international institutions to protect the rights of those displaced by climate change.

—A.deS., K.W. and C.E.

BRENT STIRTON *Getty Images*

Mexico and Central America are home to millions of farmers whose crops depend on regular rainfall. Yet in the past few decades, drought has become increasingly frequent, threatening livelihoods and pushing individuals into the cities and up to the U.S.



Population Density
(individuals per square kilometer)

- 1–4
- 5–24
- 25–249
- 250–999
- 1,000+

Rural Living
Much of Mexico's population is spread out over the central and southern parts of the country, home to the country's agricultural belt.

Suitability of Agricultural Land for Rain-Fed Crops

- poor
- satisfactory
- good
- excellent
- no data

Mexico's Heartland
Irrigated lands are sparse, and much of Mexico and Central America's farmland depends exclusively on rainfall.

Drought Conditions
(percent of growing season that experienced drought, 1988–2007)

- up to 10%
- 10%–20%
- 20%–30%
- 30%–40%
- 40%–60%
- no data

Less Rain Falling
In recent years much of the region has suffered from severe drought.

Predicted Change in Runoff

- 5%–24% more
- 5%–24% less
- 25%–50% less
- no data

The Dry Future
Climate models project that by 2080, much of Mexico will suffer from significantly reduced rainfall because of the effects of climate change. In some areas total rainfall could be cut by half.

SOURCES: CIESIN; IFPRI; WORLD BANK; CIAT; 2009 GRUMP, BETA VERSION: POPULATION DENSITY GRIDS; SEDAC (*population density*); 2007 COMBINED SUITABILITY OF CURRENTLY AVAILABLE LAND FOR PASTURE AND RAINFED CROPS (LOW INPUT LEVEL) FROM THE FOOD AND AGRICULTURE ORGANIZATION'S FGGD (*rain-fed agricultural areas*); "IMPACT OF CLIMATE CHANGE ON RIVER RUNOFF," BY DAISUKE NOHARA ET AL., IN *JOURNAL OF HYDROMETEOROLOGY*, VOL. 7, NO. 5; OCTOBER 2006; DATA OBTAINED FROM AUTHORS VIA PERSONAL COMMUNICATION (*rainfall-runoff change*); BRADFIELD LYON *IRI/Earth Institute, Columbia University*; RAINFALL DATA FROM GPCC AND IRI DATA LIBRARY (*drought*)

Ross D. King is a professor of computer science at Aberystwyth University in Wales. He researches the science of science, including ways to apply computer science to chemistry and biology.

COMPUTER SCIENCE

Rise of the Robo Scientists

Machines can devise a hypothesis, carry out experiments to test it and assess results—without human intervention

By Ross D. King

IS IT POSSIBLE TO AUTOMATE SCIENTIFIC DISCOVERY? I DON'T MEAN automating experiments. I mean: Is it possible to build a machine—a robot scientist—that can discover new scientific knowledge? My colleagues and I have spent a decade trying to develop one.

We have two main motives. The first is to better understand science. As famed physicist Richard Feynman noted: "What I cannot create, I do not understand." In this philosophy, trying to build a robot scientist forces us to make concrete engineering decisions involving the relation between abstract and physical objects and between observed and theoretical phenomena, as well as the ways hypotheses are created.

Our second motivation is technological. Robot scientists could make research more productive and cost-efficient. Some scientific problems are so complex they require a vast amount of research, and there are simply not enough human scientists to do it all; automation offers our best hope for solving those problems.

Computer technology for science has been steadily improving, including "high-throughput" laboratory automation such as DNA sequencing and drug screening. Less obvious are computers that are automating the process of data analysis and that are beginning to generate original scientific hypotheses. In chemistry, for example, machine-learning programs are helping to design drugs. The goal for a robot scientist is to combine these technologies to automate the entire scientific process: forming hypotheses, devising and carrying out experiments to test those hypotheses, interpreting the results and repeating the cycle until new knowledge is found.

The ultimate question, of course, is whether we can devise a

IN BRIEF

Some scientific questions are so complex that designing and carrying out the experiments needed to find answers requires a prohibitive amount of scientists' time.

Robot scientists could fill the void. One prototype, called Adam, can originate hypotheses about yeast genes and their functions, design experiments to test the ideas and conduct the work.

Using artificial intelligence, reasoning and robotic hardware, Adam discovered three genes that encode specific yeast enzymes, a determination human scientists had not been able to make.

Skeptics say Adam is not a scientist, because it requires human input and occasional intervention. But together, human and robot scientists could achieve more than either one alone.

Illustrations by David Johnson

robot scientist that can actually accomplish the entire process. The capabilities of two robots designed at our laboratory, and a handful of others around the world, suggest we can.

ADAM TAKES ON YEAST

THE PIONEERING WORK of applying artificial intelligence to scientific discovery took place at Stanford University in the 1960s and 1970s. A computer program named DENDRAL was designed to analyze mass-spectrometer data, and the related Meta-DENDRAL program was one of the first machine-learning systems. The researchers were trying to create automated instruments that could look for signs of life on Mars during the 1975 NASA Viking mission. Unfortunately, that task was beyond the technology of the day. Since then, programs such as Prospector (for geology) and Bacon (for general discovery) and more recent successors have automated such tasks as proposing hypotheses and experiments to test them. Yet most lack the ability to physically conduct their own experiments, which is crucial if artificial-intelligence systems are to work even semi-independently.

Our robot, Adam, is not humanoid; it is a complex, automated lab that would fill a small office cubicle [*see box on opposite page*]. The equipment includes a freezer, three liquid-handling robots, three robotic arms, three incubators, a centrifuge, and more, every piece of it automated. Of course, Adam also has a powerful computational brain—a computer that does the reasoning and controls the personal computers that operate the hardware.

Adam experiments on how microbes grow, by selecting microbial strains and growth media, then observing how the strains grow in the media over several days. The robot can initiate about 1,000 strain-media combinations a day all on its own. We designed Adam to investigate an important area of biology, one that lends itself to automation: functional genomics, which investigates the relations between genes and their functions.

The first full study was on the yeast *Saccharomyces cerevisiae*—the organism used to make bread, beer, wine and whiskey. Biologists are most interested in the strain as a "model" organism for understanding how human cells work. Yeast cells have far fewer genes than human cells do. The cells grow quickly and easily. And although the last common ancestor between humans and yeast existed perhaps a billion years ago, evolution is very conservative, so most of what is true for a yeast cell is also true for our cells.

Adam focused on understanding the unsolved problem of how yeast uses enzymes—complex proteins that catalyze particular biochemical reactions—to convert its growth medium into more yeast and waste products. Scientists still do not fully understand this process, although they have studied it for more than 150 years. They know of many enzymes yeast produces, but in some cases not which genes encode them. Adam set out to discover the "parental genes" that encode these "orphan" enzymes.

To be able to discover some novel science, Adam needs to know a lot of existing science. We programmed Adam with extensive background knowledge about yeast metabolism and the functional genomics of yeast. The claim that Adam holds background "knowledge" rather than information is up for philosophical debate. We argue that "knowledge" is justified because it is used by Adam to reason and guide its interactions with the physical world.

Adam uses logic statements to represent its knowledge. Logic was first devised 2,400 years ago to describe knowledge with greater precision than natural language might allow. Modern logic is the most accurate way to represent scientific knowledge and to unambiguously exchange knowledge between robots and humans. Conveniently, logic can also be used as a programming language, which enables Adam's background to be interpreted as a computer program.

To start Adam's investigation, we programmed it with many facts. Take a typical example: in *S. cerevisiae,* the gene *ARO3* encodes an enzyme called 3-deoxy-D-arabino-heptulosonate-7-phosphate. We also gave Adam related facts, such as that this enzyme catalyzes a chemical reaction, in which the compounds phosphoenolpyruvate and D-erythrose 4-phosphate react to produce 2-dehydro-3-deoxy-D-arabino-heptonate 7-phosphate, plus phosphate.

Connected together, the facts form a model of yeast metabolism that integrates knowledge about genes, enzymes and metabolites (small chemical molecules). The difference between a model and an encyclopedia is that a model can be converted into software that can act on data to make predictions. A robot scientist can integrate abstract scientific models with laboratory robotics to automatically test and improve the models.

REASONING ABOUT GENES

WHEN SCIENTISTS FOLLOW the scientific method, they form hypotheses and then experimentally test the deductive consequences of those hypotheses. In this manner, Adam first hypothesizes new facts about yeast biology, then deduces the experimental consequences of the facts using its model of metabolism. Next Adam experimentally tests the consequences to see if the hypothesized facts are consistent with the observations.

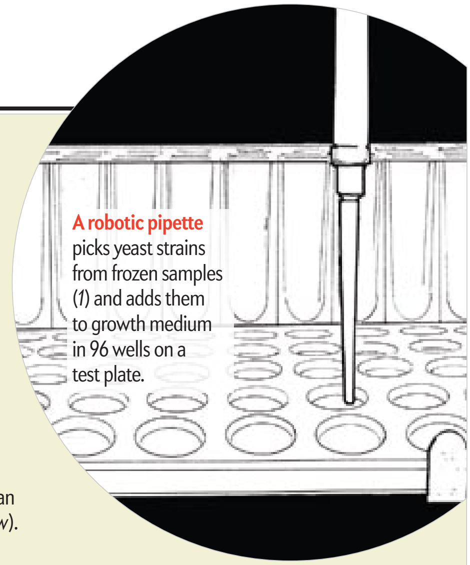
The cycle begins with Adam forming hypotheses about which genes could be the parents of orphan enzymes [*see box on page 76*]. To focus on the most likely hypotheses, Adam used its knowledge base. As an example, one orphan enzyme it knew about was 2-aminoadipate transaminase. This enzyme catalyzes the reaction: 2-oxoadipate plus L-glutamate yields L-2-aminoadipate plus 2-oxoglutarate (the reaction also occurs in the reverse direction). This reaction is important because it is a potential target for antifungal drugs, but the parental gene is unknown. To form a hypothesis about which yeast gene could encode this enzyme, Adam first interrogated its knowledge base to see if any genes from other organisms are known to encode the enzyme. This query returned the fact that in *Rattus norvegicus* (the brown rat) a gene called *Aadat* encodes the enzyme.

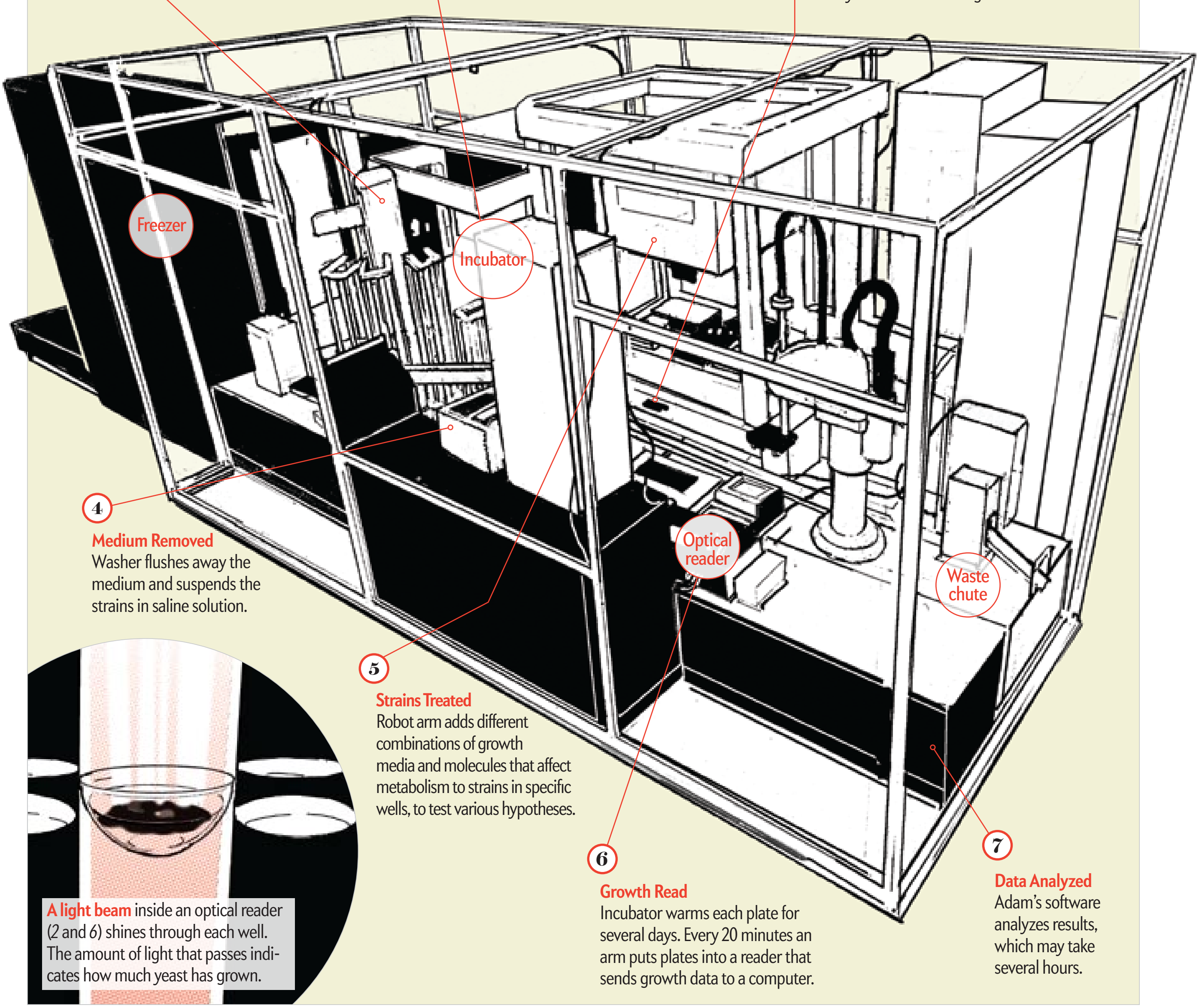
Adam took the protein sequence of the enzyme encoded by the *Aadat* gene and examined whether any similar protein sequences are encoded in the yeast genome. Adam knows that if protein sequences are similar enough, it is reasonable to infer that the sequences are homologous—that they share a common ancestor. Adam also knows that if protein sequences are homologous, then the function of their common ancestor may have been conserved. Therefore, from similar protein sequences Adam can reason that their encoding genes may have the same function. Adam found three yeast genes with sequences similar to *Aadat: YER152c, YJL060w* and *YJL202w.* It hypothesized that these genes each encode the enzyme 2-aminoadipate transaminase.

To test its hypotheses, Adam conducted numerous physical experiments. It grew certain yeast strains selected from a complete collection in its freezer, where each strain has a specific

Robotic Biology

Adam, a robot scientist at Aberystwyth University in Wales, investigates the relations between genes and their functions. In early work, its artificial-intelligence computer formulated 20 hypotheses about which genes might encode specific enzymes that are critical to yeast's growth. It then performed thousands of experiments to find evidence for whether the hypotheses were true or false. Here's how.





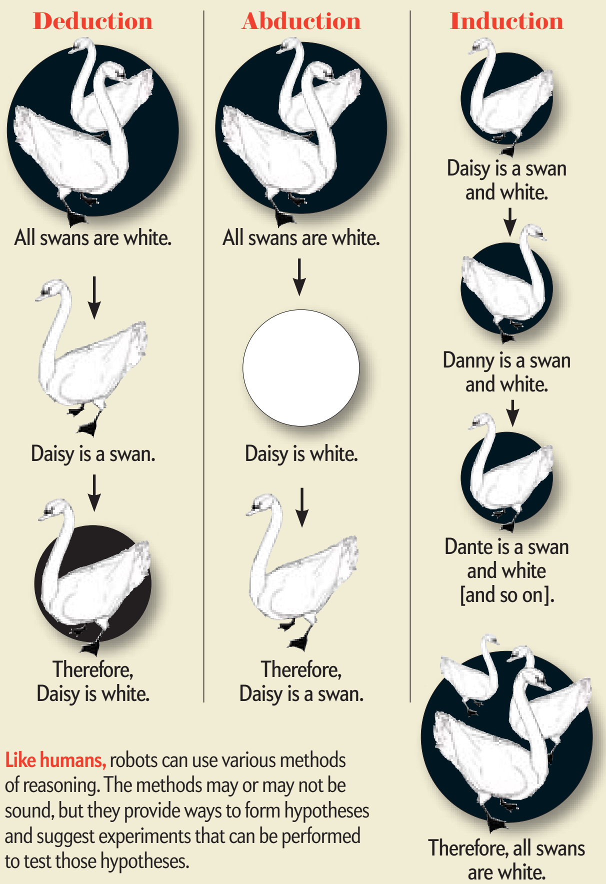
THOUGHT EXPERIMENT

How Robots Reason

How does a robot scientist "reason?" It uses the same options people use. One is deductive inference, which is the foundation for mathematics and computer science. Deductive reasoning is "sound." That is, if you start with truth you can infer only new truths. Unfortunately, in the absence of a consummate "theory of everything," deduction is insufficient for science, because it can work out only the consequences of what is already known.

A second option, abductive reasoning, is not sound, as is obvious from the swan example below; many things are white but are not swans. Yet abduction does provide a way of generating hypotheses that may be true. The great insight of science is that the way to decide truth is not by pure deduction from assumptions but rather by experimenting on the physical world. If Adam hypothesizes that Daisy is a swan, then the way to decide on the truth of this proposition is for Adam to experimentally catch Daisy and test whether she is a swan, a duck or something else.

Induction, like abduction, provides a way to infer new hypotheses. If every swan we see is white, it is natural to infer, as Aristotle actually did, that all swans are white. But induction is not sound, and Aristotle's induction was disproved by the discovery of black swans in Australia. We constantly use induction in our daily lives. It reassures us that the sun will rise tomorrow and that our breakfast won't poison us. Induction's role in science is controversial, however, because the main justification for induction is that it generally works, which is itself an induction.



Like humans, robots can use various methods of reasoning. The methods may or may not be sound, but they provide ways to form hypotheses and suggest experiments that can be performed to test those hypotheses.

gene removed. The robot examined the growth of three yeast strains that were missing the genes *YER152c, YJL060w* and *YJL202w,* respectively, when grown in the presence of chemicals such as L-2-aminoadipate that are involved in the reaction catalyzed by the enzyme.

The next step would be to experiment on the strains. Money for science is always limited. And often scientists race to be the first to solve a problem. We therefore designed Adam to devise efficient experiments that test hypotheses cheaply and quickly. To achieve this goal, Adam assumes that every hypothesis has a probability of being true. This assumption is controversial, and some philosophers such as Karl Popper have denied that hypotheses can have associated probabilities. Most working scientists, however, tacitly assume that certain types of hypotheses are more likely to prove true than others. For example, they generally follow the notion of "Occam's razor"—that all else being equal, a simpler hypothesis is more probable than a complex one. Adam also considers the cost of a possible experiment, which currently is just the cost of the chemicals involved. A better approach would include the "cost" of time as well.

Given a set of hypotheses with associated probabilities and a set of possible experiments with associated costs, the goal we set for Adam is to choose a series of experiments that minimizes the expected cost of eliminating all but one hypothesis. Pursuing this approach optimally is computationally very difficult, but our analyses have shown that Adam's approximate strategy selects experiments that solve problems more cheaply and quickly than other strategies, such as simply choosing the cheapest experiment. In some cases, Adam can design one experiment that can shed light on many hypotheses. Human scientists struggle to do the same; they tend to consider one hypothesis at a time.

20 HYPOTHESES, 12 NOVEL

ONCE ADAM'S ARTIFICIAL-INTELLIGENCE SYSTEM homes in on the most promising experiments, Adam uses its robotics to carry them out and observe the results. Adam cannot directly observe genes or enzymes; its observations consist only of how much light shines through cultures of yeast. From these data, through a complicated chain of reasoning, Adam infers whether or not the evidence is consistent with hypotheses about genes and enzymes. Such chains of reasoning are typical of science; astronomers, for example, infer what is happening in distant galaxies from the radiation they observe in their instruments.

Deciding on the consistency of hypotheses was one of the most difficult tasks for Adam, because scientists have already discovered all the genes whose removal causes qualitative differences in yeast's growth. Removing other genes generally produces only minor growth differences. To decide whether any of the minor differences is significant when a gene is removed, Adam uses sophisticated machine-learning techniques.

Adam generated and experimentally confirmed 20 hypotheses about which genes encode specific enzymes in yeast. Like all scientific claims, Adam's needed to be confirmed. We therefore checked Adam's conclusions using other sources of information not available to it and using new experiments we did with our own hands. We determined that seven of Adam's conclusions were already known, one appeared wrong and 12 were novel to science.

As a check, our own manual experiments confirmed that three genes (*YER152c, YJL060w* and *YJL202w*) encode the enzyme 2-aminoadipate transaminase. The probable reason that the role of these genes had not previously been discovered is that the three genes encode the same enzyme, and the enzyme can catalyze a series of related reactions; a simple mapping of one gene to one enzyme function—the common scenario—was not the case here. Adam's careful experimentation and statistical analysis were required to disentangle these complications.

IS THE ROBOT A SCIENTIST?

SOME PEOPLE OBJECT to the term "robot scientist," pointing out, with some justification, that Adam resembles more of an assistant than an independent scientist. So is it legitimate to claim that Adam autonomously discovered new scientific knowledge? Let's start with "autonomously." We cannot simply set up Adam and come back several weeks later to examine its conclusions. Adam is a prototype, and its hardware and software often break down, requiring a technician. Integrating Adam's software modules also needs to be improved so that they work together seamlessly without some human interaction. Adam's process of hypothesizing and experimentally confirming new knowledge, however, does not depend on human intellectual or physical effort.

The term "discovered" raises an argument that dates back to the 19th century and the romantic figure of Lady Ada Lovelace. She was the daughter of the poet Lord Byron and collaborated with Charles Babbage, the first person to conceive of a general-purpose computing machine. Lady Lovelace argued: "The Analytical Engine has no pretensions to *originate* anything. It can *do whatever we know how to order it* to perform" (her italics). One hundred years later the great computer scientist Alan M. Turing proposed a counterargument by way of an analogy to children. Just as teachers do not get all the credit for their pupils' discoveries, it would be unfair for humans to claim all the credit for the ideas of our machines. These arguments are of growing commercial importance; for example, in U.S. patent law only a "person" can "invent" something.

SEE A VIDEO OF ADAM AND EVE
ScientificAmerican.com/jan2011/king

Finally, how novel is Adam's science? Some of the mappings between genes and enzyme functions in *S. cerevisiae* that Adam has hypothesized and experimentally confirmed are certainly novel. Although this knowledge is modest, it is not trivial. In the case of the enzyme 2-aminoadipate transaminase, Adam found three separate genes that may solve a 50-year-old puzzle. Of course, some of Adam's conclusions could be wrong; all scientific knowledge is provisional. Yet it seems unlikely that all the conclusions are wrong. Adam's results have now been in the public domain for two years, and no one has noted any mistakes. As far as I know, scientists outside of my group have not yet tried to reproduce Adam's results.

Another way of assessing whether Adam is a scientist is whether Adam's approach to generating novel hypotheses is generalizable. Once Adam was off running experiments, we began developing a second robot. Eve applies the same automated cycles of research to drug screening and design, an important medical and commercial pursuit. The design lessons we learned from Adam make Eve a much more elegant system. Eve's research is focused on malaria, schistosomiasis, sleeping sickness and Chagas disease. We are still developing Eve's software, but the robot has already found some interesting compounds that show promise of being active against malaria.

Some researchers are applying approaches that are similar to Adam's. Hod Lipson of Cornell University is using automated experimentation to improve the design of mobile robotics and to understand dynamic systems. Other researchers are trying to develop robot scientists for chemistry, biology and engineering.

Several groups, including my own, are looking into ways to automate quantum physics research, in particular how to control quantum processes. For example, Herschel A. Rabitz of Princeton University is investigating ways to use femtosecond (10^{-15}) lasers to learn how to make or break targeted chemical bonds. Here the challenge is how to quickly formulate intelligent experiments.

HUMAN PARTNERS

IF WE ACCEPT that robots can be scientists, we would like to know their limits. Comparing the task of automating science with automating chess is instructive. Automating chess is essentially a solved problem. Computers play chess as well or better than the best humans and make strikingly beautiful moves. Computer mastery is possible because chess is a bounded, abstract world: 64 squares, 32 pieces. Science shares much of the abstract nature of chess, but automating science will be harder because experimentation takes place in the physical world. I expect, however, that developing robot scientists capable of performing quality science will probably be easier than developing artificial-intelligence systems that can socially interact with humans. In science it is safe to assume that the physical world is not trying to deceive you, whereas that is not true in society.

The most accomplished human chess masters now use computers to improve their game—to analyze positions and to prepare new attacks. Similarly, human and robot scientists working together, with contrasting strengths and weaknesses, could achieve more than either one could alone. Advances in computer hardware and in artificial-intelligence systems will lead to ever smarter robot scientists.

Whether these creations will ever be capable of paradigm-shifting insights or be limited to routine scientific inquiries is a key question about the future of science. Some leading scientists, such as physics Nobel laureate Philip Anderson, argue that paradigm-shifting science is so profound that it may not be accessible to automation. But another physics Nobel laureate, Frank Wilczek, has written that in 100 years the best physicist will be a machine. Time will tell who is correct.

Either way, I see a future where networks of human and robot scientists will collaborate. Scientific knowledge will be described using logic and disseminated instantaneously using the Web. The robots will gradually assume an ever greater role in the advancement of science. SA

MORE TO EXPLORE

Computing Machinery and Intelligence. A. M. Turing in *Mind,* Vol. LIX, No. 236, pages 433–460; October 1950. **http://loebner.net/Prizef/TuringArticle.html**

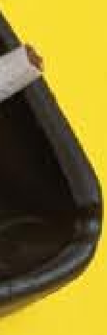
How DENDRAL Was Conceived and Born. Joshua Lederberg. ACM Symposium on the History of Medical Informatics, National Library of Medicine, November 5, 1987. **http://profiles.nlm.nih.gov/BB/A/L/Y/P/_/bbalyp.pdf**

An Introduction to the Philosophy of Science. Rudolf Carnap. Edited by Martin Gardner. Dover, 1995.

The Chemistry of Life. Fourth edition. Steven Rose. Penguin, 1999.

The Automation of Science. Ross D. King et al. in *Science,* Vol. 324, pages 85–89; April 3, 2009.

Brianna Rego was born in Antigua, Guatemala, grew up in Idaho, and is a graduate student in history of science at Stanford University. A paper she published in 2009 on the tobacco industry's research on polonium—part of her Ph.D. thesis—was distributed to members of Congress by the National Center for Tobacco-Free Kids to help the passage of landmark legislation on smoking.



PUBLIC HEALTH

Radioactive Smoke

The tobacco industry has known for decades how to remove a dangerous isotope from cigarettes but has done nothing about it. The government now has the power to force a change

By Brianna Rego

In November 2006 former KGB operative Alexander Litvinenko died in a London hospital in what had all the hallmarks of a cold war–style assassination. Despite the intrigue surrounding Litvinenko's death, the poison that killed him, a rare radioactive isotope called polonium 210, is far more widespread than many of us realize: people worldwide smoke almost six trillion cigarettes a year, and each one delivers a small amount of polonium 210 to the lungs. Puff by puff, the poison builds up to the equivalent radiation dosage of 300 chest x-rays a year for a person who smokes one and a half packs a day.

Although polonium may not be the primary carcinogen in cigarette smoke, it may nonetheless cause thousands of deaths a year in the U.S. alone. And what sets polonium apart is that these deaths could be avoided with simple measures. The tobacco industry has known about polonium in cigarettes for nearly 50 years. By searching through internal tobacco industry documents, I have discovered that manufacturers even devised processes that would dramatically cut down the isotope's concentrations in cigarette smoke. But Big Tobacco consciously decided to do nothing and to keep its research secret. In consequence, cigarettes still contain as much polonium today as they did half a century ago.

The situation may be about to change, however. In June 2009 President Barack Obama signed the Family Smoking Prevention and Tobacco Control Act into law. The legislation brings tobacco for the first time under the jurisdiction of the Food and Drug Administration, allowing the agency to regulate certain components of cigarettes. Forcing the industry to finally remove polonium from cigarette smoke would be one of the most straightforward ways to start making cigarettes less deadly.

IN BRIEF

Tobacco plants accumulate small concentrations of polonium 210, a radioactive isotope that mostly originates from natural radioactivity in fertilizers.

Smokers inhale the polonium, which settles in "hot spots" in the lungs and can cause cancer. Its effects may lead to thousands of deaths a year in the U.S. alone.

The tobacco industry has known for decades how to virtually eliminate the polonium from cigarette smoke but kept its knowledge secret and failed to act.

The Food and Drug Administration now has the authority to regulate tobacco and could begin to use it by forcing manufacturers to reduce polonium content.

Photograph by Kevin Van Aelst

HOT SPOTS

THE FIRST HINT that polonium 210 was making its way into the lungs of smokers came almost by chance. In the first half of the 1960s the health effects of radiation, and in particular of radioactive fallout, were very much on the minds of scientists—as well as on the minds of most other people. At the time, radiochemist Vilma R. Hunt and her colleagues at the Harvard School of Public Health were developing a technique to measure very low levels of radium and polonium, the two elements discovered by Pierre and Marie Curie in 1898. As Hunt recalls, one day in 1964 her gaze was wandering around the lab when it paused on the cigarette ash of one of her colleagues. On a whim, she decided to test the ash with her new technique.

When she saw the results, she was astonished to find no signs of polonium. Trace concentrations of radioactive isotopes are common in the environment and contribute to the natural radiation background. No other organic material Hunt had researched, including plants, had tested negative for polonium when radium was present. But at the temperatures of smoldering tobacco, polonium turns into vapor. So, she suddenly realized, the missing polonium must have gone up in smoke! And that meant smokers would inhale it directly into their lungs.

Hunt, along with her Harvard colleague Edward P. Radford, published the discovery—with direct measurements of polonium in cigarette smoke—in *Science*. Soon others at Harvard were studying polonium both in cigarettes and in the lungs of smokers. In 1965 radiobiologist and physician John B. Little examined lung tissue from smokers for signs of polonium. The task was not easy. Getting tissue samples from living smokers would have been too invasive, so he had to work on cadavers. "The problem is that the mucosal lining of the lung after someone dies decays within two to three hours," he says. He had to extract it soon after death, which involved many dashes to the hospital at all times of day and night. Little was able to demonstrate that polonium did in fact collect in specific areas of the lung. Because of the way our airways branch into bronchi, bronchioles and alveoli, the radioisotopes settle and concentrate at the points of bifurcation. There they form "hot spots" of radioactivity, emitting alpha particles.

Over the next 10 years scientists continued to research polonium in cigarette smoke and also how the radioisotope gets into the tobacco plant itself—and thus at what stage of the cigarette-manufacturing process it could be most effectively taken out. Polonium 210 is a decay product of lead 210; in their 1964 paper Radford and Hunt had speculated on two possibilities: either the daughter isotopes of natural atmospheric radon 222, including lead 210, settled on the leaves, or lead 210 in fertilized soil was absorbed through the plant's roots. As it turned out, both were true.

Researchers at the U.S. Department of Agriculture took up the question of polonium from fertilizer. A 1966 experiment by the USDA and the Atomic Energy Commission tested two different kinds of fertilizers, a commercial "superphosphate" one and a special mix made from chemically pure calcium phosphate. The differences were remarkable. The commercial fertilizer had about 13 times more radium 226 than the special mix, resulting in nearly seven times more polonium in the leaves. Edward Martell of the National Center for Atmospheric Research in Boulder, Colo., revisited this issue in 1974. Martell suggested that soils containing uranium-rich phosphate fertilizer would release radon 222 into the surrounding atmosphere, raising its concentration above normal levels. The radon would then decay into lead 210, which would deposit on the growing plants, sticking to the thousands of little hairs called trichomes that cover tobacco leaves.

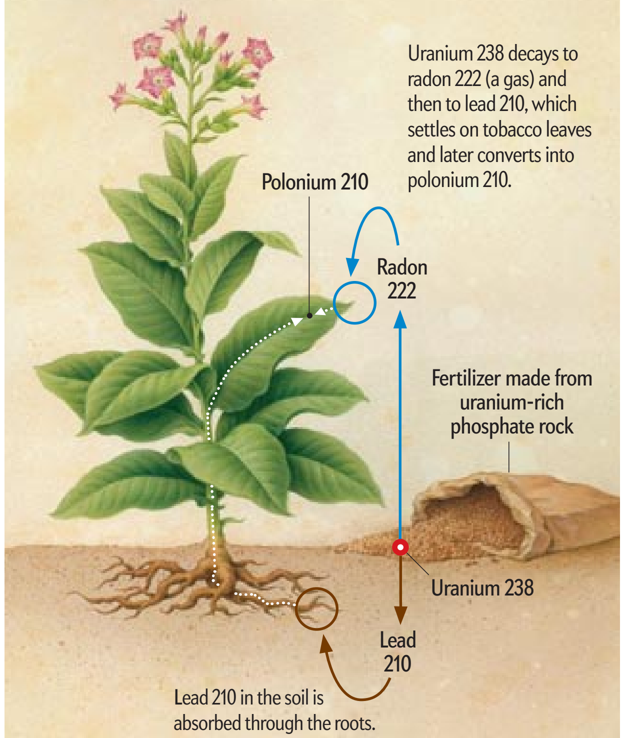
Like the Harvard group, Martell was also concerned with the buildup of polonium 210 in particular areas of the lung. It had been generally accepted for some time that exposure to radiation from radon "daughters" was the principal cause of elevated cancer risk in uranium miners. Thus, he reasoned that because of smokers' chronic exposure to low, concentrated doses, polonium 210 was likely the primary cause of their lung cancer and perhaps—as he suggested later—of other types of cancer as well.

As in the case of miners, the danger would come not with a high dose at any given time but, rather, with continued exposure

PROBLEM/SOLUTION

How Polonium Creeps into Tobacco

Polonium 210 is one of many decay products of uranium. Uranium occurs naturally in the soil—but in much higher concentration in phosphate rock from which fertilizer is made. Researchers have discovered two pathways leading from uranium to polonium in tobacco: through the air and through the roots.



The Solutions

Research by tobacco manufacturers has shown that combinations of the following measures could virtually eliminate polonium 210 from cigarette smoke:

- Add chemicals to tobacco so polonium 210 does not vaporize and get inhaled
- Switch to low-uranium fertilizer
- Wash leaves after harvest
- Use ion-exchange cigarette filters to capture polonium
- Genetically engineer the tobacco plant to have "hairless" leaves

Illustration by Cherie Sinnen

to small doses over an extended period. A smoker stockpiles his or her supply of polonium with each drag; therefore, the high exposure associated with a lifetime of smoking would leave the smoker at a risk for cancer despite the relatively low dose of polonium 210 per cigarette. In 1974, after forcing polonium into the tracheas of hamsters, Little and fellow Harvard scientist William O'Toole were able to confirm that hypothesis: 94 percent of hamsters in the highest-exposure group developed lung tumors with doses so small that their tissues showed no inflammation.

Since then, of course, other components of cigarette smoke have also been found to be powerful carcinogens, and today most experts would probably say that the main ones are chemicals such as polycyclic aromatic hydrocarbons and nitrosamines. Still, conservative estimates based on risk from radiation exposure suggest that polonium 210 may be responsible for 2 percent of smoke-induced lung cancers, and thus for several thousands of deaths a year in the U.S. alone. Moreover, some experts point out that the effects of radiation damage and of other carcinogens probably exacerbate one another. To Big Tobacco, polonium seemed dangerous enough to require extensive studies.

"NO COMMERCIAL ADVANTAGE"

IN CONTRAST to external scientists, industry scientists never publicized or published their research on polonium. But in the 1990s historic lawsuits brought by 46 U.S. states against the industry forced manufacturers to admit that smoking is dangerous and addictive, and resulted in the release of millions of internal documents. Thousands of those documents showed that polonium had long been widely discussed in the tobacco industry, all the way up to its highest ranks.

The original Radford and Hunt paper appeared only a few days after the surgeon general's landmark warning on the risks of smoking issued on January 11, 1964. In the immediate wake of these two announcements, internal memos show that the tobacco manufacturers were concerned that they might suffer a public affairs disaster if what they knew about polonium came to light. Aware of this risk, the industry soon began to devote extensive manpower and money to developing internal research programs on polonium, which operated behind closed doors.

ANSWER POLL AND SEE DECLASSIFIED DOCUMENTS
ScientificAmerican.com/jan2011/polonium

A flurry of Philip Morris documents from the late 1970s and early 1980s revealed that scientists and executives debated whether the company should publish its own research. That debate happened during a lull in external scientific publications—outside the industry, interest in polonium in tobacco has been intermittent—and the tobacco men were wary of disturbing that peace.

In 1977, for instance, scientists at Philip Morris had completed a draft of a paper entitled "Naturally Occurring Radon-222 Daughters in Tobacco and Smoke Condensate," which the authors wanted to submit to *Science*. The director of product development emphasized in a 1978 memo to another Philip Morris scientist that he was wary of publishing the manuscript. That scientist responded: "It has the potential of waking a sleeping giant," he wrote. "The subject is rumbling, and I doubt we should provide facts." What worried Philip Morris's legal department was that despite differing numbers, the proffered manuscript essentially agreed with published research: there is polonium in tobacco, and it *is* harmful. By the middle of July, on advice of the legal department, the manuscript was denied approval for publication.

The tobacco manufacturers, however, continued to monitor external research on the subject and to explore potential solutions to the polonium problem. The industry debated the drawbacks and benefits of various ways to reduce polonium in cigarette smoke, among them adding materials to tobacco that would react with lead and polonium to prevent their transfer to smoke and developing a filter that would block polonium vapor.

Another straightforward option, following Martell's research in the 1970s, was to simply wash the tobacco leaves with a dilute solution of hydrogen peroxide. Yet other ideas included using fertilizers with limited uranium 238 daughter isotopes and removing lead-collecting trichomes from the cured tobacco leaf. "We went as far as trying to genetically modify the tobacco plant" so that the leaves would be smooth, says William A. Farone, a former director of applied research at Philip Morris who later became a whistleblower against the industry's practices and now works as a consultant for the FDA. In 1975 USDA scientist T. C. Tso estimated that 30 to 50 percent of polonium could easily be removed from fertilizer and that washing could eliminate another 25 percent. Adding to that the effects of a filter, the polonium content of tobacco could have been almost completely eliminated. But as a memo from R. J. Reynolds put it, "Removal of these materials would have no commercial advantage."

As is often the case in history, however, the industry's refusal to face a problem has only delayed it. After the Family Smoking Prevention and Tobacco Control Act passed in June 2009, the American Cancer Society lauded it for requiring the tobacco industry to disclose the "poisons in its products." This legislation offers the first opportunity to challenge and force the tobacco industry to act on the results of their years of study.

Polonium would be an excellent first "poison" to ban from tobacco. It is a single isotope, rather than a complex ingredient of smoke. Other poisons—such as tar or carbon monoxide—are difficult to keep out of the smoke, but polonium is not. The industry's four decades of research could give the FDA a head start toward getting concrete results. Moreover, some of the same steps that would reduce polonium concentrations in smoke—such as washing tobacco leaves—might also help remove toxic metals such as lead, arsenic and cadmium. This is precisely the kind of regulation and change the FDA now has the power to enforce.

The World Health Organization has made clear that smoking is the most avoidable cause of death. It estimates that 1.3 million people die of lung cancer worldwide every year, 90 percent because of smoking. If polonium had been reduced through methods known to the industry, many thousands of those deaths could have been avoided. The industry's lawyers made the conscious choice not to act on the results of their own scientists' investigations. But it is the customers who have had to live with—and die from—that decision. SA

MORE TO EXPLORE

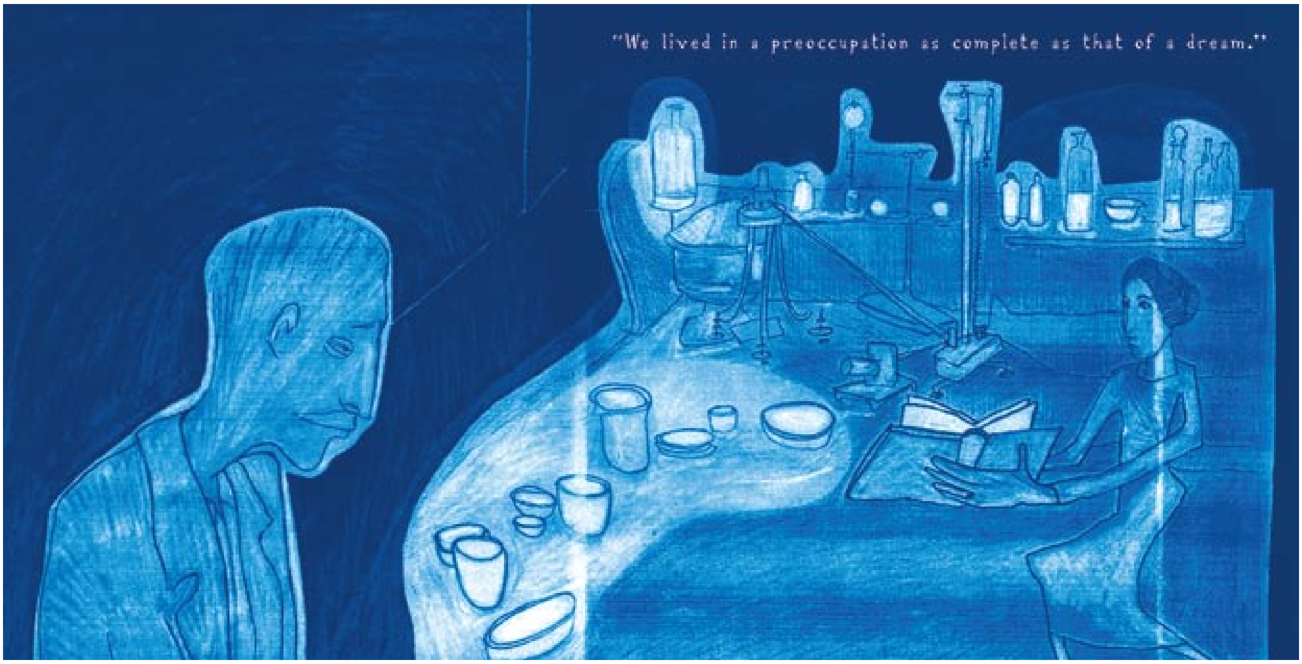
Polonium-210: A Volatile Radioelement in Cigarettes. Edward P. Radford, Jr., and Vilma R. Hunt in *Science,* Vol. 143, pages 247–249; January 17, 1964.

Puffing on Polonium. Robert N. Proctor in *New York Times*; December 1, 2006.

The Cigarette Century: The Rise, Fall, and Deadly Persistence of the Product That Defined America. Allan M. Brandt. Basic Books, 2007.

Waking a Sleeping Giant: The Tobacco Industry's Response to the Polonium-210 Issue. Monique E. Muggli et al. in *American Journal of Public Health,* Vol. 98, No. 9, pages 1643–1650; July 16, 2008.

The Polonium Brief: A Hidden History of Cancer, Radiation, and the Tobacco Industry. Brianna Rego in *Isis,* Vol. 100, No. 3, pages 453–484; September 2009.

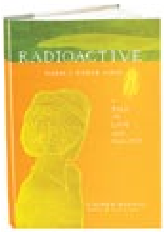


EXCERPT

Radioactive: Marie & Pierre Curie, a Tale of Love and Fallout

by Lauren Redniss. HarperCollins, 2010 ($29.99)

***The story of Marie and Pierre Curie** and their Nobel Prize–winning research on radiation has been oft told. But it finds new life in the hands of writer and artist Lauren Redniss, who weaves together deft narrative and vivid illustrations to create a thoroughly modern account of the scientific and romantic passions of the Curies, as well as the repercussions of their discoveries. Here Redniss describes how, following Marie's observation of radioactivity in a mineral called pitchblende, the Curies isolated for the first time a compound containing radium, a radioactive element.*



"The Curies had demonstrated the existence of polonium and radium through their radioactivity, but fellow scientists remained skeptical.... Chemists in particular wanted to see them, to touch them. Only concrete evidence would be persuasive.

"And so, the Curies plunged into a Sisyphean task. Procuring seven tons of pitchblende—a mountain of black rubble strewn with pine needles—from the Bohemian mines, they began trying to extract measurable amounts of their new elements. They asked the Sorbonne for laboratory space to complete the work. The University gave the Curies a dilapidated wooden shed previously used for human dissection....

"After four years of steady labor, four hundred tons of water, and forty tons of corrosive chemicals, on March 28, 1902, they managed to extract one tenth of a gram of radium chloride....

"Marie: 'It was exhausting work....'

"With the constant companionship that accompanied their research, the Curies' love deepened. They cosigned their published findings. Their handwritings intermingle in their notebooks. On the cover of one black canvas laboratory log, the initials 'M' and 'P' before the surname Curie are scripted directly one atop the other, as if to pull apart even just the letters of their names would be too brutal. Though the long, poisonous task of separating the elements would ultimately cleave the couple, for now the arduous work bound them together."

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ALSO NOTABLE

BOOKS

The Tell-Tale Brain: A Neuroscientist's Quest for What Makes Us Human, by V. S. Ramachandran. W. W. Norton, 2011 ($26.95)

How I Killed Pluto and Why It Had It Coming, by Mike Brown. Spiegel & Grau, 2010 ($25)

The Evolutionary World: How Adaptation Explains Everything from Seashells to Civilization, by Geerat J. Vermeij. St. Martin's Press, 2010 ($27.99)

Dog, Inc.: The Uncanny Inside Story of Cloning Man's Best Friend, by John Woestendiek. Avery Books, 2010 ($26)

How Old Is the Universe? by David A. Weintraub. Princeton University Press, 2011 ($29.95)

Stolen World: A Tale of Reptiles, Smugglers, and Skulduggery, by Jennie Erin Smith. Crown, 2011 ($25)

The Planet in a Pebble: A Journey into Earth's Deep History, by Jan Zalasiewicz. Oxford University Press, 2010 ($27.95)

Here Is a Human Being: At the Dawn of Personal Genomics, by Misha Angrist. HarperCollins, 2010 ($26.99)

Dance of the Photons: From Einstein to Quantum Teleportation, by Anton Zeilinger. Farrar, Straus and Giroux, 2010 ($26)

Written in Stone: Evolution, the Fossil Record, and Our Place in Nature, by Brian Switek. Bellevue Literary Press, 2010 ($16.95)

TELEVISION

Making Stuff: Stronger, Smaller, Smarter, Cleaner. Four-hour NOVA series premieres January 19 at 9 P.M. ET/PT.

FROM *RADIOACTIVE*, BY LAUREN REDNISS

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

The Science of Right and Wrong

Can data determine moral values?

Ever since the rise of modern science, an almost impregnable wall separating it from religion, morality and human values has been raised to the heights. The "naturalistic fallacy," sometimes rendered as the "is-ought problem"—the way something "is" does not mean that is the way it "ought" to be—has for centuries been piously parroted from its leading proponents, philosophers David Hume and G. E. Moore, as if pronouncing it closes the door to further scientific inquiry.

We should be skeptical of this divide. If morals and values should not be based on the way things are—reality—then on what should they be based? All moral values must ultimately be grounded in human nature, and in my book *The Science of Good and Evil* (Times Books, 2004), I build a scientific case for the evolutionary origins of the moral sentiments and for the ways in which science can inform moral decisions. As a species of social primates, we have evolved a deep sense of right and wrong to accentuate and reward reciprocity and cooperation and to attenuate and punish excessive selfishness and free riding. On the constitution of human nature are built the constitutions of human societies.

Grafted onto this evolutionary ethics is a new field called neuroethics, whose latest champion is the steely-eyed skeptic and cogent writer Sam Harris, a neuroscientist who in his book *The Moral Landscape* (Free Press, 2010) wields a sledgehammer to the is-ought wall. Harris's is a first-principle argument, backed by copious empirical evidence woven through a tightly reasoned narrative. The first principle is the well-being of conscious creatures, from which we can build a science-based system of moral values by quantifying whether or not *X* increases or decreases well-being. For instance, Harris asks, Is it right or wrong to force women to dress in cloth bags and to douse their faces in acid for committing adultery? It doesn't take rocket science—or religion, Harris astringently opines—to conclude that such "cultural values" decrease the well-being of the women so affected and thus are morally wrong.

These examples are the low-hanging fruit on the tree of the knowledge of good and evil, so it is easy for both science and religion to pluck the ripe ones and declare with confidence that such acts as, say, lying, adultery and stealing are wrong because they destroy trust in human relationships that depend on truth telling, fidelity and respect for property. It is when moral issues become weighted with political, economic and ideological baggage that the moral landscape begins to undulate.

Harris's program of a science-based morality is a courageous one that I wholeheartedly endorse, but how do we resolve conflicts over such hotly contested issues as taxes? Harris's moral landscape allows the possibility of many peaks and valleys—more than one right or wrong answer to moral dilemmas—so perhaps liberals, conservatives, libertarians, Tea partiers, Green partiers and others can coexist on different peaks. Live and let live I say, but what happens when the majority of residents on multiple moral peaks pass laws that force those in the minority on other peaks to help pay for their programs of social well-being for everyone? More scientific data are unlikely to eliminate the conflict.

I asked Harris about this potential problem. "'Live and let live' is often a wise strategy for minimizing human conflict," he agreed. "But it only applies when the stakes are not very high or when the likely consequences of our behavior are unclear. To say that 'more scientific data are unlikely to eliminate the conflict' is simply to say that nothing will: because the only alternative is to argue without recourse to facts. I agree that we find ourselves in this situation from time to time, often on economic questions, but this says nothing about whether right answers to such questions exist."

Agreed. Just because we cannot yet think of how science might resolve this or that moral conflict does not mean that the problem is an insoluble one. Science is the art of the soluble, and we should apply it where we can. SA

COMMENT ON THIS ARTICLE ONLINE
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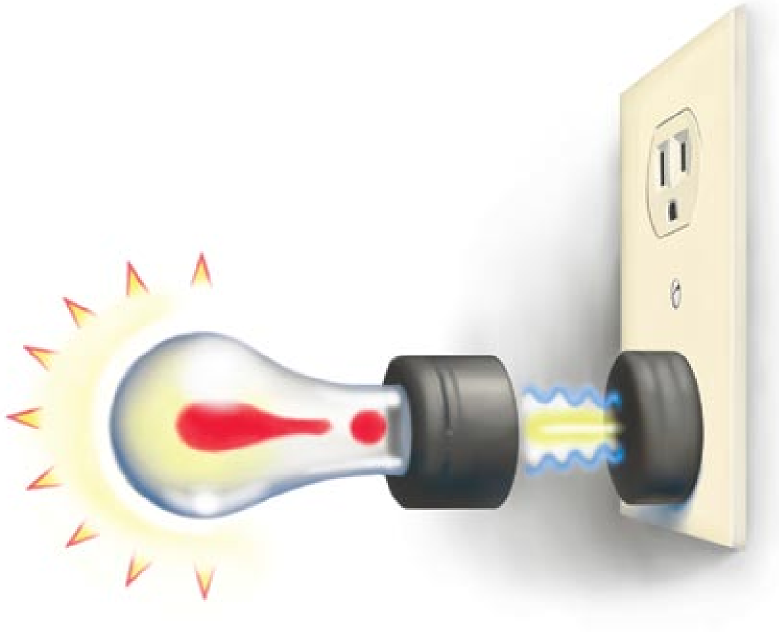
Illustration by A. Richard Allen

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column for 100 years, within an order of magnitude. He also hosts the *Scientific American* podcast Science Talk.



They're Young, and They're Restless

While we fret, some college students are busy creating the future

Reading a newspaper, watching CNN or even just looking around can bring on a feeling of impending doom. But in late October I ran into a few individuals who recharged my batteries. Because they do things like figure out better ways to recharge batteries. They were the 10 teams of finalists in the National Inventors Hall of Fame's 20th Annual Collegiate Inventors Competition in Alexandria, Va.

I first covered the competition, which awards prizes to the best undergraduate and graduate student inventing teams, back in 2004 [see "The New College Try," February 2005]. The grand prize winner that year was Ozgur Sahin. When he was 11, he built a mechanical adding machine from his Lego set. He won the 2004 competition for his improved atomic force microscope. (My greatest intellectual achievement to date was figuring out how to set the time on a digital answering machine.)

Of the 2010 efforts, the one I wanted to own immediately was an ingenious device invented by Lehigh University undergrads Michael Harm (whose nickname would be "First Do No" if I had anything to say about it), Gregory Capece and Nicholas Rocha. As freshmen, they were told to come up with a kitchen product that would help elderly people to remain in their homes longer.

Let's think. A refrigerator with a built-in magnification system so elders can more easily see what's in back? A table with legs of variable length that automatically levels itself on uneven floors, so that diners aren't reduced to wedging matchbooks under a leg in a vain attempt to stop the wobble? A countertop TV that reduces anxiety by switching to soothing music whenever it detects a politician scaremongering about nonexistent death panels?

One of the intrepid undergrads, Rocha, instead did a truly novel piece of research to put his team on the right track: he spoke to senior citizens. "I'm from Vero Beach, Florida," he told the audience at the awards dinner. "Quite a few retirees. I talked to my grandparents and their friends to find out what they had troubles with in the kitchen. And they said, 'I like to use my blender, my toaster oven, my electric can opener, all sorts of things, and it clutters the counter space to have all that up there at once.' So they're constantly plugging and unplugging, which is a pretty big chore for them." I'm still a far piece from Social Security, but even I sometimes think that ripping three-pronged plugs out of the wall should be an Olympic event.

Guided by the philosophy that a grandmother's necessity is the mother of invention, the young men came up with a two-part cylinder they call the MPlug. One part plugs into the wall outlet permanently. The other part stays connected to the plug at the end of the cord of the coffeemaker or other appliance. (You'd want a few of this second part of the cylinder, one for each of the other appliances that will be shuttled in and out of the available socket.) Simply bring the two parts close to each other, and, voilà (or a trumpet fanfare if you dislike a word that looks like a string instrument), built-in magnets snap them together. And there's no preferred orientation, as in a three-prong plug—as long as the two faces are flush, the electronics will complete the circuit.

The kids showed off a prototype, but they say that they need to fine-tune the magnet strength—so that the two parts stay together, but your sainted mum can still easily pry them apart to remove the coffeemaker after breakfast and plug in the blender to start on the postgolf daiquiris.

Other undergrad projects included a surgical sponge that, if accidentally left inside the patient, can harmlessly break down, much as the hopes and dreams of surgeons currently do if their sponge counts come up short. Another was an intelligent drill for teaching novice orthopedic surgeons to zap bone in exactly the right direction. (Present-day practice includes the experienced surgeon touching the far side of the bone and having the newbie aim for that highly trained finger.) The graduate student projects were even more complicated than Sahin's adding machine. For a complete roundup of the finalists and winners, go to www.invent.org/collegiate. And keep plugging. SA

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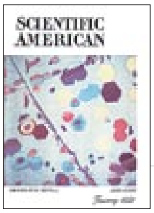
Illustration by Matt Collins



January 1961

Mechanism of Immunity

"Although the practical problems of immunization have been solved, immunology remains an important branch of medicine. The immunologist of today, however, is not so much interested in finding out how to immunize people more effectively against diphtheria or poliomyelitis as he is concerned with understanding what happens when people become immune. He asks more sophisticated questions than in the past. For example: Why can a surgeon successfully graft skin or other tissue from one part of the body to another but not from one individual to another, except in the case of grafts between identical twins? Any modern formulation of immunological theory must supply at least provisional answers to these and other equally complex questions. —Sir Macfarlane Burnet"

Burnet won a Nobel Prize in 1960 for his work in immunology.

January 1911

Edison's Battery

"Stored electricity finds its greatest usefulness in propelling cars and road vehicles, and it has been for this application, primarily, that the Edison storage battery has been developed. Mr. Edison saw that there are two viewpoints: that of the electrical man with his instruments, his rules of efficient operation and reasonable life of the battery, his absolute knowledge that the same care should be given a vehicle battery that is given a valued horse or even a railroad locomotive; and that of the automobile driver, who simply wishes to go somewhere with his car, and who, when he arrives somewhere, wishes to go back. And in the long-promised storage battery the highly practical nature of Edison's work is once more exemplified in that he has held uncompromisingly to the automobilist's point of view."

This article is available in full on the Web at www.ScientificAmerican.com/jan2011

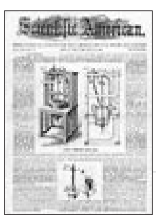
The Brilliant Curie

"We cannot help feeling that in this advanced age, in such a center of enlightenment as Paris, and where a scientist of such brilliant performance as Madame Curie is concerned, this discussion as to whether she is eligible for admission to the French Academy of Sciences is altogether deplorable. When science comes to the matter of bestowing its rewards, it should be blind to the mere accident of sex; and one does not have to be an enthusiast on the subject of the extension of the rights and privileges of her sex, to feel that here is a woman who, by her brilliant achievement, has won the right to take her place with her compeers in the Academy."

After much political maneuvering, the Académie denied Curie a seat.

The automobile issue: Our annual overview of a burgeoning industry, 1911

SCIENTIFIC AMERICAN, VOL. CIV, NO. 2; JANUARY 14, 1911



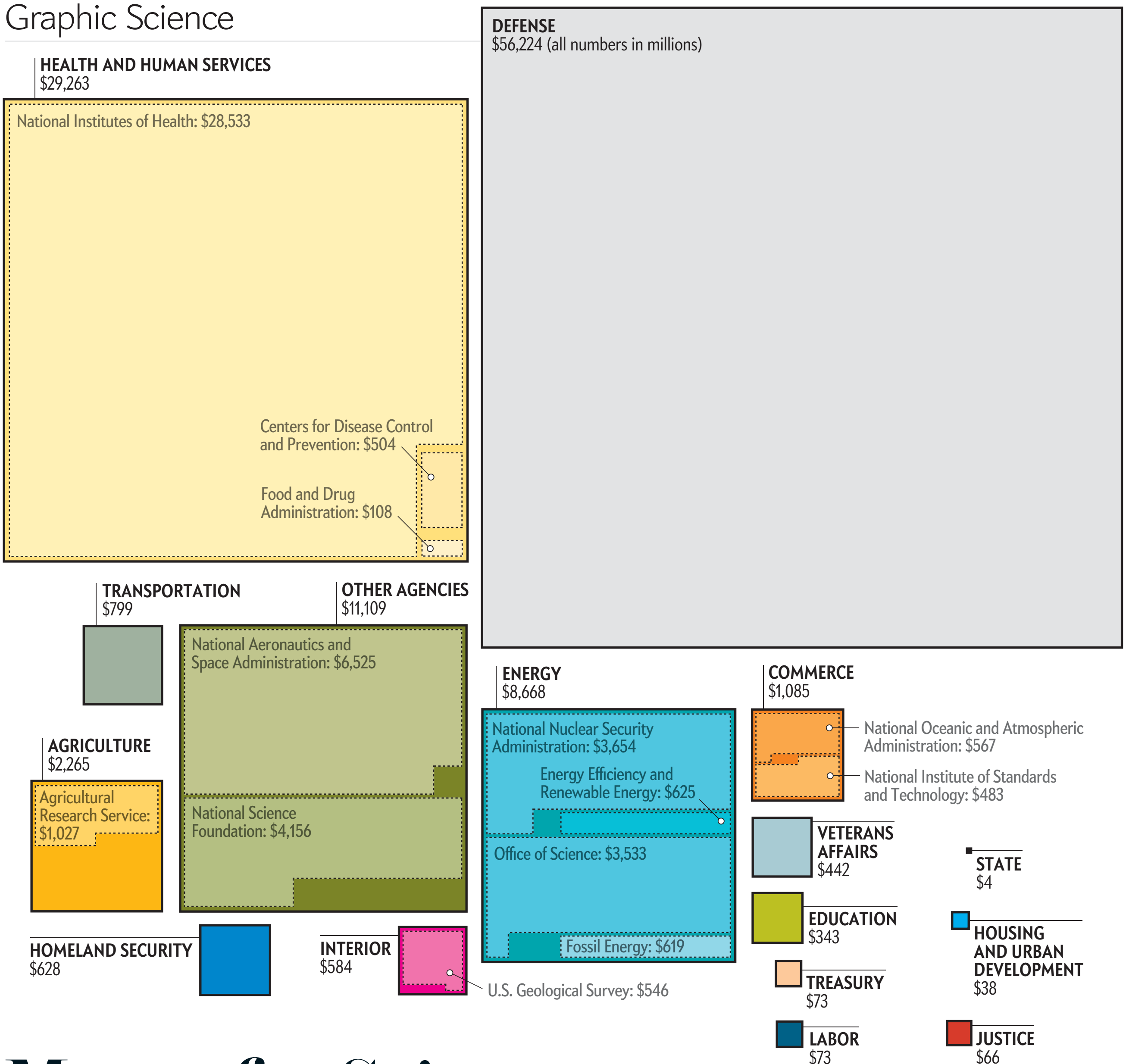
January 1861

The Risks of Secession

"One inventor hesitates to apply for a patent until our political difficulties are settled; because, should the Southern states secede from the Northern and middle states, his rights would not be respected in but about half the States, and thus his patent would be worth only half price. Now, all these troubles which haunt the mind of inventors are imaginary, so far as securing their patents or protecting them is concerned. It is the manufacturing and mechanical States of the North which have ever been the great patrons of the patentee, and while we do not apprehend any permanent division of the union of States, and interests between the North and South, even should an event so deplorable to all sections occur, we see no reason why patent property should be materially depreciated."

Soap and Civilization

"According to Liebig, the quantity of soap consumed by a nation would be no inaccurate measure whereby to estimate its wealth and civilization. Political economists, indeed, will not give it this rank; but whether we regard it as joke or earnest, it is not the less true, that, of two countries, with an equal amount of population, we may declare with positive certainty, that the wealthiest and most highly civilized is that which consumes the greatest weight of soap. This consumption does not subserve sensual gratification, nor depend upon fashion, but upon the feeling of the beauty, comfort, and welfare, attendant upon cleanliness." SA



Money for Science

Federal R&D spending shows how government priorities stack up

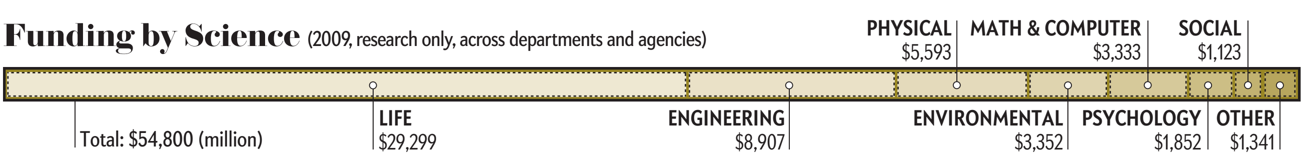
Politicians argue over the federal budget every time Congress reconvenes in January. But the money that the government spends each year, which can differ from the budget, reveals how much funding departments and agencies actually receive. The outlays for research and development, shown here for 2009 (latest available), largely support the nation's science work. The relative proportions have been fairly constant in recent years (data do not include one-time American Recovery and Reinvestment Act money).

When the dollars are plotted by agency, department and selected organizations within departments, interesting patterns emerge: defense swamps all other recipients. The country spends as much on fossil energy as it does on renewable energy and efficiency. It invests more in nuclear energy than it does in all of agriculture. Some members of the new Congress have already vowed to cut all nonmilitary R&D.

—Mark Fischetti

SEE FUNDING BY SCIENCE OVER TIME
ScientificAmerican.com/jan2011/graphic-science

Funding by Science (2009, research only, across departments and agencies)



SOURCE: NATIONAL SCIENCE FOUNDATION

Graphic by Arno Ghelfi

It's 2011. Do you know where your children are?

Our kids are growing up in a very different world from the one you used to know. Different expectations. Stronger pressures and temptations. More choice. Bigger choices. Greater dangers.

And when the pace of change is so fast even the kids have trouble keeping up, what hope is there for the parents?

No matter how much you try to stay up to speed with what your kids are doing, there will always be plenty you don't know.

The Partnership at Drugfree.org is here to help parents prevent, intervene in, and find treatment for drug and alcohol use by their children. So even if you don't always know exactly where your children are, at least you'll always know where they're at.

Come visit us anytime at drugfree.org

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